Deep Learning on Azure

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Preface

This repository contains materials to help you learn about Deep Learning with the Microsoft Cognitive Toolkit (CNTK) and Microsoft Azure. Students can find slides, tutorial notebooks, and scripts covering a variety of deep learning fundamentals and applications. These course assets will teach you how to implement convolutional networks, recurrent networks, and generative models and apply them to problems in computer vision, natural language processing, and reinforcement learning. The course materials will pay particular attention on how to implement these algorithms most effectively using the resources provided by the Azure infrastructure, and best practices when working with CNTK.

1.1 Part I - Fundamentals and Azure for Machine Learning

- 1. Pretensions to Thinking and Learning Overview of Machine Learning
- 2. A Minimal Introduction to AI, Representation Learning, and Deep Learning
- 3. Deploying and Accessing the Linux Data Science Virtual Machine
- 4. Computational Graphs, Symbolic Differentiation, and Auto-Differentiation
- 5. Overview of the Microsoft Cognitive Toolkit (CNTK) and Other Deep Learning Frameworks
- 6. Activation Functions and Network Architectures
- 7. Representational Power and Capacity

1.2 Part II - Optimization

- 1. Backpropagation and Stochastic Optimization for Training Neural Networks
- 2. Momentum and Acceleration Methods
- 3. Regularization, Normalization, and Dropout
- 4. Distributed Training and Evaluation with Azure Batch AI
- 5. Practical Bayesian Optimization for Hyperparameter Search
- 6. Evolutionary Strategies for Parameter Search

1.3 Part III - Convolutional Neural Networks

- 1. Scaling Networks to Images
- 2. Receptive Fields, Spatial Arrangements, Strides and Filters
- 3. Dilated Convolutions and Pooling
- 4. Skip Connections and Residual Networks

1.4 Part IV - Recurrent Networks

- 1. Dense Word Vector Representations
- 2. Comparison of word2Vec, GloVe, and fasttext
- 3. Recurrent Neural Networks and Language Models
- 4. GRUs, LSTMs, and Recursive Architectures
- 5. Vanishing and Exploding Gradients
- 6. Memory and Attention

1.5 Part V - Reinforcement Learning

- 1. Optimal Control and Planning
- 2. Policy Gradients
- 3. Q-learning
- 4. Actor-Critic Methods
- 5. Evolutionary Strategies as an Alternative to Policy Methods

1.6 Part VI - Generative Models

- 1. Visualizing and Understanding Neural Networks with Saliency Maps
- 2. Adversarial Attacks on Neural Networks
- 3. Metrics on Distributions for Implicit Generative Models
- 4. Generative Adversarial Networks
- 5. Belief Nets and Change of Variable Models
- 6. Approximate Methods using the Variational Autoencoder

1.7 Part VII - Operationalization Methods

- 1. HDInsight, pyspark and mmlspark
- 2. Azure Batch Shipyard / Azure Batch Training
- 3. Azure container services
- 4. SQL Server 2017
- 5. The embedding learning library and web applications

1.8 Useful Resources

1.8.1 Online Courses

- Deep Learning Explained, edX 2017
 - Online MOOC that covers the fundamentals of Deep Learning with the Microsoft Cognitive Toolkit
 - Consists of 7 modules
 - Released in June 2017
- deeplearning.ai Coursera Specialization Taught by Andrew Ng
 - Specialization consisting of 5 MOOCs on Deep Learning taught by Andrew Ng
 - Taught using TensorFlow
- fastAI

- 2 Deep Learning courses taught by Jeremy Howard and Rachel Thomas at USF
- CS231n Convolutional Networks for Visual Recognition
- CS224n Natural Language Processing with Deep Learning

1.8.2 Online Books and Blogs

- Neural Networks and Deep Learning Michael Nielsen
- Deep Learning Ian Goodfellow, Youshua Bengio & Aaron Courville
- Chris Olah's Blog
- Distill Publications
- Andrej Karpathy's Blog
- Denny Britz's Blog
- Edwin Chen's Blog
- Off the Convex Path Join blog with Sanjeev Arora, Moritz Hardt & Nisheeth Vishnoi
- BAIR Berkeley AI Research Blog

Provisioning Linux DSVMs with Azure CLI 2.0

What You'll Need

- An Azure Subscription
- Bash
- Azure Cloud Shell
 - The Azure cloud shell provides a complete bash (and powershell) environment. The shell is automatically authenticated with Azure CLI 2.0 so you can provision and run all the scripts listed below using this shell. Shell:
- Windows Subsystem for Linux
 - In addition to WSL, you'll need to install Azure CLI 2.0. See the instructions below or refer to the Azure CLI 2.0.

In this lab you will provision your own Linux Data Science Virtual Machine (DSVM). The DSVM is a virtual machine that contains a large number of data science and machine learning tools preinstalled, including deep learning libraries like CNTK, Tensorflow, Caffe2, PyTorch, Keras, MXNet, and a lot more.

In this course, we will specifically use the Ubuntu version of the DSVM, since it is the most common distribution for machine learning and data science. Other operating system variants of the DSVM are available in CentOS and Windows (2012 and 2016 Server Editions).

You can provision, start, and stop the Linux DSVM from the Azure portal itself. You are recommended to take a look at the Azure portal and learn the interface. However, in this course we will introduce you to the Azure CLI 2.0, which is a command-line interface built in Python and available on macOS, Linux, and Windows. Learning a bit about the CLI can greatly improve your productivity with Azure resources, and will allow you to configuration and management scripts into your daily workflow. For Windows 10 users, I highly recommend you install the Windows Subsystem for Linux to get a complete bash environment on your system. In addition, I use conemu as my main console, which has a number of nice features including tabbed support for multiple consoles, including Ubuntu Bash, PowerShell and Git Bash.

