CoNNOR: Convolutional Neural Network for Outsole Recognition

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Background: Footwear and Forensic Analysis

- Shoe prints and outsole characteristics are pattern evidence
- May want to identify print at crime scene as made from a certain type of shoe or by a given suspect
- Also useful to determine the frequency of a given shoe (or features of the shoe) in a local population
- **Goal:** Develop an efficient method to automatically identify footwear outsole characteristics

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Classification

- What features does your brain use to classify objects?

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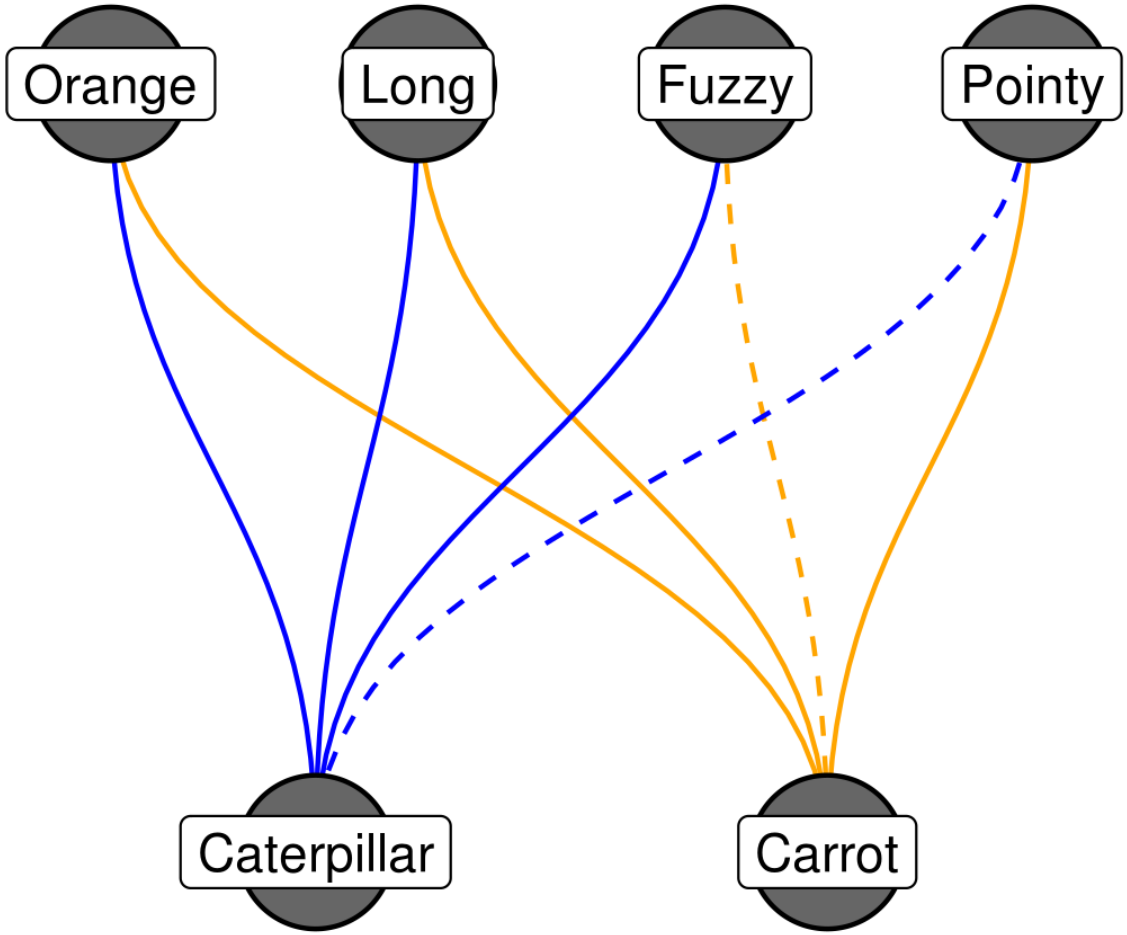
Classification



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Classification

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Convolutional Neural Networks (CNNs)

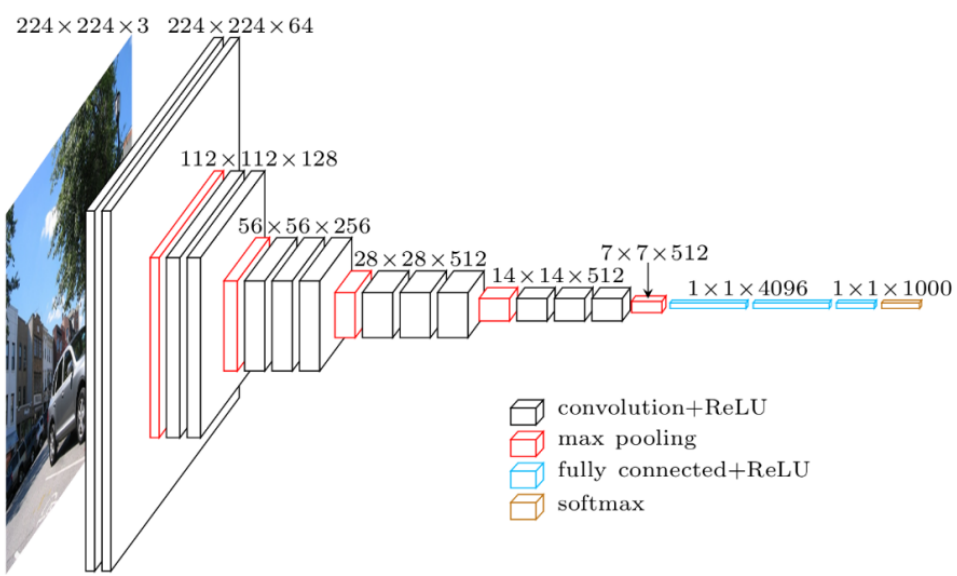
- Tool for supervised deep-learning, well-suited to image analysis
- Translation-invariant pattern detection
- Analogous to how our eyes detect features and our brain weights them for classification
  - Eyes $\rightarrow$ Brain $\rightarrow$ Classification
- Use combinations of convolutional and pooling layers to filter raw information into features

Pre-trained CNNs

- Large, complex networks trained to identify a subset of images from ImageNet
  - $\sim$1.2 million images spanning 1,000 categories
- Examples: LeNet (1998), AlexNet (2012), GoogLeNet/Inception (2014), **VGG** (2014), ResNet (2015)
  - More on how they compare here and here
- Contain both “eyes" to detect features and “brain" to weight those features for classification

VGG16 Architecture

- 16 “functional" layers – 13 convolution and 3 fully connected
- 5 max-pooling layers, summarize features and structure model



