# Udacity Term 2 Robotic Inference Project

## Abstract

This project has two classification data models using Deep Neural Network technology. The first one is classifying the bottles, candy wrappers and nothing on a moving belt. The second one classified the dog A, dog B or nothing. The image data are come from public dataset. The project used the three model: AlexNet, GoogLeNet and LeNet. For both classifications, the best results were presented in this article.

## Introduction

Classification includes a broad range of decision-theoretic approaches to the identification of images (or parts thereof). All classification algorithms are based on the assumption that the image in question depicts one or more features (*e.g.*, geometric parts in the case of a manufacturing classification system, or spectral regions in the case of remote sensing) and that each of these features belongs to one of several distinct and exclusive classes. The classes may be specified *a priori* by an analyst (as in *supervised classification*) or automatically clustered (*i.e.* as in *unsupervised classification*) into sets of prototype classes, where the analyst merely specifies the number of desired categories[1].

In this project used NVIDIA's DIGITS workflow[2] to rapidly prototype ideas that can be deployed on the Jetson in close to real time. The DIGITS will prototype classification networks, detection networks, segmentation networks!

There are two parts in the project:

1. P1 moving belt image classification part used P1 dataset pictures of candy boxes, bottles, and nothing (empty conveyor belt).
2. Dog image classification part used the dog image dataset (dog A, dog B and nothing) which Author collected  from iPhone.

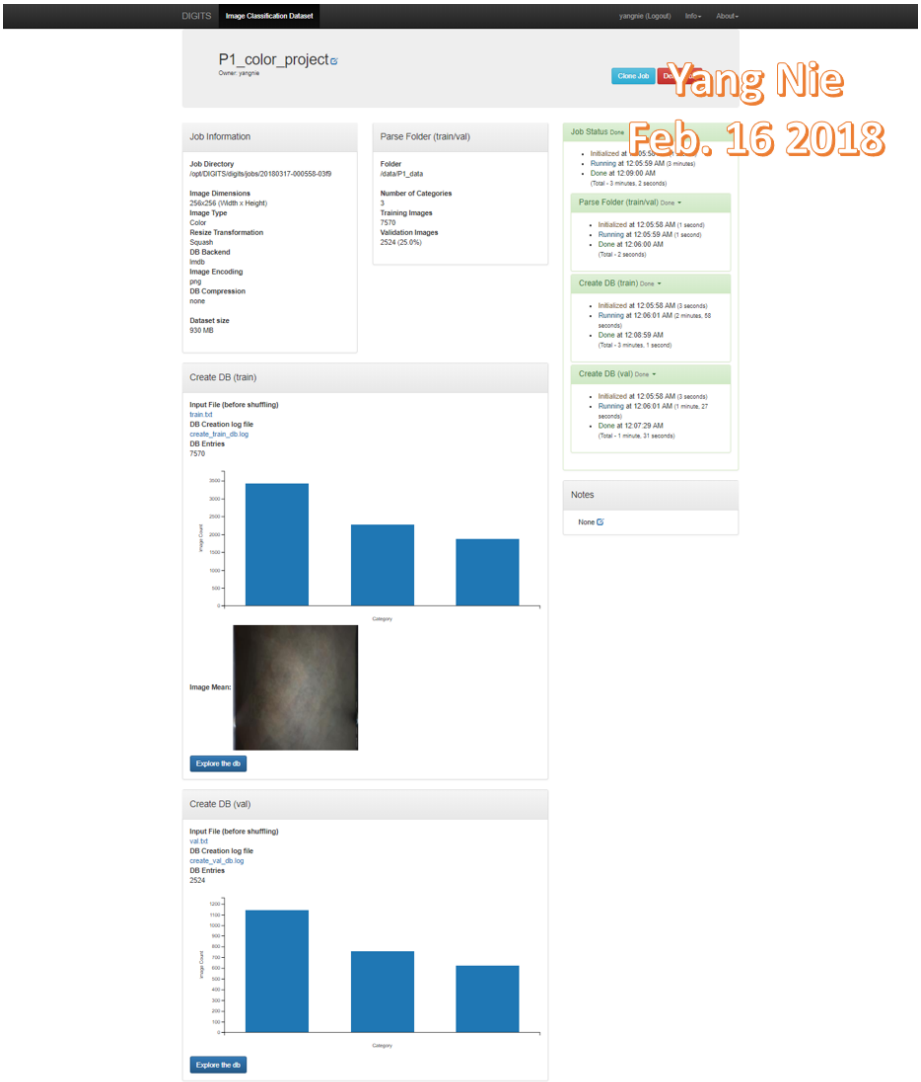
## 1. P1 moving belt image classification

### Background / Formulation

The P1 image dataset is stored in /data/P1/ directory. It include all images of bottles, candy wrappers and no object on a conveyor belt passing under a camera. A swing arm is used to sort all right objects to correct the bins depending on classifying results.