2.1 Installing and Testing the Azure CLI

Follow the instructions on the Azure CLI 2.0 webpage for the latest information on how to install the CLI. Once you have installed the Azure CLI, and added it to your \$PATH, you should be able to call it from your terminal.

*NOTE If you're using the Azure Cloud Shell, you don't need to install Azure CLI 2.0 or authenticate. All that is already done for you. Skip to section Deploying Via a Custom Script.

```
alizaidi@MININT-C510VH5:~$ which az
/home/alizaidi/anaconda3/bin/az
```

2.2 Login to Your Azure Account

In order to the use the Azure CLI 2.0 to manage and create resources in Azure, you'll need to login to your Azure account:

```
alizaidi@MININT-C510VH5:~$ az login
```

This will prompt you to open a browser and activate your session:

```
alizaidi@MININT-C510VH5:~$ az login
To sign in, use a web browser to open the page https://aka.ms/devicelogin and enter the code FA5JZBPGA
```

Once you're logged into your account, you can list all the Azure subscriptions assoicated with your account by running az account list, and the one you're currently defaulting to using az account show:

```
alizaidi@MININT-C510VH5:~$ az account show
  "environmentName": "AzureCloud",
  "id": "please-dont-steal-my-acount",
  "isDefault": true,
  "name": "Not for you",
  "state": "Enabled",
  "tenantId": "nah",
  "user": {
   "name": "alizaidi@microsoft.com",
    "type": "user"
}
alizaidi@MININT-C510VH5:~$ az account list
    "cloudName": "AzureCloud",
    "id": "please-dont-steal-my-acount",
    "isDefault": true,
    "name": "Not for you",
    "state": "Enabled",
    "tenantId": "nah",
      "name": "alizaidi@microsoft.com",
      "type": "user"
    }
  }
]
```

You can use the option --output table to print the output in a tabular format.

Device Login

Enter the code that you received from the application on your device

FA5JZBPGA

Microsoft Azure Crossplatform Command Line Interface

Application publisher:

Click Cancel if this isn't the application you were trying to sign in to on your device.

Continue

Cancel

Figure 2.1:

2.3 Deploying Via Custom Script

Rather than doing this manually, I have created a custom script that will create the DSVM for you, and also run some configuration settings on your VM's network to allow for easier access.

You can simply deploy the DSVM by navigating to the labs/O-dsvm-deploy-script directory and running alizaidi:\$./deploydsvm.sh

The default parameters will use your bash username as your username for the VM, and a simple password. Feel free to change these by specThis will create your virtual machine, open up all the necessary ports on your VM's network security group, and save the credentials in a text file creds.txt.

2.4 Updating DSVM OS Disk Size

By default, your primary partition on the DSVM is only 50 GBs. Fortunately, expanding it is pretty easy. Let's again use two helper scripts I created to make this process trivally easy. Using the \$VMNAME and \$RG values saved in the file creds.txt, fill in the following command:

```
expand-osdisk.sh "os-size-in-GB" "RG" "VMNAME"

For example, I'd run
```

expand-disk.sh 200 azaididlclass azaididsvm

Now you're ready to log into your VM and have some fun!

2.5 Deploying Manually (Only Proceed if You Didn't Use the Script Above!)

If you didn't use the scripts above, I've written out the instructions manually below.

2.5.1 Create a New Resource Group

Resource groups are a convenient way of consolidating related resources together. This is particularly handy when you have a project that will require a variety of Azure resources and you'd like to see them all in one-place.

Please make sure your resource group is in "East US" region (you could potentially use South Central US).

In this example, I'll create a resource group called azteachdl in eastus

```
alizaidi:$ az group create -n azteachdl -l eastus
{
    "id": "/subscriptions/stay-away-from me/resourceGroups/azteachdl",
    "location": "eastus",
    #"managedBy": null,
    "name": "azteachdl",
    "properties": {
        "provisioningState": "Succeeded"
    },
    "tags": null
}
```

2.5.2 Create Your DSVM

Now let's create the Linux DSVM. Edit the parameters below with your configurations. In particular, you'll need to specify your own resource-group name, a name for the data science virtual machine, and your username.

```
az vm create \
    --resource-group azteachdl \
    --name azdsvmclass \
    --admin-username alizaidi \
    --public-ip-address-dns-name algoclass \
    --image microsoft-ads:linux-data-science-vm-ubuntu:linuxdsvmubuntu:latest \
    --size Standard_NC6 \
    --generate-ssh-keys
```

While the resources are being deployed, you will see a "Running" message displayed in your terminal. Upon completion, you should see an output JSON table with information about your resources:

2.5.3 Create a Password for the User

In the scripted solution, the authentication is done through a password.

In the manual setup we showed how you could create a virtual machine using the <code>generate-ssh-keys</code> option, which authenticates using SSH keys, which by default are saved as a pair of private and public keys in ~/.ssh/id_rsa and ~/.ssh/id_rsa.pub. In order to access certain web applications like Jupyter, we'll need a password for our user.

To create a password for the user, run the following:

```
sudo passwd $USERNAME
```

where \$USERNAME is the username you used to create the VM.

You can now navigate to the portal and check for your resources.

Upgrading CNTK and CUDNN

In this lab, we'll upgrade from CNTK version 2.0 to CNTK 2.2.

3.1 Updating CNTK

CNTK is available in a variety of precompiled binaries, which you can install using the pip installer.

3.2 Updating CNTK With a Single Script

I've created a single script to make the upgrade process a lot simper:

```
./cntk-install.sh
```

This will create a new conda environment called cntk-py35 with your new CNTK installation.