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Filters and Convolution

1	1	1	0	0
0	1	1	1	0
0	0	1	1	1
0	0	1	1	0
0	1	1	0	0

Input

1	0	1
0	1	0
1	0	1

Filter / Kernel

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Filters and Convolution

1x1	1x0	1x1	0	0
0x0	1x1	1x0	1	0
0x1	0x0	1x1	1	1
0	0	1	1	0
0	1	1	0	0

Input x Filter

4		

Feature Map

Filters and Convolution

1	1x1	1x0	0x1	0
0	1x0	1x1	1x0	0
0	0x1	1x0	1x1	1
0	0	1	1	0
0	1	1	0	0

Input x Filter

4	3	

Feature Map

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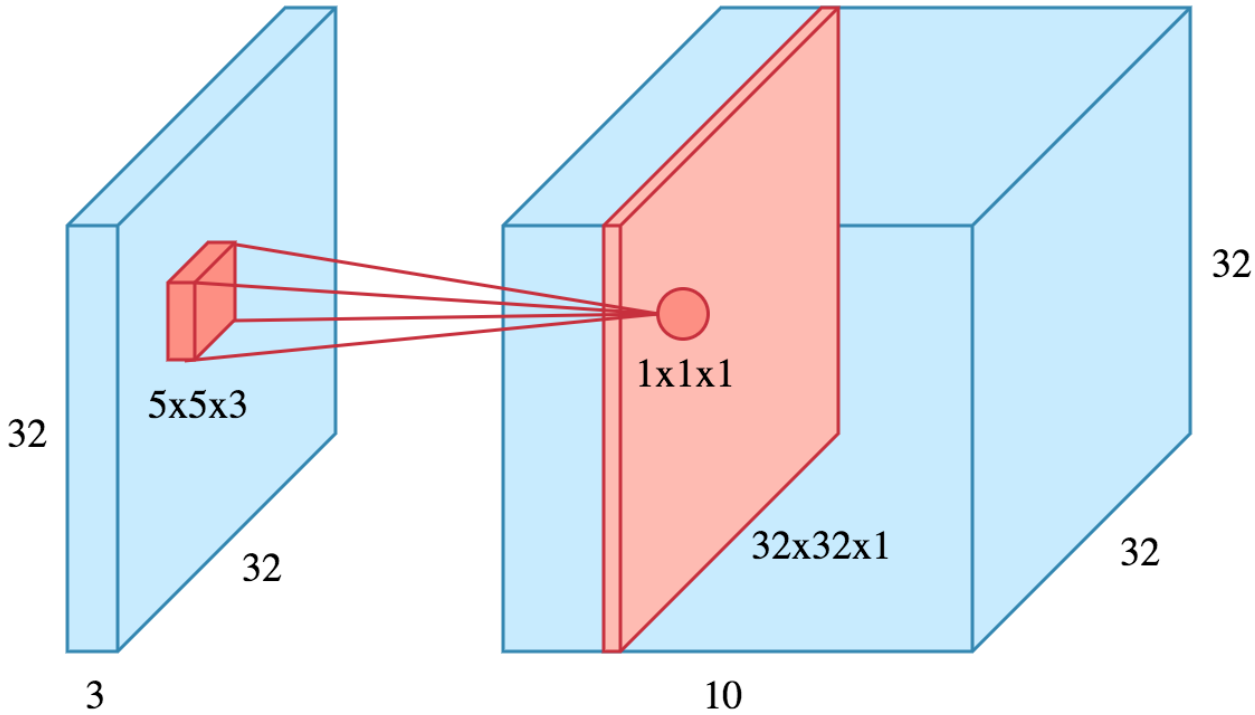
Filters and Convolution



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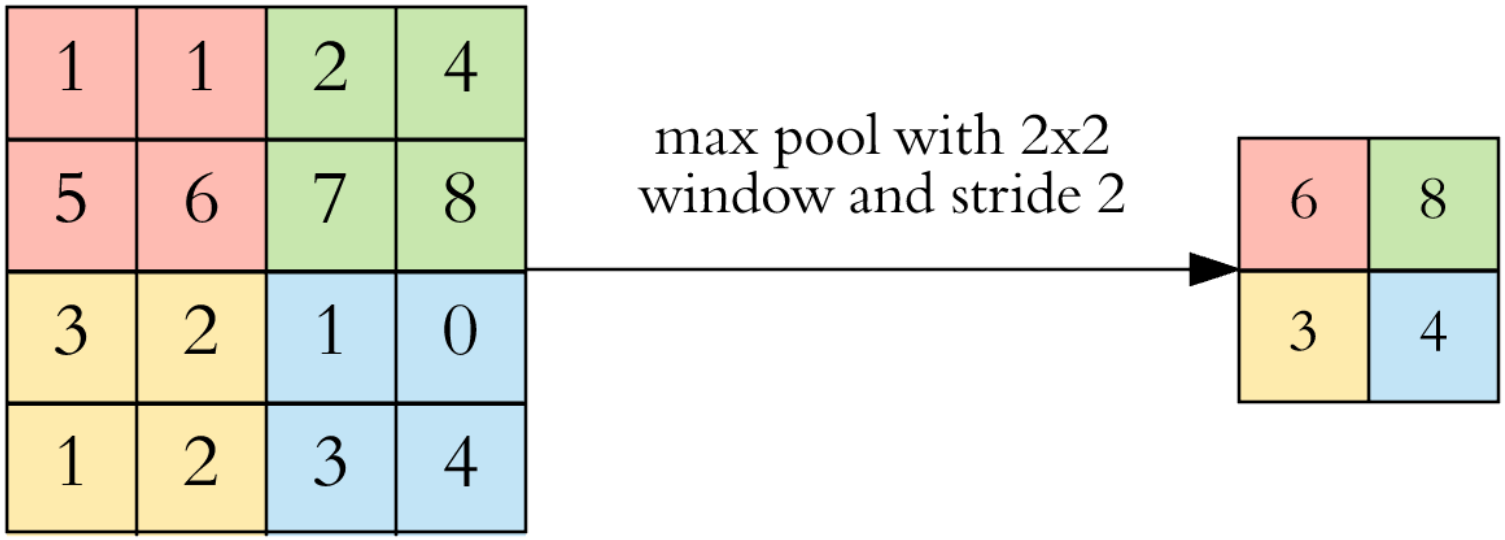
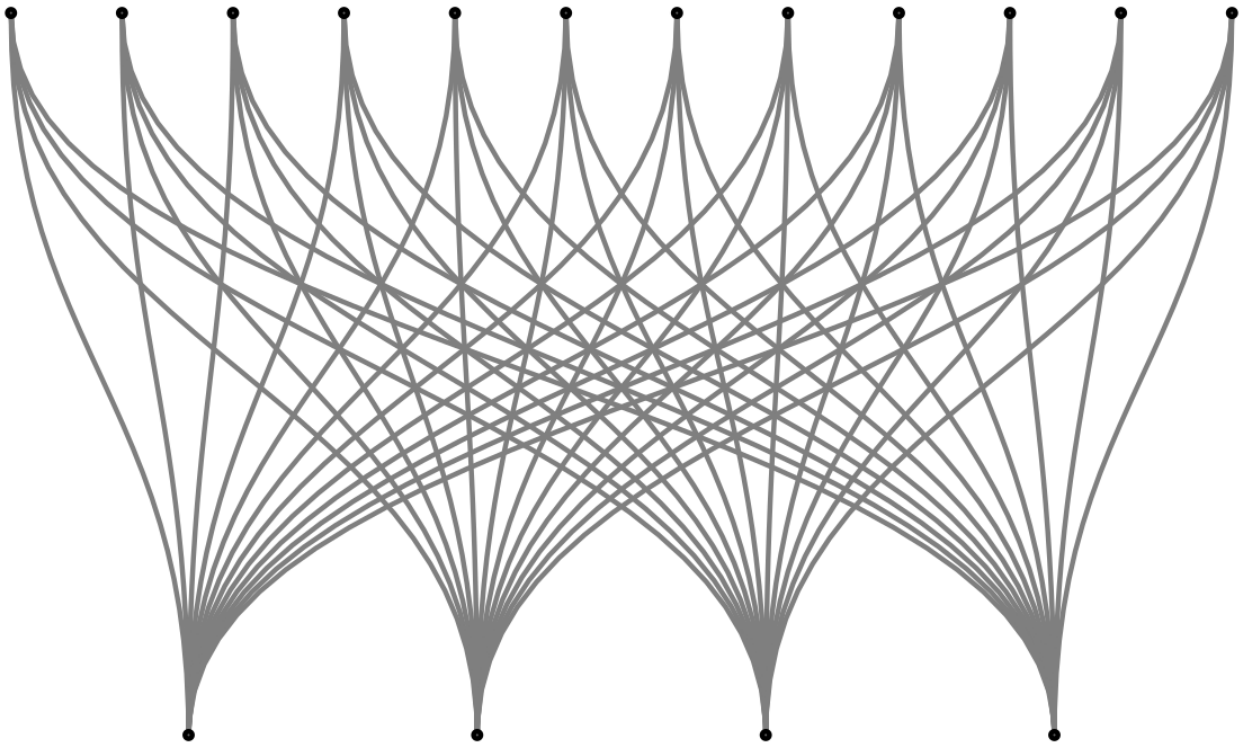
Max Pooling