P1 dataset image example:


P1 dataset was split two training and validation parts, the color image size is 256 X 256



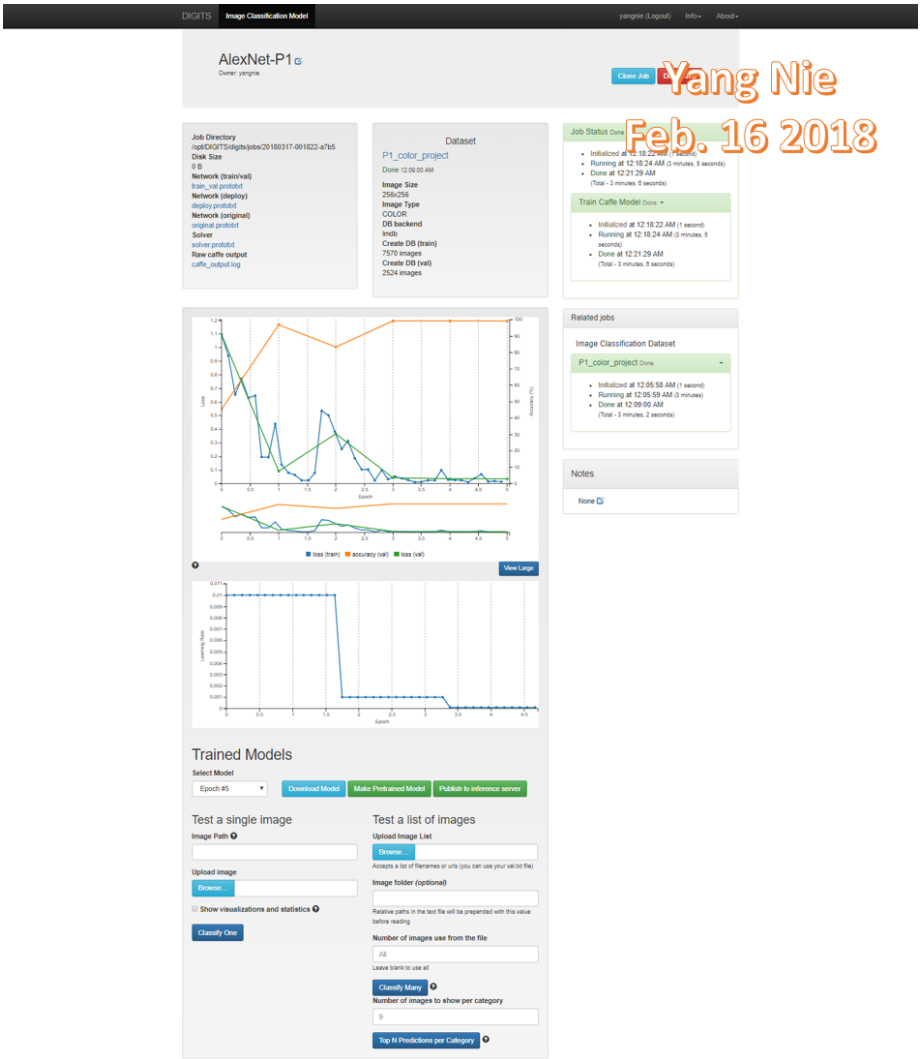

## Data Acquisition:

The P1 dataset is provided from Udacity Robotics lesson.

It were split to two sets: training and validation dataset. They are color image and size is 256 x 256. This dataset is provided from Udacity robotics class.

## Model creation:

AlexNet Model was built as:



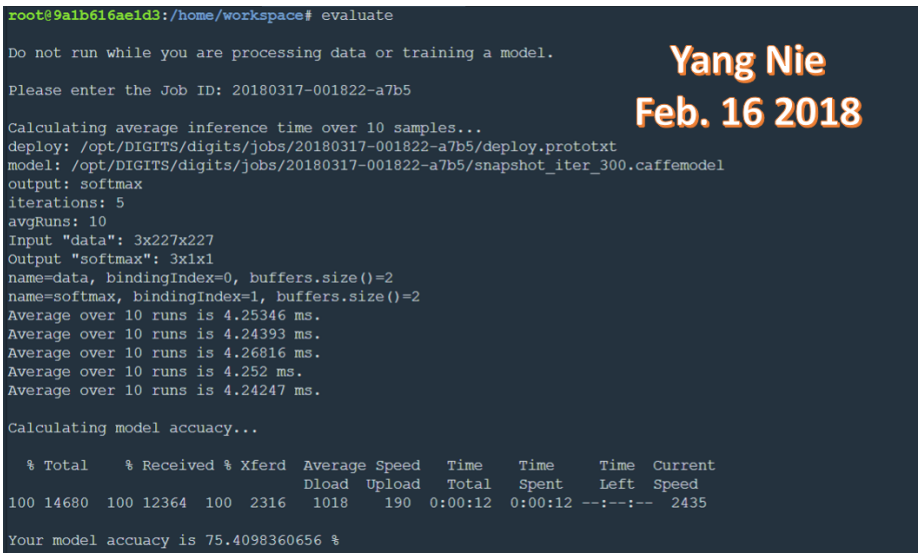

GoogLeNet Model was built as:


**The parameter setting:**

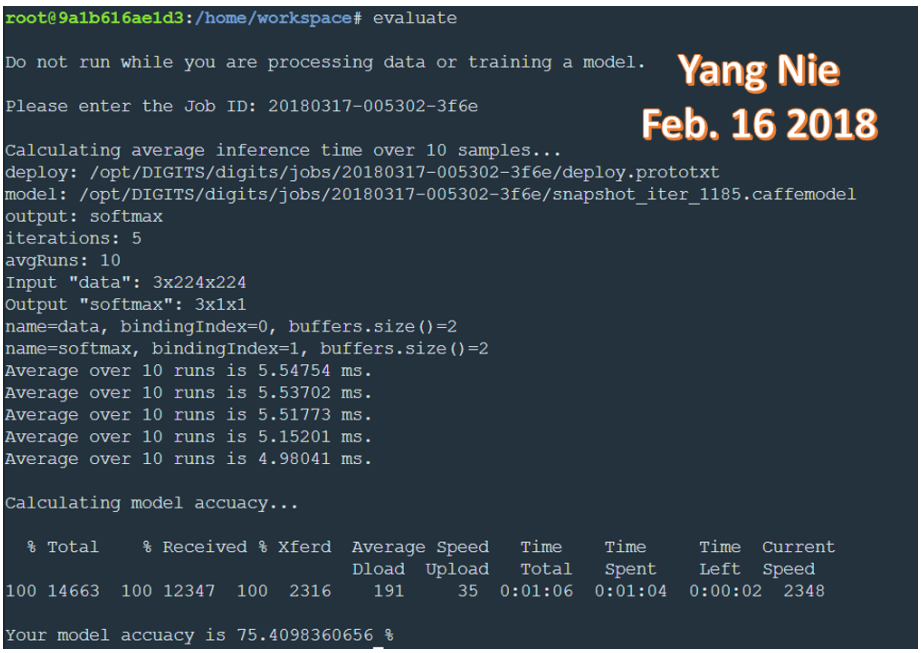
Both epoch were set to 5. All other parameters used as default.

## Results

Evaluating result for AlexNet Model as:




Evaluating result for GoogLeNet Model as:




Both AlexNet and GoogLeNet models are at least 75 percent accuracy and an inference time of less than 10 ms.

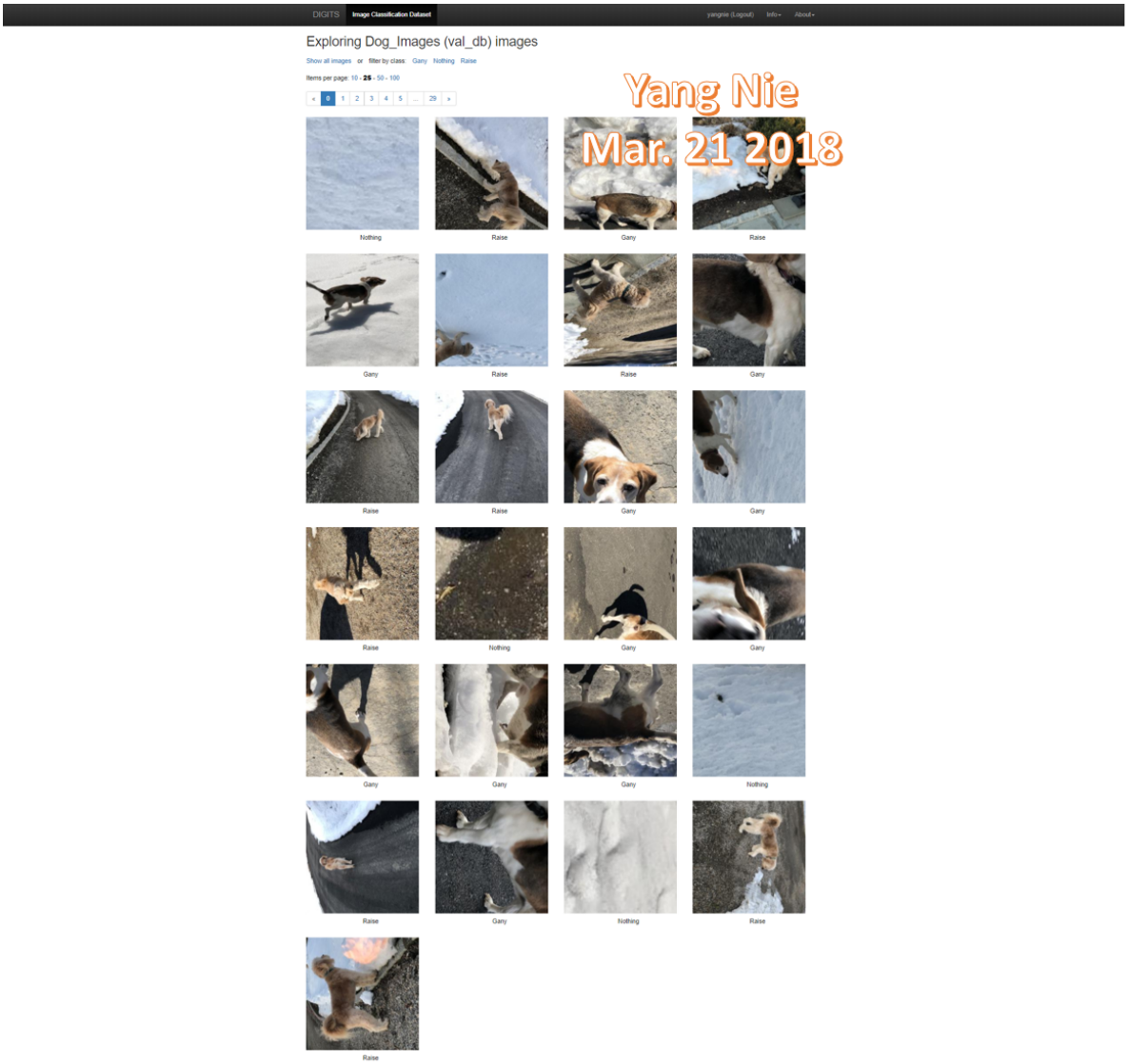
| | AlexNet | GoogLeNet |
|---|---|---|
| Accuacy | 75.4090360656% | 75.4090360656% |
| Average inference Time | 4.254004 ms | 5.34768 ms |