3.2.1 Launch JupyterLab

JupyterLab is an updated environment based on Jupyter. In addition to the notebooks popularized by Jupyter, JupyterLab has an inspector for viewing help files quickly, a terminal, and a file browser. This makes for a more complete interactive development experience!

To launch JupyterLab and keep it running, I recommend first creating a password you can use to log into your server without having to use special tokens (see the documentation here. Moreover, since we want to keep JupyterLab running in the background even after we close out our terminal session, I'd recommend using tmux to launch your Jupyter session.

```
tmux new -s jupyterlab
jupyter notebook --generate-config
jupyter notebook password
jupyter lab --ip="*"
tmux detach
jupyter notebook list
```

Now navigate to your :8888 to interact with JupyterLab!

3.3 Manually Updating CNTK and Launching Jupyter (No Need to Do This if You Use the Script)

Only follow the steps below if the script above didn't work or if you like doing this manually...

3.3.1 Create Conda Virtual Environment

For this tutorial, we'll use the conda virtual environment manager to create and modify Python virtual environments. You can create a Python 3.5 environment with conda by using the conda create command: conda create -n cntk-py35 python=3.5 anaconda

The environment will be named cntk-py35 and the additional flag anaconda ensures that the distribution will install over a 100 prebuilt Python packages for scientific computing (list here).

3.3.2 Install CNTK Using pip Binary Wheels

We can activate that environment by running

```
source activate cntk-py35
```

Now that we are in our virutla environment for CNTK, let's install the appropriate Python binary using a Python "wheel". For example, here are the installation instructions for CNTK on a Python 3.5 environment with Ubuntu 16.04 system with GPU support:

pip install https://cntk.ai/PythonWheel/GPU/cntk-2.1-cp35-cp35m-linux_x86_64.whl

3.3.3 Temporary Fixes

Let's take complete ownership of our home and anaconda directories:

```
sudo chown alizaidi:alizaidi -R /home/alizaidi
source deactivate
sudo chown alizaidi:alizaidi -R /anaconda/
pip install -U pip
```

IMPORTANT replace alizaidi with the username you used to create the DSVM.

Update ipython and related packages:

```
pip install --upgrade --force-reinstall jupyter
```

Remove az_ml_magic from ipython startup:

```
rm ~/.ipython/profile_default/startup/az_ml_magic.py
```

3.3.4 Conda Extensions

Since we created a new environment, let's also install some extensions that will make it easier to find that environment from JupyterHub.

```
conda install nb_conda
conda install ipykernel
```

3.3. MANUALLY UPDATING CNTK AND LAUNCHING JUPYTER (NO NEED TO DO THIS IF YOU USE THE S

python -m ipykernel install --user --name cntk-py35 --display-name "cntk-py35" jupyter kernelspec list

3.3.5 Install Keras

Let's also install Keras in this specific Python environment

source activate cntk-py35
pip install keras

Transfer Learning with CNTK

4.1 Classifying Dogs and Cats Using a Pre-Trained Network

This notebook provides a walkthrough of how to use an existing model, trained on a large corpus of images, and retrain it on a narrower class of images for a specific domain. In particular, we will be looking at the famous Kaggle competition, Cats vs. Dogs.

Let's import our core scientific python modules, numpy, matplotlib and pandas. In addition, we import CNTK. If you have trouble getting CNTK to run on a GPU (and you're sure you have one properly installed), you can manually request CNTK use the gpu device by commenting out the line after the import.

We have some helper functions in the utils.py script that we'll use to download our pre-trained network from a repository.

```
import os, cv2, random
import numpy as np
import os, shutil
import random
from glob import glob
np.random.seed(123)
import matplotlib.pyplot as plt
from matplotlib import ticker
import matplotlib.image as mpimg
import seaborn as sns
import itertools
import pandas as pd
sns.set(style="white")
%matplotlib inline
import cntk as C
# C.device.try_set_default_device(C.device.gpu(0))
import cntk.io.transforms as xforms
from __future__ import print_function
from utils.download_model import models, download_model_by_name, list_available_models
from PIL import Image
from IPython.display import display, SVG
```

```
%load_ext autoreload
```

4.1.1 Download Data

One of the easiest ways to download data from Kaggle competitions is using the kaggle-cli.

```
kg download -u <username> -p <password> -c dogs-vs-cats-redux-kernels-edition
```

For now, you can download the data just by running the bash commands below, which will download the data from my public blob storage account. Note, the data set is ~ 815 MB in size, and is in a storage container in *Central US*.

```
%%bash
wget -q https://alizaidi.blob.core.windows.net/training/catsdogs/data.zip
unzip data.zip
cd data
unzip *.zip
rm ../data.zip
```

4.2 Create Train, Test and Validate Sets

Our data arrives in a rather simple structure:

```
train/
    cat.****.jpg
    dog.****.jpg
test/
    *****.jpg
```

In order to evaluate our model (especially if we are tinkering with hyperparameters), it is important we separate a portion of our train set and use that for evaluation/validation. You shouldn't use your test set to guide your choice of hyperparameters, as this will likely lead to overfitted networks.