Densely Connected Layers



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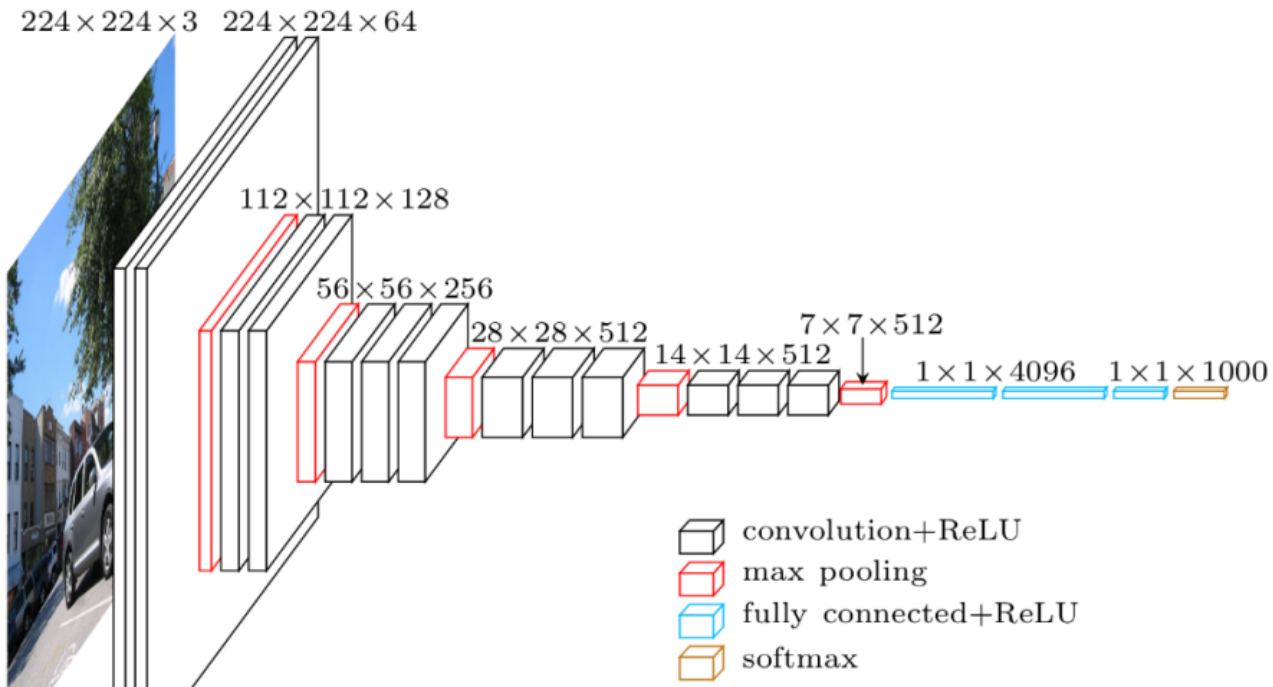
VGG16 Architecture

- Rectified Linear Units (ReLU) $= x * \mathrm{I}_{\{x>0\}}$



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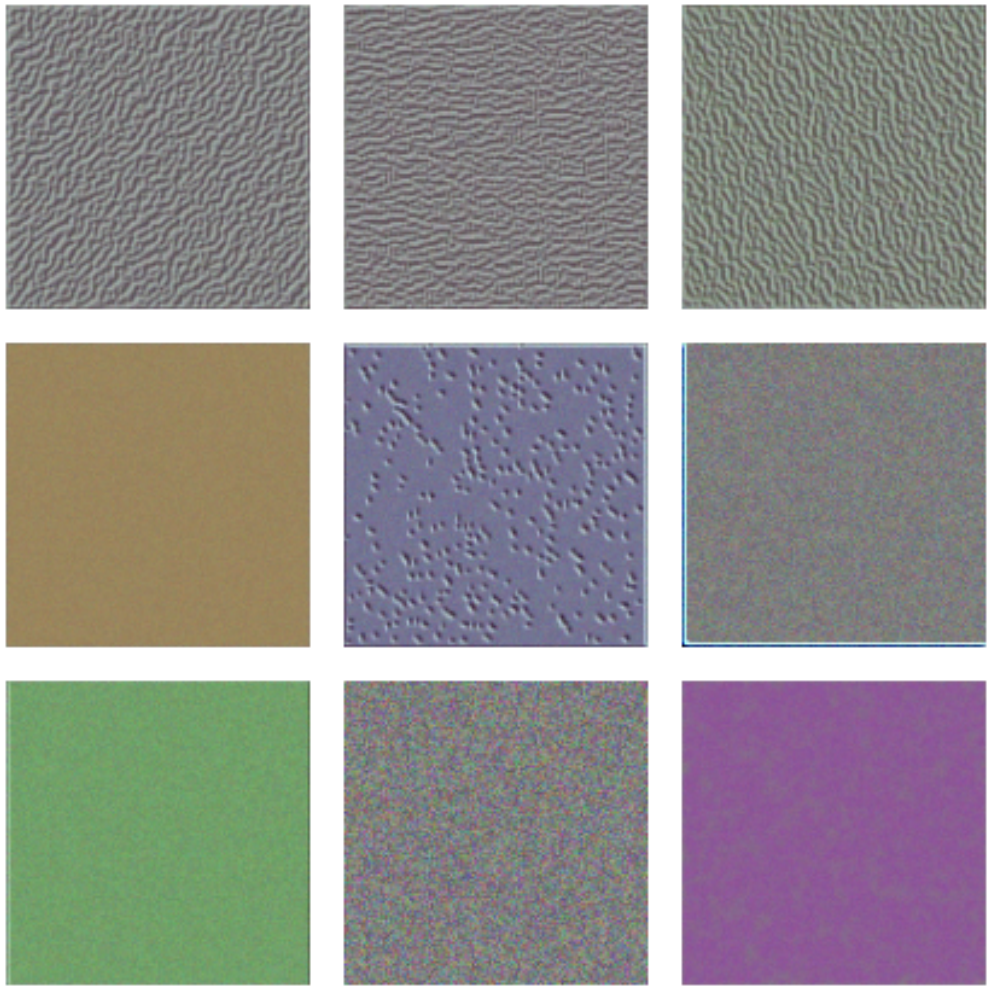
VGG16 Filters - First Block



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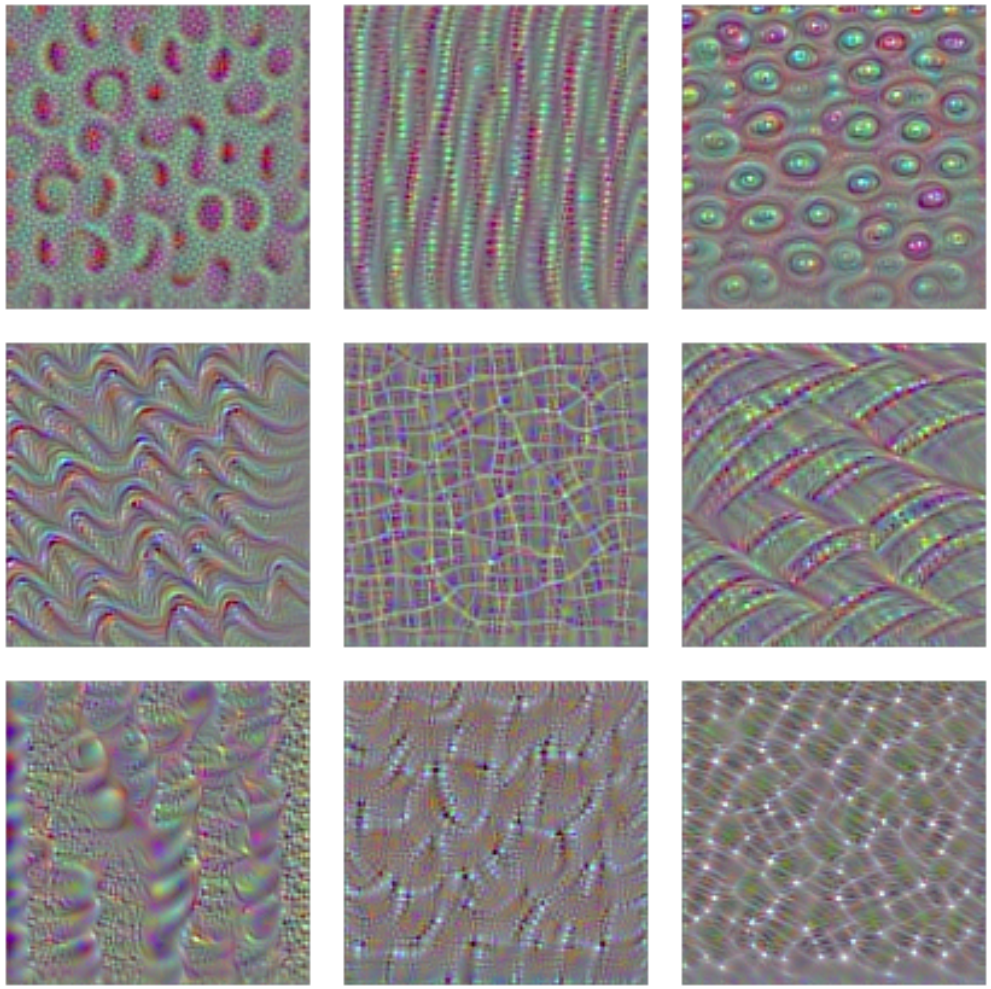
VGG16 Filters - Fourth Block