# 2. Dog image classification

## Background / Formulation

The dog image files located in Output folder, it includes three subfolders, Gany for dog A, Raise for dog B, Nothing for no object.

Dog image example:




Dog image dataset was split three training, validation and test parts, the color image size is 256 X 256

DIGITS | Image Classification Dataset | yangnie (Logout) | Info | About

# Dog_Images

Owner: yangnie

Clone Job | Delete Job

Yang Nie
Mar. 21 2018

## Job Information

**Job Directory**
/opt/DIGITS/digits/jobs/20180321-182200-7ee0

**Image Dimensions**
256x256 (Width x Height)
**Image Type**
Color
**Resize Transformation**
Squash
**DB Backend**
lmdb
**Image Encoding**
png
**DB Compression**
none

**Dataset size**
264 MB

## Parse Folder (train/val/test)

**Folder**
/home/workspace/Output

**Number of Categories**
3
**Training Images**
2182
**Validation Images**
698 (24.0%)
**Test images**
28 (1.0%)

- Initialized at 06:22:00 PM (1 second)
- Running at 06:22:01 PM (1 minute, 11 seconds)
- Done at [illegible] PM
(Total - 1 minute, [illegible])

Parse Folder (train/val/test) Done

- Initialized at 06:22:00 PM (1 second)
- Running at 06:22:02 PM (1 second)
- Done at 06:22:03 PM
(Total - 2 seconds)

Create DB (train) Done

- Initialized at 06:22:00 PM (2 seconds)
- Running at 06:22:03 PM (1 minute, 9 seconds)
- Done at 06:23:12 PM
(Total - 1 minute, 12 seconds)

Create DB (val) Done

- Initialized at 06:22:00 PM (2 seconds)
- Running at 06:22:03 PM (30 seconds)
- Done at 06:22:33 PM
(Total - 32 seconds)

Create DB (test) Done

- Initialized at 06:22:00 PM (2 seconds)
- Running at 06:22:03 PM (2 seconds)
- Done at 06:22:05 PM
(Total - 5 seconds)

## Create DB (train)

**Input File (before shuffling)**
train.txt
**DB Creation log file**
create_train_db.log
**DB Entries**
2182

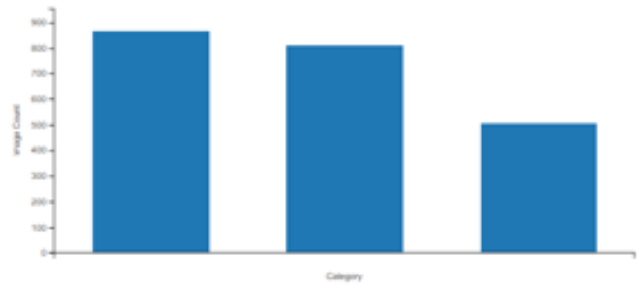
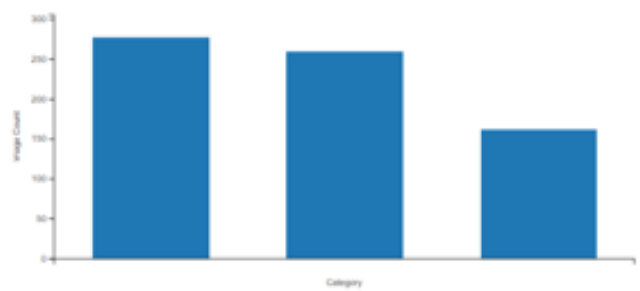