The function below takes a 20% sample from the train directory and puts it in a new directory called val. It leaves the data/train directory completely untouched, and instead makes a fully copy to ./train from where it takes the sample and moves it to ./val.

```
def train_val_split(train_path, split_train_path, split_val_path):
    if(os.path.exists(split_train_path)): shutil.rmtree(split_train_path)
    os.mkdir(split_val_path)

# Next copy everything in the combined training directory to the split training directory
    shutil.copytree(train_path, split_train_path)

num_folds = 5 # One of the folds to be val, the rest for train...

for subdir in glob(split_train_path + '*'):
    g = glob(subdir + '/*.jpg')
    shuf = np.random.permutation(g)
    for i in range(int(round(len(shuf)/num_folds))):
        print("Transferring ", shuf[i], " to ",
```

```
split_val_path + "/" + shuf[i].split('/')[2])
           os.rename(shuf[i], split_val_path + "/" + shuf[i].split('/')[2])
train_val_split(train_path = "data/train", split_train_path="./train", split_val_path="./val")
             ./train/cat.6109.jpg to
Transferring
                                      ./val/cat.6109.jpg
Transferring ./train/dog.5873.jpg to
                                       ./val/dog.5873.jpg
             ./train/dog.9468.jpg to
Transferring
                                       ./val/dog.9468.jpg
Transferring
             ./train/cat.9550.jpg to
                                       ./val/cat.9550.jpg
Transferring
             ./train/dog.111.jpg to
                                      ./val/dog.111.jpg
Transferring
             ./train/cat.2628.jpg to
                                       ./val/cat.2628.jpg
             ./train/dog.6430.jpg to
Transferring
                                       ./val/dog.6430.jpg
Transferring
              ./train/dog.642.jpg to
                                      ./val/dog.642.jpg
Transferring
              ./train/dog.9465.jpg to
                                       ./val/dog.9465.jpg
Transferring
             ./train/dog.10947.jpg to
                                        ./val/dog.10947.jpg
              ./train/cat.10475.jpg to
Transferring
                                        ./val/cat.10475.jpg
Transferring
              ./train/dog.6433.jpg to
                                       ./val/dog.6433.jpg
Transferring
             ./train/cat.5853.jpg to
                                       ./val/cat.5853.jpg
Transferring
             ./train/cat.10527.jpg to
                                       ./val/cat.10527.jpg
Transferring
              ./train/cat.11977.jpg to
                                        ./val/cat.11977.jpg
Transferring
              ./train/dog.5173.jpg to
                                       ./val/dog.5173.jpg
Transferring
             ./train/cat.9391.jpg to
                                       ./val/cat.9391.jpg
             ./train/cat.3189.jpg to
Transferring
                                       ./val/cat.3189.jpg
Transferring
              ./train/dog.4299.jpg
                                   to
                                       ./val/dog.4299.jpg
Transferring
             ./train/dog.11492.jpg
                                        ./val/dog.11492.jpg
                                   to
Transferring
             ./train/dog.10894.jpg to
                                        ./val/dog.10894.jpg
Transferring
             ./train/cat.2177.jpg to
                                       ./val/cat.2177.jpg
             ./train/cat.9712.jpg to
Transferring
                                       ./val/cat.9712.jpg
             ./train/cat.5060.jpg to
Transferring
                                       ./val/cat.5060.jpg
Transferring
             ./train/cat.8942.jpg to
                                       ./val/cat.8942.jpg
Transferring
             ./train/cat.3977.jpg to
                                       ./val/cat.3977.jpg
                                       ./val/cat.6462.jpg
Transferring
              ./train/cat.6462.jpg
                                   to
Transferring
              ./train/dog.8681.jpg
                                   to
                                       ./val/dog.8681.jpg
Transferring
             ./train/dog.6768.jpg to
                                       ./val/dog.6768.jpg
Transferring
              ./train/dog.11025.jpg to
                                       ./val/dog.11025.jpg
Transferring
              ./train/cat.895.jpg to
                                      ./val/cat.895.jpg
Transferring
              ./train/dog.5775.jpg to
                                       ./val/dog.5775.jpg
             ./train/cat.5206.jpg to
Transferring
                                       ./val/cat.5206.jpg
Transferring
              ./train/cat.7135.jpg to
                                       ./val/cat.7135.jpg
             ./train/cat.5365.jpg to
                                       ./val/cat.5365.jpg
Transferring
Transferring
             ./train/cat.5888.jpg to
                                       ./val/cat.5888.jpg
             ./train/cat.11863.jpg to
Transferring
                                       ./val/cat.11863.jpg
Transferring
              ./train/cat.44.jpg to ./val/cat.44.jpg
Transferring
              ./train/dog.8802.jpg to
                                       ./val/dog.8802.jpg
                                       ./val/cat.5389.jpg
Transferring
             ./train/cat.5389.jpg to
Transferring
             ./train/cat.1922.jpg to
                                       ./val/cat.1922.jpg
Transferring
              ./train/cat.11303.jpg to
                                        ./val/cat.11303.jpg
Transferring
              ./train/dog.7221.jpg to
                                       ./val/dog.7221.jpg
Transferring
             ./train/dog.10890.jpg to
                                        ./val/dog.10890.jpg
Transferring
              ./train/cat.12050.jpg to
                                        ./val/cat.12050.jpg
Transferring
              ./train/dog.1726.jpg to
                                       ./val/dog.1726.jpg
              ./train/dog.1230.jpg to
Transferring
                                       ./val/dog.1230.jpg
Transferring
             ./train/dog.10810.jpg to
                                        ./val/dog.10810.jpg
             ./train/cat.11925.jpg to
Transferring
                                        ./val/cat.11925.jpg
```

```
./val/dog.4675.jpg
Transferring
             ./train/dog.4675.jpg to
Transferring
             ./train/cat.7273.jpg to
                                       ./val/cat.7273.jpg
Transferring
             ./train/cat.4016.jpg to
                                       ./val/cat.4016.jpg
Transferring
             ./train/cat.10264.jpg to
                                       ./val/cat.10264.jpg
Transferring
              ./train/dog.2864.jpg to
                                       ./val/dog.2864.jpg
             ./train/cat.8417.jpg to
Transferring
                                       ./val/cat.8417.jpg
Transferring
             ./train/dog.11487.jpg to
                                       ./val/dog.11487.jpg
Transferring
              ./train/cat.3400.jpg to
                                       ./val/cat.3400.jpg
Transferring
              ./train/dog.7898.jpg to
                                       ./val/dog.7898.jpg
Transferring
              ./train/dog.53.jpg to ./val/dog.53.jpg
Transferring
             ./train/dog.3764.jpg to
                                       ./val/dog.3764.jpg
Transferring
              ./train/dog.466.jpg to
                                      ./val/dog.466.jpg
              ./{	train/dog.3664.jpg} to
Transferring
                                       ./val/dog.3664.jpg
                                       ./val/dog.4542.jpg
Transferring
             ./train/dog.4542.jpg to
Transferring
             ./train/cat.40.jpg to ./val/cat.40.jpg
Transferring
              ./train/dog.828.jpg to
                                      ./val/dog.828.jpg
Transferring
              ./train/cat.4011.jpg to
                                       ./val/cat.4011.jpg
             ./train/dog.4882.jpg to
Transferring
                                       ./val/dog.4882.jpg
Transferring
             ./train/dog.10431.jpg to
                                        ./val/dog.10431.jpg
Transferring
              ./train/cat.11108.jpg to
                                        ./val/cat.11108.jpg
Transferring
              ./train/dog.9434.jpg to
                                       ./val/dog.9434.jpg
Transferring
             ./train/cat.10261.jpg to
                                       ./val/cat.10261.jpg
             ./train/dog.5239.jpg to
                                       ./val/dog.5239.jpg
Transferring
Transferring
              ./train/dog.10800.jpg to
                                        ./val/dog.10800.jpg
Transferring
              ./train/dog.6166.jpg to
                                       ./val/dog.6166.jpg
Transferring
             ./train/cat.3282.jpg to
                                       ./val/cat.3282.jpg
Transferring
              ./train/dog.5340.jpg to
                                       ./val/dog.5340.jpg
              ./train/dog.381.jpg to
Transferring
                                      ./val/dog.381.jpg
Transferring
             ./train/cat.7004.jpg to
                                       ./val/cat.7004.jpg
             ./train/cat.916.jpg to
Transferring
                                      ./val/cat.916.jpg
Transferring
              ./train/cat.897.jpg to
                                      ./val/cat.897.jpg
Transferring
              ./train/dog.11691.jpg to