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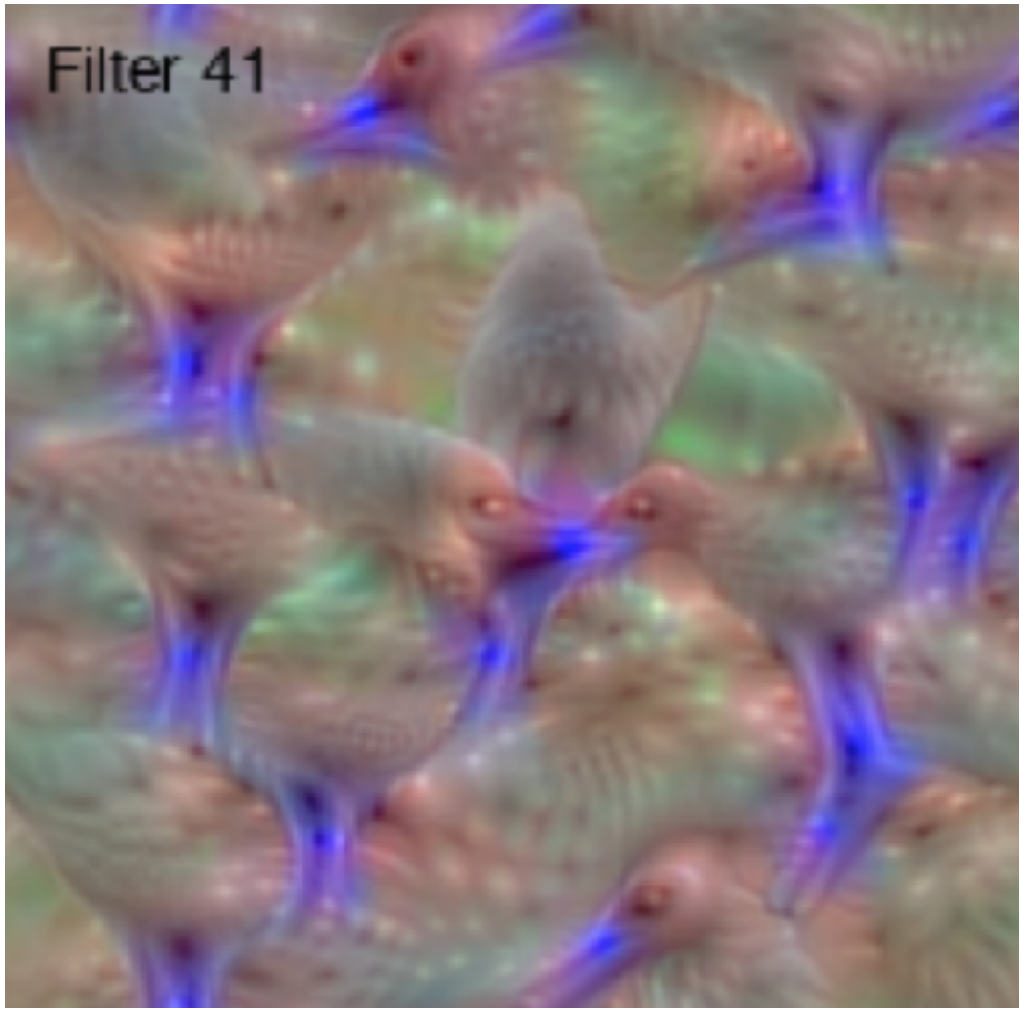
VGG16 Filters - Fifth Block



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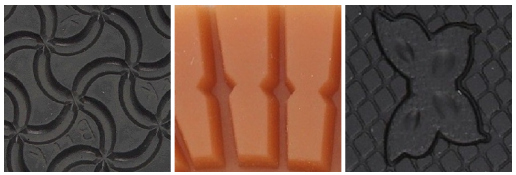
Using a Pre-trained CNN for a New Task

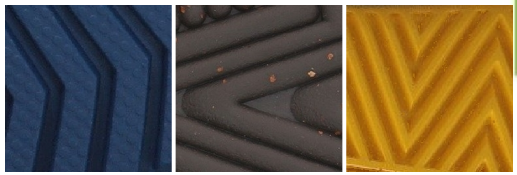
- Large CNNs with many layers have millions of parameters to train
  - VGG16 “eyes" have 14,714,688 trainable parameters
- Using the existing “eyes" and training only a “brain" brings number of images required from millions to only thousands
  - “Eyes" = convolutional and pooling layers
  - “Brain" = fully connected layers