**Image Mean:**

Explore the db

## Create DB (val)

**Input File (before shuffling)**
val.txt
**DB Creation log file**
create_val_db.log
**DB Entries**
698




Explore the db

## Notes

None


## Data Acquisition:

The dog images were taken from iPhone, then used Augmentation[3] code to generate 500 to 1000 additional images depend the object type.

| | Dog A (Dany) | Dog B (Raise) | No object (Nothing) |
|---|---|---|---|
| iPhone images | 193 | 156 | 62 |
| Augment generated images | 887 | 998 | 612 |
| Total images | 1080 | 1154 | 674 |

The dog database was created as:

| | Training | Validating | Testing |
|---|---|---|---|
| Image number | 2185 | 695 | 28 |
| Percentage | 75% | 24% | 1% |

## Model creation:

GoogLeNet Model was created as : (Use default GoogLeNet network, no change in model itself)

DIGITS | Image Classification Model | yangnie (Logout) | Info | About

# GoogLeNet_Dog_50

Owner: yangnie

Clone Job | Delete Job

Yang Nie

Mar. 21 2018

**Job Directory**
/opt/DIGITS/digits/jobs/20180321-191601-e56c
**Disk Size**
0 B
**Network (train/val)**
train_val.prototxt
**Network (deploy)**
deploy.prototxt
**Network (original)**
original.prototxt
**Solver**
solver.prototxt
**Raw caffe output**
caffe_output.log

Dataset

Dog_Images

Done 06:23:13 PM

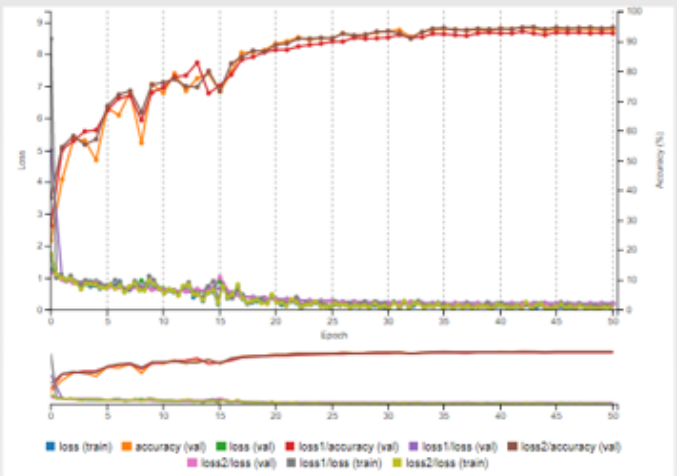
**Image Size**
256x256
**Image Type**
COLOR
**DB backend**
lmdb
**Create DB (train)**
2182 images
**Create DB (val)**
698 images
**Create DB (test)**
28 images

Job Status Done

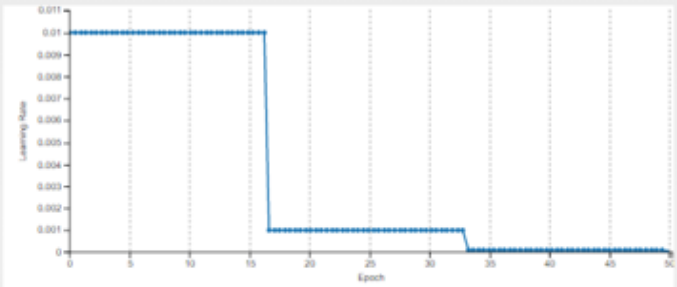
- Initialized at 07:16:01 PM (1 second)
- Running at 07:16:02 PM (26 minutes, 26 seconds)
- Done at 07:42:29 PM
(Total - 26 minutes, 27 seconds)

Train Caffe Model Done

- Initialized at 07:16:01 PM (1 second)
- Running at 07:16:02 PM (26 minutes, 26 seconds)
- Done at 07:42:29 PM
(Total - 26 minutes, 27 seconds)




View Large




## Trained Models

**Select Model**

Epoch #50 | Download Model | Make Pretrained Model | Publish to inference server

### Test a single image

**Image Path**

**Upload image**

Browse...