                                       ./val/dog.11691.jpg
Transferring
             ./train/dog.7296.jpg to
                                       ./val/dog.7296.jpg
             ./train/dog.10832.jpg to
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Transferring
Transferring
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Transferring
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Transferring
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Transferring
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Transferring
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Transferring
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Transferring
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Transferring
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Transferring
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Transferring
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Transferring
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Transferring
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Transferring
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Transferring
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Transferring
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Transferring
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Transferring
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Transferring
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Transferring
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Transferring
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Transferring
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Transferring
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Transferring
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Transferring
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Transferring
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Transferring
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Transferring
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Transferring
Transferring
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Transferring
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Transferring
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Transferring
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Transferring
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Transferring
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Transferring
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Transferring
Transferring
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Transferring
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Transferring
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Transferring
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Transferring
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Transferring
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Transferring
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Transferring
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Transferring
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Transferring
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Transferring
Transferring
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                                        ./val/cat.10909.jpg
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Transferring
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Transferring
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Transferring
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Transferring
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Transferring
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Transferring
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Transferring
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Transferring
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Transferring
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Transferring
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Transferring
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Transferring
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              ./train/dog.4227.jpg to
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Transferring
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Transferring
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Transferring
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Transferring
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Transferring
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Transferring
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Transferring
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Transferring
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Transferring
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Transferring
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Transferring
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Transferring
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Transferring
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Transferring
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Transferring
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Transferring
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                                   to
Transferring
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Transferring
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Transferring
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Transferring
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             ./train/cat.12027.jpg to
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Transferring
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Transferring
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                                       ./val/cat.4399.jpg
Transferring
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Transferring
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Transferring
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Transferring
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Transferring
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                                       ./val/cat.8321.jpg
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Transferring
                                       ./val/dog.1549.jpg
Transferring
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Transferring
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Transferring
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Transferring
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                                       ./val/cat.11968.jpg
Transferring
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Transferring
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Transferring
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Transferring
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                                       ./val/dog.11249.jpg
Transferring
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                                       ./val/cat.1860.jpg
              ./train/cat.348.jpg to
Transferring
                                      ./val/cat.348.jpg
Transferring
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Transferring
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Transferring
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             ./train/dog.3833.jpg to ./val/dog.3833.jpg
Transferring
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Transferring
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Transferring
                                    to
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Transferring
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Transferring
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Transferring
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Transferring
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Transferring
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Transferring
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Transferring
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Transferring
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Transferring
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Transferring
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Transferring
                                    to
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Transferring
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                                    to
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Transferring
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                                        ./val/dog.7360.jpg
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Transferring
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Transferring
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Transferring
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Transferring
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Transferring
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Transferring
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Transferring
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Transferring
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Transferring
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Transferring
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Transferring
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Transferring
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Transferring
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Transferring
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Transferring