Outsole Class Characteristics

Bowtie



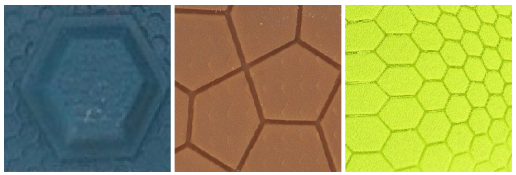
Chevron



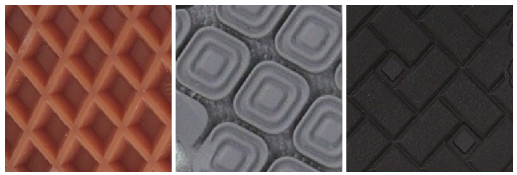
Circle

Line

Polygon



Quad



Star

Text

Triangle

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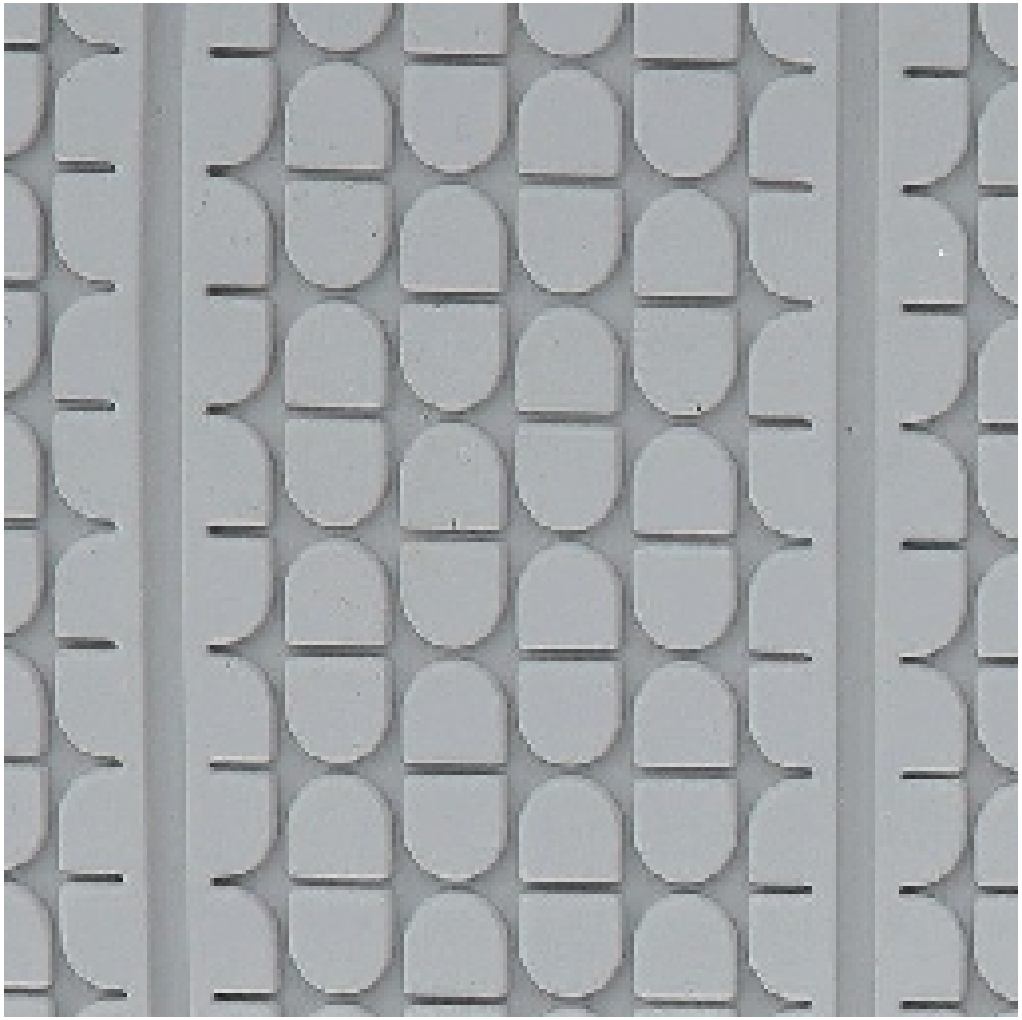
Circle or Quadrilateral?



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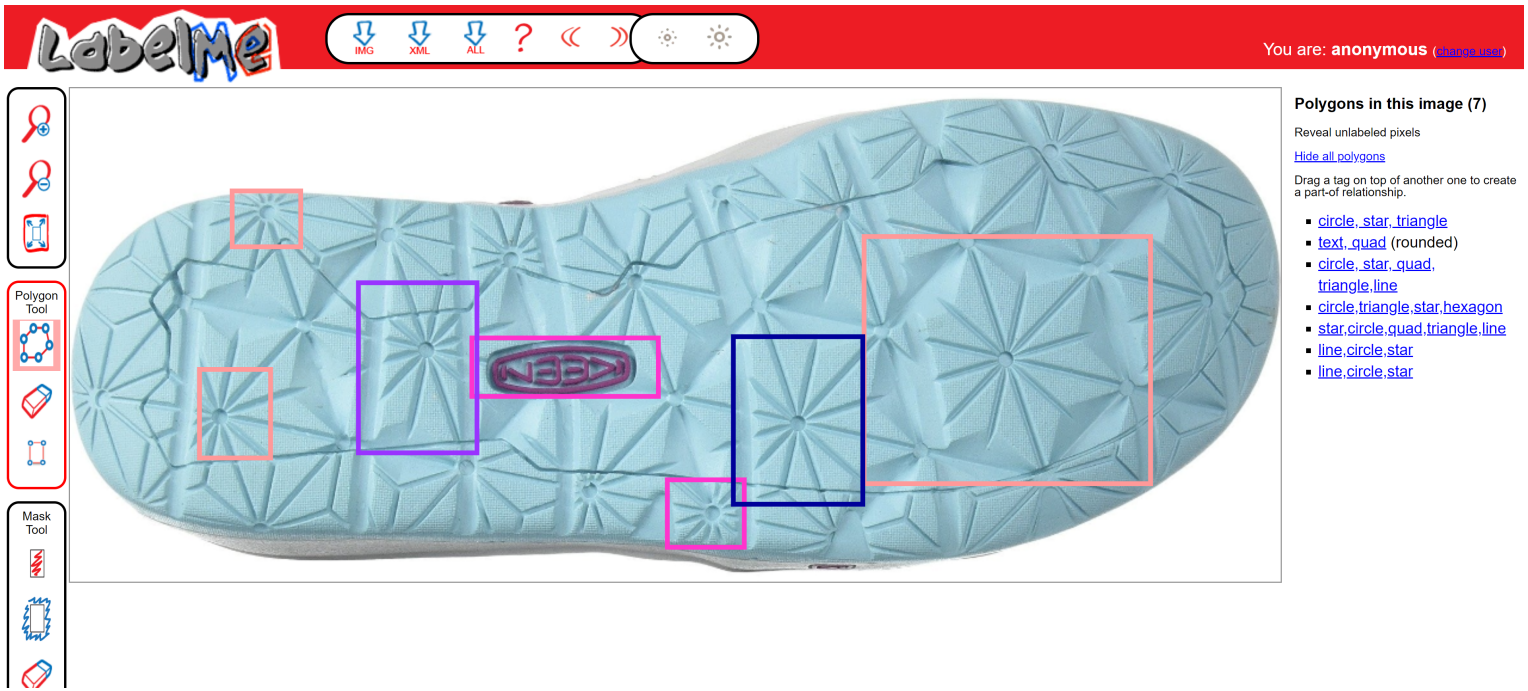
Data Collection



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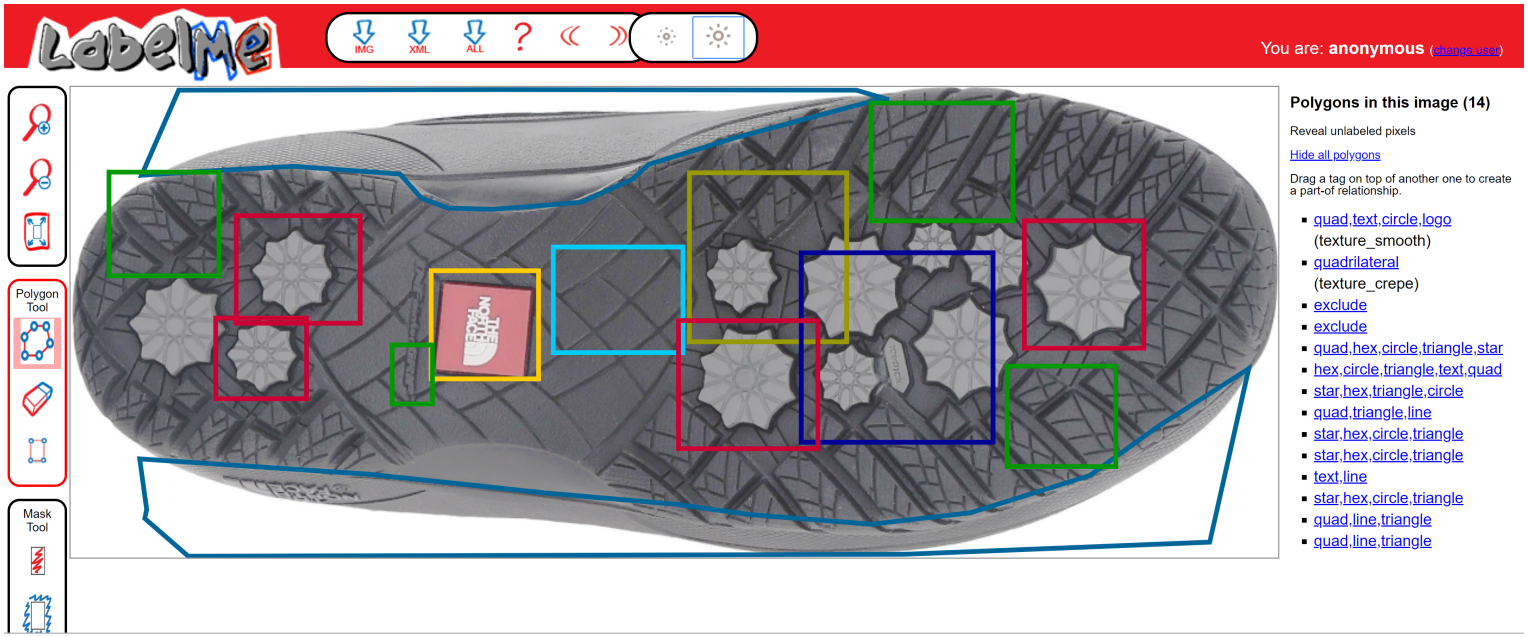
Data Collection