Show visualizations and statistics

Classify One

### Test a list of images

**Upload Image List**

Browse... test28.txt

Accepts a list of filenames or urls (you can use your val.txt file)

**Image folder** *(optional)*

Relative paths in the text file will be prepended with this value before reading

**Number of images use from the file**

All

Leave blank to use all

Classify Many

Related jobs

Image Classification Dataset

Dog_Images Done

- Initialized at 06:22:00 PM (1 second)
- Running at 06:22:01 PM (1 minute, 11 seconds)
- Done at 06:23:13 PM
(Total - 1 minute, 12 seconds)

Image Classification Model

AlexNet_Dog Done

- Initialized at 06:25:52 PM (1 second)
- Running at 06:25:53 PM (3 minutes, 47 seconds)
- Done at 06:29:41 PM
(Total - 3 minutes, 49 seconds)

GoogLeNet_Dog Done

- Initialized at 06:44:29 PM (1 second)
- Running at 06:44:30 PM (10 minutes, 58 seconds)
- Done at 06:55:29 PM
(Total - 10 minutes, 59 seconds)

Notes

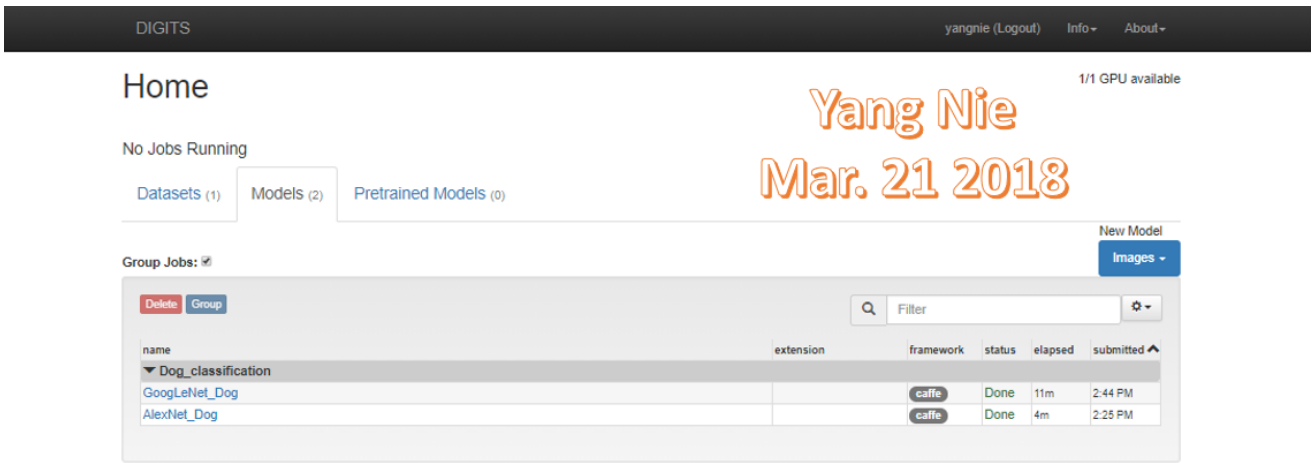
None


**The parameter setting:**

Both epoch were set to 50 and Batch size = 50. All other parameters used as default.

## Results:

AlexNet and GoogLeNet models, both were built and tested. Compare both of them, the GoogLeNet model has better results. This article only shows GoogLeNet model result.




This is GoogLeNet model results (epoch = 50, batch size = 50): The result is very good, the accuracy for all three classes are 100%.

Note: The number in table is the number of image:

| | Dog A (Gany) | Dog B (Raise) | No object (Nothing) | Per-class accuracy |
|---|---|---|---|---|
| Dog A (Gany) | 11 | 0 | 0 | 100% |
| Dog B (Raise) | 0 | 11 | 0 | 100% |
| No object (Nothing) | 0 | 0 | 6 | 100% |

Digits test results screen copy:

DIGITS GoogLeNet_Dog_50 **Classify Many** yangnie (Logout) Info About

# Classify Many Images

Owner: yangnie

Yang Nie

Mar. 21 2018

Delete Job

## GoogLeNet_Dog_50 Image Classification Mode

- Running at 07:43:58 PM (3 seconds)
- Done at 07:44:01 PM

(Total - 4 seconds)

Infer Model Done

### Summary

**Top-1 accuracy**
100.0%

**Top-5 accuracy**
100.0%

### Notes

None

### Confusion matrix

| | Gany | Nothing | Raise | Per-class accuracy |
|---|---|---|---|---|
| **Gany** | 11 | 0 | 0 | 100.0% |
| **Nothing** | 0 | 6 | 0 | 100.0% |
| **Raise** | 0 | 0 | 11 | 100.0% |