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Transferring
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Transferring
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Transferring
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Transferring
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Transferring
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Transferring
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Transferring
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Transferring
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Transferring
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Transferring
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Transferring
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              ./train/cat.2484.jpg
Transferring
                                    to
                                        ./val/cat.2484.jpg
              ./train/dog.7338.jpg
Transferring
                                    to
                                        ./val/dog.7338.jpg
                                        ./val/cat.2595.jpg
Transferring
              ./train/cat.2595.jpg
                                    to
Transferring
              ./train/cat.10253.jpg
                                         ./val/cat.10253.jpg
Transferring
              ./train/dog.4526.jpg to
                                        ./val/dog.4526.jpg
              ./train/dog.769.jpg to
                                       ./val/dog.769.jpg
Transferring
Transferring
              ./train/dog.2520.jpg to
                                        ./val/dog.2520.jpg
Transferring
              ./train/cat.3616.jpg
                                    to
                                        ./val/cat.3616.jpg
Transferring
              ./train/dog.11488.jpg to
                                         ./val/dog.11488.jpg
Transferring
              ./train/dog.3393.jpg
                                    to
                                        ./val/dog.3393.jpg
              ./train/cat.9578.jpg
Transferring
                                        ./val/cat.9578.jpg
                                    to
Transferring
              ./train/cat.3870.jpg
                                        ./val/cat.3870.jpg
              ./train/dog.1102.jpg
Transferring
                                    to
                                        ./val/dog.1102.jpg
Transferring
              ./train/dog.9141.jpg
                                    to
                                        ./val/dog.9141.jpg
Transferring
              ./train/dog.9732.jpg
                                        ./val/dog.9732.jpg
                                    to
Transferring
              ./train/cat.5873.jpg
                                        ./val/cat.5873.jpg
                                    to
              ./train/cat.8117.jpg
                                        ./val/cat.8117.jpg
Transferring
                                    to
                                        ./val/cat.3003.jpg
Transferring
              ./train/cat.3003.jpg
                                    to
Transferring
              ./train/dog.10897.jpg
                                    to
                                         ./val/dog.10897.jpg
Transferring
              ./train/cat.7338.jpg to
                                        ./val/cat.7338.jpg
Transferring
              ./train/dog.11701.jpg
                                         ./val/dog.11701.jpg
                                    to
                                        ./val/cat.6471.jpg
Transferring
              ./train/cat.6471.jpg to
              ./train/cat.3023.jpg
                                        ./val/cat.3023.jpg
Transferring
                                    to
Transferring
              ./train/dog.4156.jpg
                                    to
                                        ./val/dog.4156.jpg
              ./train/dog.7002.jpg
Transferring
                                    to
                                        ./val/dog.7002.jpg
Transferring
              ./train/dog.9855.jpg
                                    to
                                        ./val/dog.9855.jpg
Transferring
              ./train/cat.8013.jpg
                                    to
                                        ./val/cat.8013.jpg
Transferring
              ./train/cat.2915.jpg
                                        ./val/cat.2915.jpg
                                    to
Transferring
              ./train/dog.3352.jpg
                                    to
                                        ./val/dog.3352.jpg
              ./train/dog.9601.jpg
Transferring
                                    to
                                        ./val/dog.9601.jpg
Transferring
              ./train/cat.9021.jpg
                                    to
                                        ./val/cat.9021.jpg
Transferring
              ./train/dog.10359.jpg
                                         ./val/dog.10359.jpg
                                    to
Transferring
              ./train/dog.11817.jpg
                                         ./val/dog.11817.jpg
                                     to
              ./train/dog.7737.jpg to
Transferring
                                        ./val/dog.7737.jpg
Transferring
              ./train/cat.3445.jpg
                                    to
                                        ./val/cat.3445.jpg
              ./train/cat.10069.jpg to
                                         ./val/cat.10069.jpg
Transferring
              ./train/dog.9136.jpg to
                                        ./val/dog.9136.jpg
Transferring
```

```
./train/cat.1431.jpg to
Transferring
                                       ./val/cat.1431.jpg
Transferring
             ./train/dog.7269.jpg to
                                       ./val/dog.7269.jpg
Transferring ./train/cat.2084.jpg to
                                      ./val/cat.2084.jpg
Transferring
             ./train/cat.3620.jpg to
                                       ./val/cat.3620.jpg
Transferring
             ./train/cat.8593.jpg to
                                       ./val/cat.8593.jpg
Transferring ./train/cat.6015.jpg to
                                       ./val/cat.6015.jpg
Transferring ./train/cat.7960.jpg to
                                       ./val/cat.7960.jpg
Transferring
             ./train/cat.1756.jpg to
                                       ./val/cat.1756.jpg
Transferring ./train/cat.8079.jpg to
                                       ./val/cat.8079.jpg
Transferring ./train/cat.2351.jpg to
                                       ./val/cat.2351.jpg
Transferring
             ./train/cat.2216.jpg to
                                       ./val/cat.2216.jpg
Transferring
             ./train/dog.976.jpg to
                                      ./val/dog.976.jpg
Transferring
             ./train/dog.9309.jpg to
                                       ./val/dog.9309.jpg
                                       ./val/dog.8506.jpg
Transferring
             ./train/dog.8506.jpg to
Transferring
             ./train/dog.1968.jpg
                                       ./val/dog.1968.jpg
                                   to
Transferring
             ./train/dog.10876.jpg to
                                       ./val/dog.10876.jpg
             ./train/dog.4517.jpg to
Transferring
                                       ./val/dog.4517.jpg
             ./train/cat.9830.jpg to
Transferring
                                       ./val/cat.9830.jpg
             ./train/dog.7461.jpg
Transferring
                                   to
                                       ./val/dog.7461.jpg
             ./train/dog.3015.jpg
                                       ./val/dog.3015.jpg
Transferring
                                   to
Transferring
             ./train/cat.7302.jpg to
                                       ./val/cat.7302.jpg
Transferring ./train/dog.2785.jpg to
                                       ./val/dog.2785.jpg
             ./train/cat.3066.jpg to
                                       ./val/cat.3066.jpg
Transferring
Transferring
             ./train/dog.2521.jpg to
                                       ./val/dog.2521.jpg
Transferring
             ./train/cat.9558.jpg to
                                       ./val/cat.9558.jpg
Transferring
             ./train/dog.8991.jpg
                                   to
                                       ./val/dog.8991.jpg
Transferring
             ./train/cat.11593.jpg to
                                       ./val/cat.11593.jpg
             ./train/cat.7034.jpg to
                                       ./val/cat.7034.jpg
Transferring
Transferring
             ./train/dog.9897.jpg
                                       ./val/dog.9897.jpg
             ./train/dog.7600.jpg to
Transferring
                                       ./val/dog.7600.jpg
Transferring
             ./train/cat.2618.jpg to
                                       ./val/cat.2618.jpg
Transferring
             ./train/cat.5047.jpg to
                                       ./val/cat.5047.jpg
Transferring
             ./train/cat.10434.jpg to
                                       ./val/cat.10434.jpg
             ./train/dog.10016.jpg to ./val/dog.10016.jpg
Transferring
Transferring
             ./train/cat.5742.jpg to
                                       ./val/cat.5742.jpg
Transferring
             ./train/cat.5194.jpg to
                                       ./val/cat.5194.jpg
Transferring ./train/cat.1617.jpg to
                                       ./val/cat.1617.jpg
```