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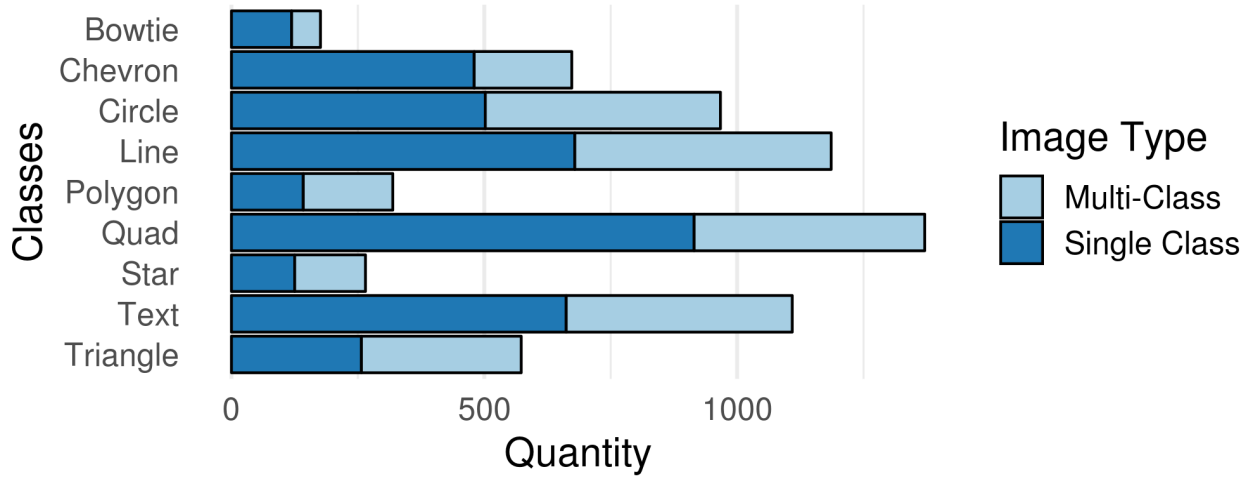
Training a Neural Network – Data Structure

- 24,000 **multi-label** images from 2,200 shoes
  - Outsole images web-scraped from Zappos.com
- Partition existing data
  - 50% for training*
  - 25% for validation, used to regulate training
  - 25% for testing, used to evaluate model performance



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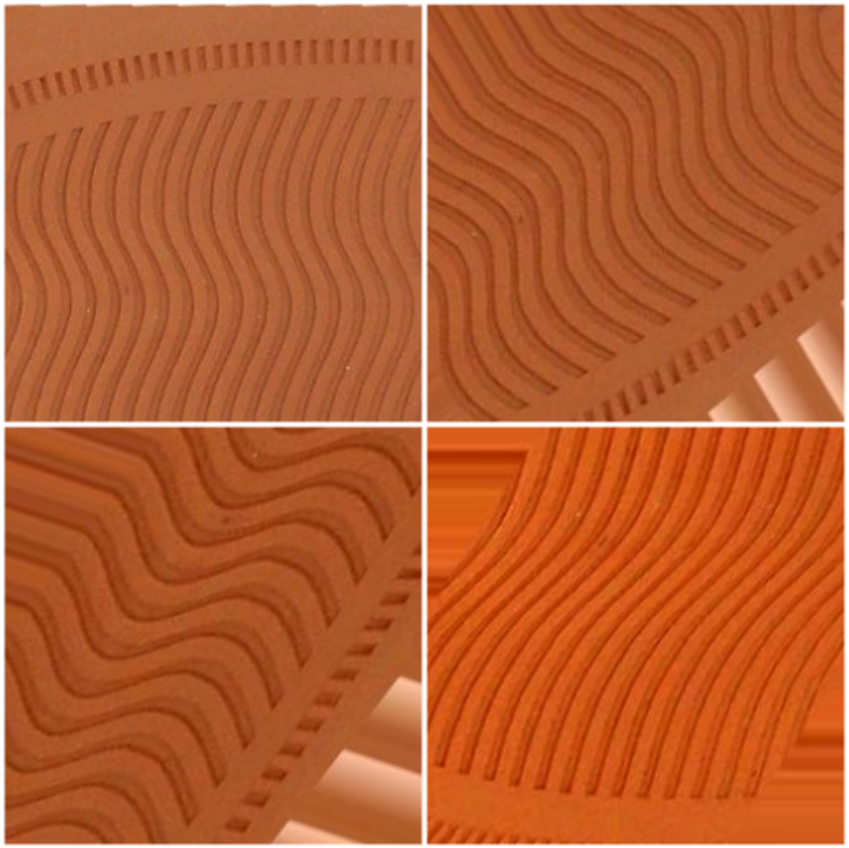
Training Technique – Augmentation

- More training data, helps prevent over-fitting



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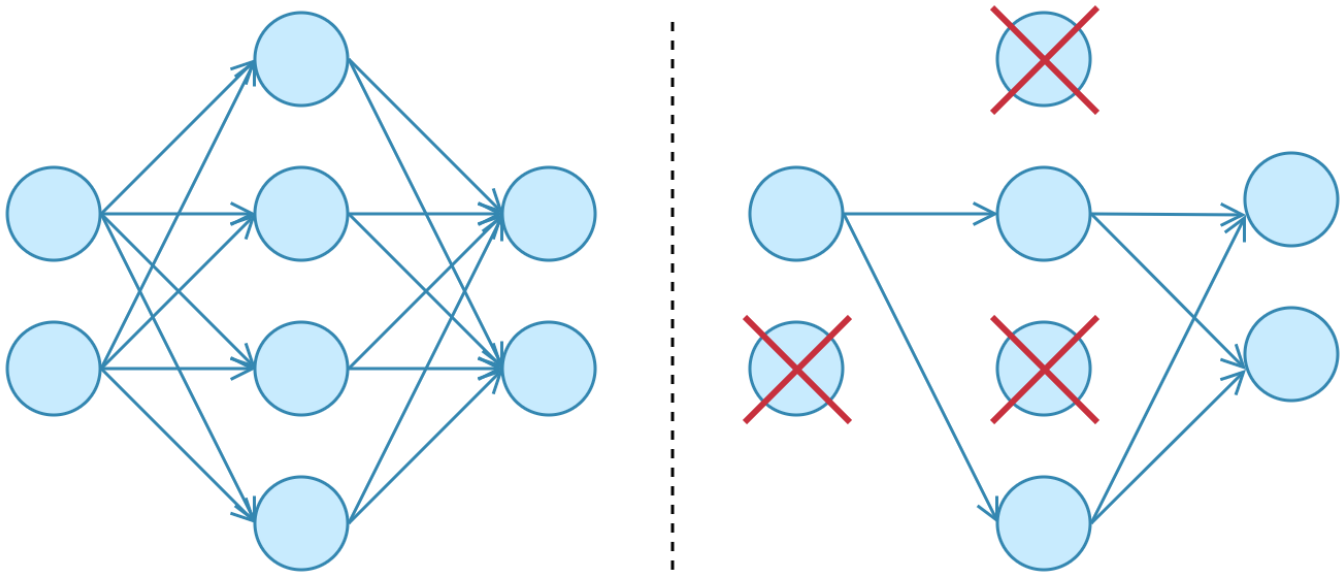
Training Technique – Drop-out