### All classifications

| | Path | Ground truth | Top predictions | | | | | |
|---|---|---|---|---|---|---|---|---|
| 1 | /home/workspace/Output/Gany/Gany_original_d97e01fc-4db5-41fc-8f34-f953582da95d.JPG | Gany | Gany | 96.29% | Raise | 3.62% | Nothing | 0.1% |
| 2 | /home/workspace/Output/Gany/Gany_original_0bad9fc7-480f-4fc8-8321-30e74628ccc3.JPG | Gany | Gany | 100.0% | Nothing | 0.0% | Raise | 0.0% |
| 3 | /home/workspace/Output/Gany/Gany_original_fa10d8e7-401d-4d5d-91c0-08987c786fb8.JPG | Gany | Gany | 100.0% | Raise | 0.0% | Nothing | 0.0% |
| 4 | /home/workspace/Output/Gany/Gany_original_4f9fb6e8-a9d8-412c-992c-0539260cba76.JPG | Gany | Gany | 99.99% | Nothing | 0.01% | Raise | 0.01% |
| 5 | /home/workspace/Output/Gany/Gany_original_eb093c9d-64af-4360-b6cd-74b2ebcac2b0.JPG | Gany | Gany | 99.87% | Nothing | 0.11% | Raise | 0.02% |
| 6 | /home/workspace/Output/Gany/Gany_original_ab87266c-fbe3-402f-b18b-57af716ea280.JPG | Gany | Gany | 83.69% | Nothing | 16.23% | Raise | 0.08% |
| 7 | /home/workspace/Output/Gany/Gany_original_90fd2d01-4e24-432f-85da-30955095c13a.JPG | Gany | Gany | 99.98% | Raise | 0.02% | Nothing | 0.0% |
| 8 | /home/workspace/Output/Gany/Gany_original_e688cc17-6081-4d09-ae79-534f46ae6587.JPG | Gany | Gany | 99.97% | Nothing | 0.02% | Raise | 0.01% |
| 9 | /home/workspace/Output/Gany/Gany_original_141fc080-cc9a-4ba1-9586-eed0efb7d65d.JPG | Gany | Gany | 99.7% | Raise | 0.22% | Nothing | 0.08% |
| 10 | /home/workspace/Output/Gany/Gany_original_5ed4651e-07ce-49db-8f97-1c1a8e274986.JPG | Gany | Gany | 99.9% | Raise | 0.08% | Nothing | 0.02% |
| 11 | /home/workspace/Output/Gany/Gany_original_4a6ac335-7e1e-4a36-bb18-d5ce7d6ce930.JPG | Gany | Gany | 99.96% | Nothing | 0.03% | Raise | 0.0% |
| 12 | /home/workspace/Output/Nothing/Nothing_original_ecef059d-59ae-4fcf-85d9-2a64c55e0c79.JPG | Nothing | Nothing | 93.96% | Gany | 6.02% | Raise | 0.02% |
| 13 | /home/workspace/Output/Nothing/Nothing_original_b084f654-7f4f-4879-bbad-9492f56f48b3.JPG | Nothing | Nothing | 95.47% | Gany | 4.43% | Raise | 0.1% |
| 14 | /home/workspace/Output/Nothing/Nothing_original_85d88e53-8e65-41b3-91d8-905e2238aac6.JPG | Nothing | Nothing | 97.03% | Gany | 2.96% | Raise | 0.01% |
| 15 | /home/workspace/Output/Nothing/Gany_original_96808377-3801-44db-8b66-df3b147482c8.JPG | Nothing | Nothing | 95.4% | Gany | 4.58% | Raise | 0.02% |
| 16 | /home/workspace/Output/Nothing/Nothing_original_1c5b12bc-b35c-43cd-9bf9-eb2fa378bede.JPG | Nothing | Nothing | 96.11% | Gany | 3.79% | Raise | 0.1% |
| 17 | /home/workspace/Output/Nothing/Nothing_original_d4e2617e-ed08-4c34-a7d2-5e954e0dbd56.JPG | Nothing | Nothing | 95.51% | Gany | 4.27% | Raise | 0.22% |
| 18 | /home/workspace/Output/Raise/Raise_original_2ddbb959-8605-47b8-9865-06cbf775d5df.JPG | Raise | Raise | 99.86% | Gany | 0.14% | Nothing | 0.0% |
| 19 | /home/workspace/Output/Raise/Raise_original_55684438-2c1b-4744-be1b-c849af01afff.JPG | Raise | Raise | 99.98% | Gany | 0.02% | Nothing | 0.0% |
| 20 | /home/workspace/Output/Raise/Raise_original_5e4c19c1-320d-45b0-abb1-d44db5e21296.JPG | Raise | Raise | 99.99% | Gany | 0.01% | Nothing | 0.0% |
| 21 | /home/workspace/Output/Raise/Raise_original_8f2df227-47a5-4809-8117-09f6eca56d33.JPG | Raise | Raise | 99.98% | Gany | 0.02% | Nothing | 0.0% |
| 22 | /home/workspace/Output/Raise/Raise_original_9a54f995-ad86-48e4-a341-c0259780b1f1.JPG | Raise | Raise | 99.86% | Gany | 0.14% | Nothing | 0.0% |
| 23 | /home/workspace/Output/Raise/Raise_original_4dec83e7-d155-4383-9e50-62ae8474ac88.JPG | Raise | Raise | 97.64% | Gany | 2.33% | Nothing | 0.04% |
| 24 | /home/workspace/Output/Raise/Raise_original_12c69b1c-172f-499c-baef-0c7746740eb7.JPG | Raise | Raise | 99.98% | Gany | 0.02% | Nothing | 0.0% |
| 25 | /home/workspace/Output/Raise/Raise_original_a5927ea1-f9e4-4619-ac30-8cf8f0d8eec9.JPG | Raise | Raise | 100.0% | Gany | 0.0% | Nothing | 0.0% |
| 26 | /home/workspace/Output/Raise/Raise_original_e5aee279-c626-41c5-904d-fb5090b0d516.JPG | Raise | Raise | 99.68% | Gany | 0.32% | Nothing | 0.0% |
| 27 | /home/workspace/Output/Raise/Raise_original_d516920f-c088-48a2-bf3c-bb84a76a58db.JPG | Raise | Raise | 100.0% | Gany | 0.0% | Nothing | 0.0% |
| 28 | /home/workspace/Output/Raise/Raise_original_151a2cf6-8c25-4218-a3d6-6a563ce02344.JPG | Raise | Raise | 100.0% | Gany | 0.0% | Nothing | 0.0% |