4.3 Kittypupsploration

Let's create some pointers to our directories and create lists that map to each directory and category, i.e., cat and dog.

```
TRAIN_DIR = './data/train/'
TEST_DIR = './data/test/'
VAL_DIR = './val'

ROWS = 64
COLS = 64
CHANNELS = 3

# len(train_images)
# val_set = random.sample(train_images, k=10000)
```

```
# val_imgs = [v[13:] for v in val_set]

# for i in range(len(val_set)):
# os.rename(val_set[i], "./data/val/"+val_imgs[i])
```

We'll also make some functions to read our images using the cv2 package.

```
train_images = [TRAIN_DIR+i for i in os.listdir(TRAIN_DIR)]
               [TRAIN_DIR+i for i in os.listdir(TRAIN_DIR) if 'dog' in i]
train_dogs =
               [TRAIN_DIR+i for i in os.listdir(TRAIN_DIR) if 'cat' in i]
train_cats =
test_images = [TEST_DIR+i for i in os.listdir(TEST_DIR)]
def read_image(file_path):
   img = cv2.imread(file_path, cv2.IMREAD_COLOR)
   return cv2.resize(img, (ROWS, COLS), interpolation=cv2.INTER_CUBIC)
def prep_data(images):
    count = len(images)
   data = np.ndarray((count, CHANNELS, ROWS, COLS), dtype=np.uint8)
   for i, image_file in enumerate(images):
        image = read_image(image_file)
        data[i] = image.T
        if i%250 == 0: print('Processed {} of {}'.format(i, count))
    return data
# if you want in-memory collections of the images:
# train = prep_data(train_images)
# test = prep_data(test_images)
print("Train shape: {}".format(len(train_images)))
print("Test shape: {}".format(len(test images)))
```

Train shape: 25000 Test shape: 12500

4.4 Data Readers in CNTK

CNTK's batch readers will often perform at their best when the underlying data is properly partitioned in separate directories by class. To make this especially easy for CNTK, we'll create a mapping file that maps each file path to it's one hot encoded label. We first split the images by their labels, then create a dictionary for each image to it's label (create_class_mapping_from_folder), and finally create a map.txt containing the complete training set paths and their labels.

Some additional helper functions for creating such datasets can be found in the **CNTK/Scripts** directory of the main repository.

```
%%bash
mkdir train/cats
mkdir train/dogs
mv train/cat.*.jpg train/cats
mv train/dog.*.jpg train/dogs
```

```
def create_class_mapping_from_folder(root_folder):
    classes = []
    for _, directories, _ in os.walk(root_folder):
       for directory in directories:
            classes.append(directory)
    classes.sort()
   return np.asarray(classes)
def create_map_file_from_folder(root_folder, class_mapping, include_unknown=False):
   map_file_name = os.path.join(root_folder, "map.txt")
   lines = []
   for class_id in range(0, len(class_mapping)):
        folder = os.path.join(root_folder, class_mapping[class_id])
        if os.path.exists(folder):
            for entry in os.listdir(folder):
                filename = os.path.join(folder, entry)
                if os.path.isfile(filename) and os.path.splitext(filename)[1] in file endings:
                    lines.append("{0}\t{1}\n".format(filename, class_id))
    if include_unknown:
        for entry in os.listdir(root_folder):
            filename = os.path.join(root_folder, entry)
            if os.path.isfile(filename) and os.path.splitext(filename)[1] in file_endings:
                lines.append("\{0\}\t-1\n".format(filename))
   lines.sort()
    with open(map_file_name , 'w') as map_file:
        for line in lines:
            map_file.write(line)
   return map_file_name
train_image_folder = os.path.join("train")
file_endings = ['.jpg', '.JPG', '.jpeg', '.JPEG', '.png', '.PNG']
class_mapping = create_class_mapping_from_folder(os.path.abspath(path="train/"))
train_map_file = create_map_file_from_folder(train_image_folder, class_mapping)
%%bash
head train/map.txt
tail train/map.txt
train/cats/cat.0.jpg
train/cats/cat.1.jpg
train/cats/cat.10.jpg
train/cats/cat.100.jpg 0
train/cats/cat.1000.jpg 0
train/cats/cat.10000.jpg
train/cats/cat.10002.jpg
train/cats/cat.10004.jpg
train/cats/cat.10007.jpg
train/cats/cat.10008.jpg
train/dogs/dog.9988.jpg 1
train/dogs/dog.999.jpg 1
train/dogs/dog.9990.jpg 1
```

```
train/dogs/dog.9991.jpg 1
train/dogs/dog.9992.jpg 1
train/dogs/dog.9993.jpg 1
train/dogs/dog.9994.jpg 1
train/dogs/dog.9995.jpg 1
train/dogs/dog.9998.jpg 1
train/dogs/dog.9999.jpg 1
```

4.5 Pre-Trained Models

CNTK has a list of pre-trained models. These are models that were either trained from scratch with CNTK on a large image corpus like ImageNet 1K, or converted from other toolkits. You can find a list of pre-trained image models here.