- Ensures no neuron is too specialized, helps prevent over-fitting



No Dropout

With Dropout

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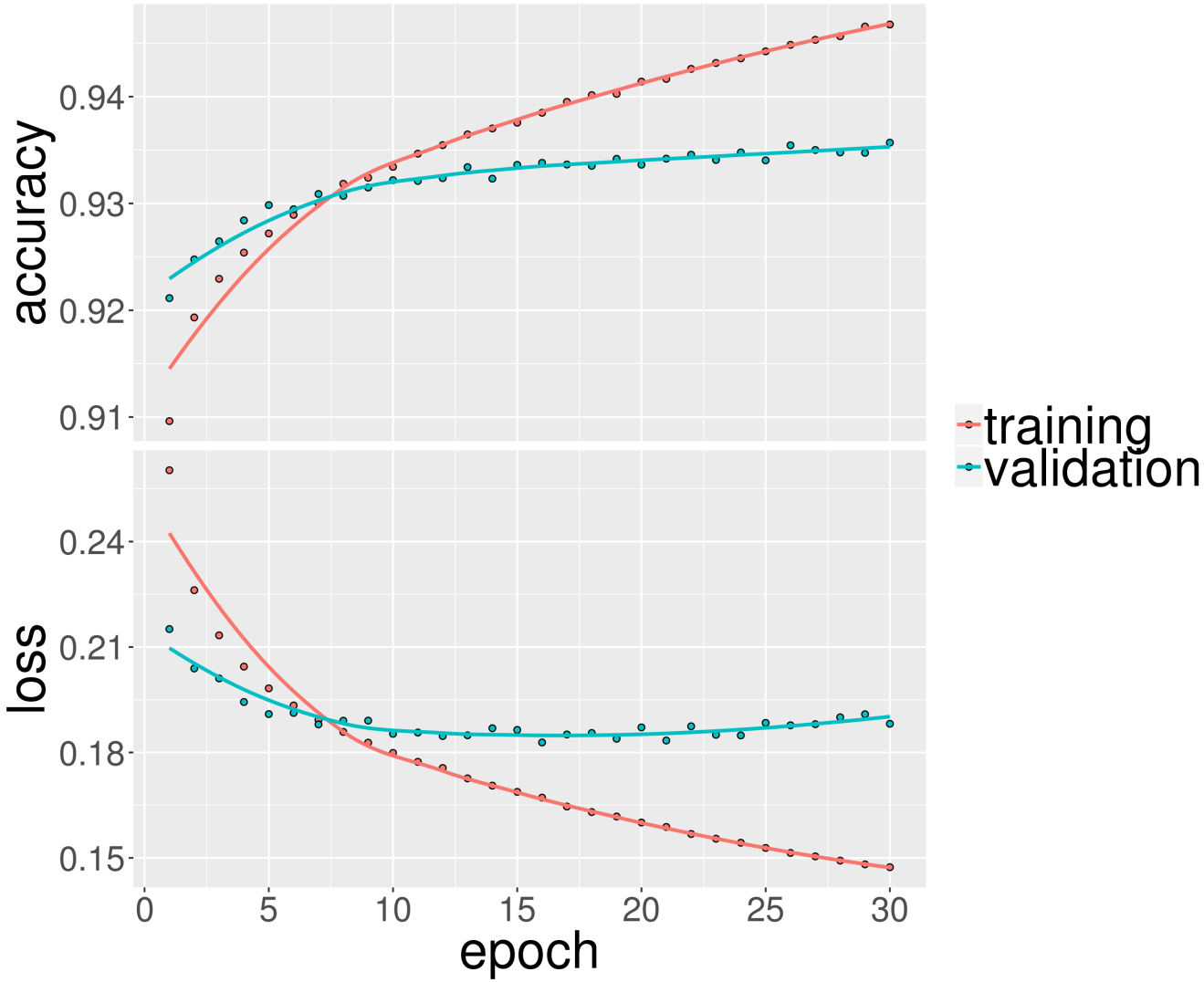
Training a Neural Network – Computation

- Keras: a neural network API, written in Python
- Supports **TensorFlow**, CNTK, or Theano as computational backend
- `Keras`: an R interface to Keras
  - For more info, see Deep Learning with R
- Note: Keras requires GPU (or *very* good CPU)
  - Seriously, don't try this on your personal machine

Training a Neural Network



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Visualizing Model Predictions

- Shiny App

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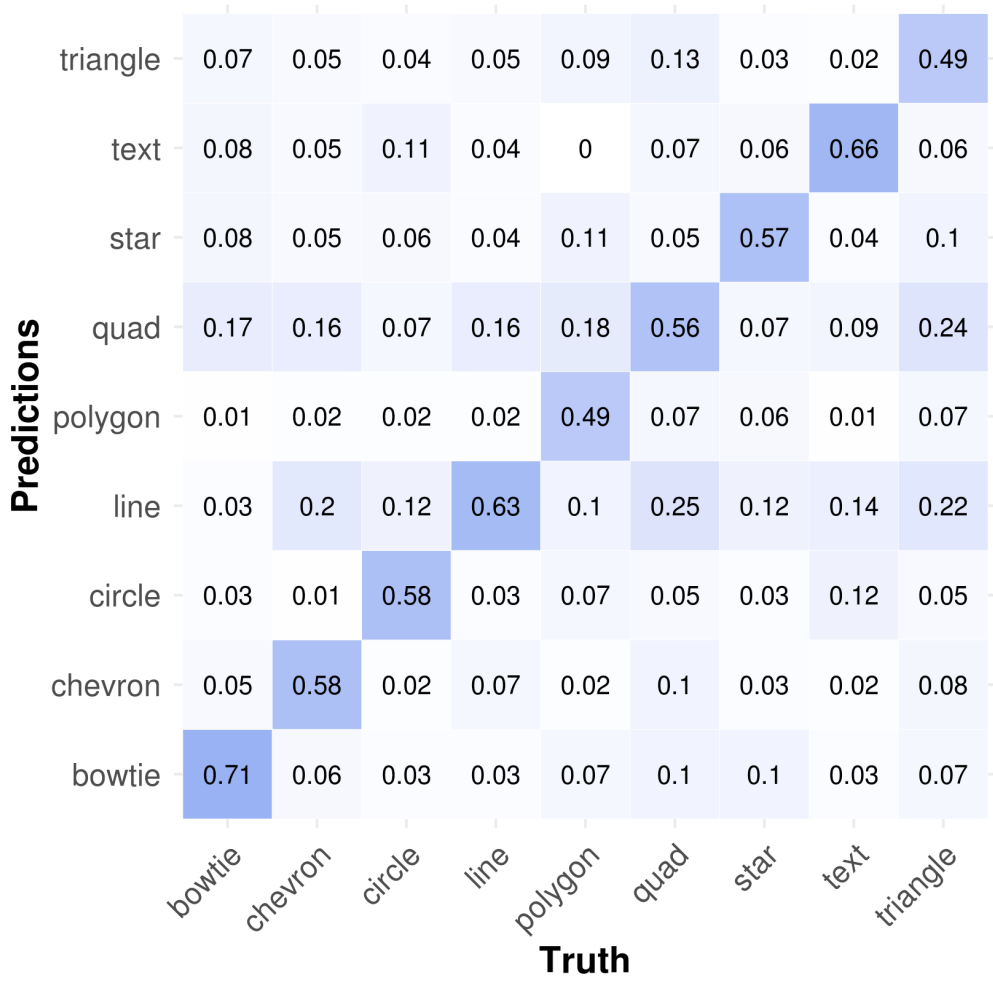
Prediction Accuracy