# Discussion

The original images are almost covering full dog body, using augment code can easily generate different angle and different part of dog body images. There is no problem to use rotate, flip and resize functions to generate new images, but crop image function can cause some image problems if the new image didn't include the target object at all. The image source quality is very important for Deep Learning training result, the manually checking was applying all these generated images to make sure no any nothing image mixed in dog image classes.

To achieve the best result, the LeNet network was not used because only 28x28 image size and gray color can be used. But AlexNet and GoogLeNet, both networks support 256x256 color image.

Both AlexNet and GoogLeNet have been tested for classification of dog image, GoogLeNet showed better accuracy than AlexNet at epoch = 20. According to the research paper from Siddharth Das[4], GoogLeNet had a better performance than AlexNet.

CNNs Architectures:LeNet, AlexNet, VGG, GoogLeNet, ResNet comparing table:

| Year | CNN | Developed by | Place | Top-5 error rate | No. of parameters |
|---|---|---|---|---|---|
| 1998 | LeNet(8) | Yann LeCun et al | | | 60 thousand |
| 2012 | AlexNet(7) | Alex Krizhevsky, Geoffrey Hinton, Ilya Sutskever | 1st | 15.3% | 60 million |
| 2013 | ZFNet() | Matthew Zeiler and Rob Fergus | 1st | 14.8% | |
| 2014 | GoogLeNet(19) | Google | 1st | 6.67% | 4 million |
| 2014 | VGG Net(16) | Simonyan, Zisserman | 2nd | 7.3% | 138 million |
| 2015 | ResNet(152) | Kaiming He | 1st | 3.6% | |

So GoogLeNet was selected to continue training and testing. Set epoch at 5, 20, 30 and 50 to train the GoogLeNet network, the best result is at epoch = 50, Batch size = 50.

Changed batch size to 50, can reduce training time and use less memory.

# Conclusion

## P1 moving belt image classification

Both AlexNet and GoogLeNet models were used with P1 dataset provided by the lesson in moving belt image classification, the results achieved the requirement of Udacity lesson (least 75 percent accuracy and an inference time of less than 10 ms.)

## Dog image classification

Using augmentation is a good and fast way to generate a large number of image from a small set of original images.

Both AlexNet and GoogLeNet models were tested, the GoogLeNet model was better results at same epoch number = 20.

The same GoogLeNet model, different epoch number 5, 20, 30 and 50 were tested.

The GoogLeNet model (with epoch = 50, Batch size = 50 and test dataset = 1% of total images) achieved the goal (All three classes accuracy are 100%).

## Future Work

1. Install Nvidia DIGITS system on local PC instead of using cloud GPU resource, the way is no time limitation to implement and test different projects and models.
2. Include testing object detection and segmentation implementation, and deploying the model on Jetson TX2 board and testing them in real world environment.
3. Using Nvidia DIGITS system to build and test the stock market trading system to classify and detect trading pattern.

## References

[1] S. Perkins, A. Walker and E. Wolfart, Classification "https://homepages.inf.ed.ac.uk/rbf/HIPR2/classify.htm" 2003

[2] Nvidia, DIGITS workflow "https://developer.nvidia.com/digits" 2018

[3] Marcus D. Bloice, Augmentor "https://github.com/mdbloice/Augmentor" 2018

[4] Siddharth Das, CNNs Architectures:LeNet, AlexNet, VGG, GoogLeNet, ResNet and more ... "https://medium.com/@siddharthdas_32104/cnns-architectures-lenet-alexnet-vgg-googlenet-resnet-and-more-666091488df5" 2017