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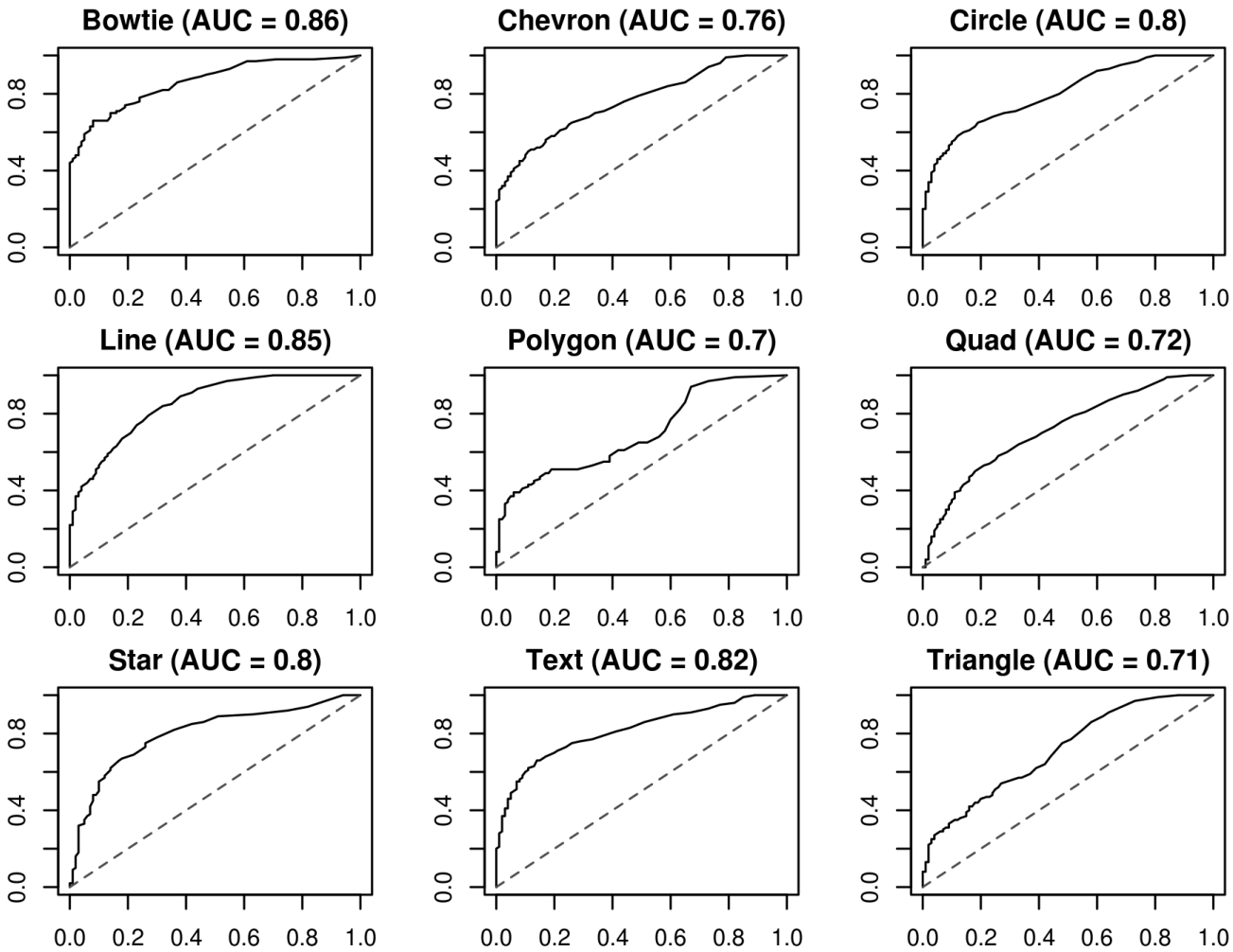
ROC



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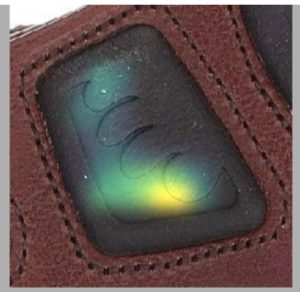
Heatmaps



Circle: 0.506

Text: 0.312

Quad: 0.302

Triangle: 0.077

Line: 0.07

Polygon: 0.066

Chevron: 0.019

Star: 0.009

Bowtie: 0.003

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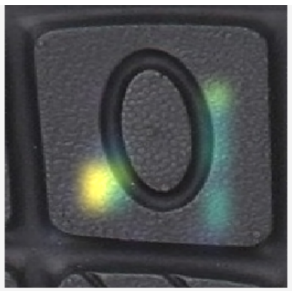
Heatmaps

Circle: 0.783

Quad: 0.543

Line: 0.075



Text: 0.059

Polygon: 0.022

Triangle: 0.017

Chevron: 0.012

Star: 0.004

Bowtie: 0.001

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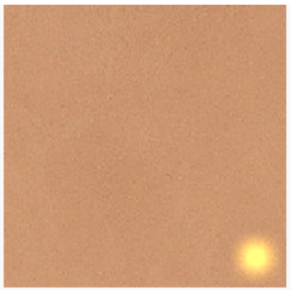
Heatmaps

Line: 0.044



Quad: 0.04

Text: 0.036

Circle: 0.032

Star: 0.031

Triangle: 0.025

Bowtie: 0.022

Chevron: 0.015

Polygon: 0.013

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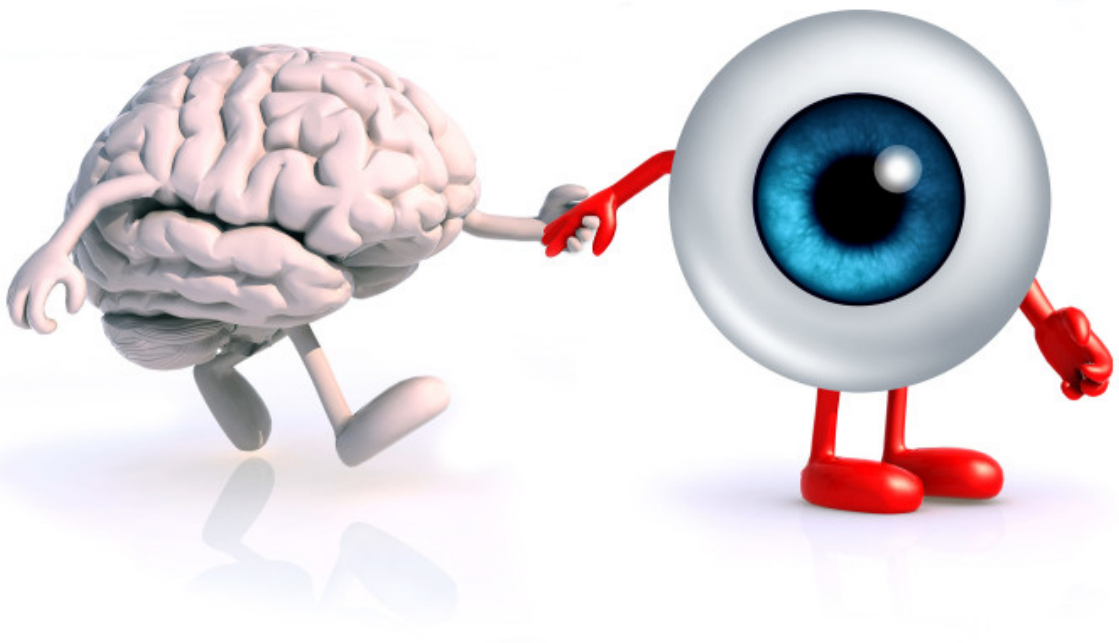
Summary

- CNNs view images as collections of features, then use those features to make classifications
- Pre-trained CNNs detect complex features and classify images from thousands of categories by learning from large image databases
- Retraining the classifier on a pre-trained CNN greatly reduces the required number of training images for a new classification task
- CNNs are well-suited to outsole classification, but the biggest challenge is getting a large amount of consistent data

Questions?



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References I

[1] Susan Gross et al. "The Variability and Significance of Class Characteristics in Footwear Impressions". 2013.

[2] Sheida Hancock et al. "The Interpretation of Shoeprint Comparison Class Correspondences". 2012.

[3] Alex Krizhevsky et al. "ImageNet Classification with Deep Convolutional Neural Networks". 2012.

[4] Karen Simonyan and Andrew Zisserman. "Very Deep Convolutional Networks for Large-Scale Image Recognition". Sept. 2014.