Our first step is to download the pre-trained image model and load it into our local directory.

We'll try using the ResNet 18 model developed by Kaiming He while he was at MSR Asia. This model is a Convolutional Neural Network built using Residual Network techniques. Convolutional Neural Networks build up layers of convolutions, transforming an input image and distilling it down until they start recognizing composite features, with deeper layers of convolutions recognizing complex patterns are made possible.

Residual Deep Learning attemps to "pass through" the main signal of the input data, so that the network winds up "learning" on just the residual portions that differ between layers. This has proven, in practice, to allow the training of much deeper networks by avoiding issues that plague gradient descent on larger networks. These cells bypass convolution layers and then come back in later before ReLU (see below), but some have argued that even deeper networks can be built by avoiding even more nonlinearities in the bypass channel. This is an area of hot research right now, and one of the most exciting parts of Transfer Learning is that you get to benefit from all of the improvements by just integrating new trained models.

%autoreload

```
list_available_models()
```

```
Available models (for more information see Readme.md):
Model name
                             Category
AlexNet_ImageNet_CNTK
                             Image Classification
AlexNet_ImageNet_Caffe
                             Image Classification
BNInception_ImageNet_Caffe
                             Image Classification
InceptionV3_ImageNet_CNTK
                             Image Classification
ResNet101 ImageNet Caffe
                             Image Classification
ResNet110_CIFAR10_CNTK
                             Image Classification
ResNet152_ImageNet_Caffe
                             Image Classification
ResNet18_ImageNet_CNTK
                             Image Classification
ResNet20_CIFAR10_CNTK
                             Image Classification
ResNet34_ImageNet_CNTK
                             Image Classification
ResNet50_ImageNet_CNTK
                             Image Classification
ResNet50_ImageNet_Caffe
                             Image Classification
VGG16_ImageNet_Caffe
                             Image Classification
VGG19_ImageNet_Caffe
                             Image Classification
Fast-RCNN_Pascal
                             Image Object Detection
Fast-RCNN_grocery100
                             Image Object Detection
base_model_file = download_model_by_name("ResNet18_ImageNet_CNTK")
```

CNTK model already available at /datadrive/kaggle/catsdogs/utils/ResNet18_ImageNet_CNTK.model

```
base_model_file
```

4.6 Defining Model Architecture

Now that we have our pretrained model saved, we'll take a look at it's node labels and use that to define our new architecture.

```
!ls -lh utils/
base_model = {
    'model_file': base_model_file,
    'feature_node_name': 'features',
    'last hidden node name': 'z.x',
    # Channel Depth x Height x Width
    'image_dims': (3, 224, 224)
}
print('Loading {} and printing all layers:'.format(base_model['model_file']))
node_outputs = C.logging.get_node_outputs(C.load_model(base_model['model_file']))
for 1 in node_outputs: print(" {0} {1}".format(l.name, l.shape))
Loading /datadrive/kaggle/catsdogs/utils/ResNet18 ImageNet CNTK.model and printing all layers:
  ce ()
  errs ()
  top5Errs ()
  z (1000,)
  ce ()
  z (1000,)
  z.PlusArgs[0] (1000,)
  z.x (512, 1, 1)
  z.x.x.r (512, 7, 7)
 z.x.x.p (512, 7, 7)
  z.x.x.b (512, 7, 7)
  z.x.x.b.x.c (512, 7, 7)
 z.x.x.b.x (512, 7, 7)
 z.x.x.b.x._ (512, 7, 7)
  z.x.x.b.x._.x.c (512, 7, 7)
  z.x.x.r (512, 7, 7)
 z.x.x.x.p (512, 7, 7)
  z.x.x.x.b (512, 7, 7)
  z.x.x.x.b.x.c (512, 7, 7)
 z.x.x.x.b.x (512, 7, 7)
  z.x.x.x.b.x. (512, 7, 7)
  z.x.x.x.b.x._.x.c (512, 7, 7)
  _z.x.x.x.r (512, 7, 7)
  z.x.x.x.p (512, 7, 7)
  _z.x.x.x.b (512, 7, 7)
  _z.x.x.b.x.c (512, 7, 7)
  _z.x.x.x.b.x (512, 7, 7)
  _z.x.x.x.b.x._ (512, 7, 7)
  _z.x.x.x.b.x._.x.c (512, 7, 7)
  z.x.x.x.r (256, 14, 14)
```

^{&#}x27;/datadrive/kaggle/catsdogs/utils/ResNet18_ImageNet_CNTK.model'

```
z.x.x.x.p (256, 14, 14)
z.x.x.x.b (256, 14, 14)
z.x.x.x.x.b.x.c (256, 14, 14)
z.x.x.x.b.x (256, 14, 14)
z.x.x.x.b.x._ (256, 14, 14)
z.x.x.x.b.x._.x.c (256, 14, 14)
z.x.x.x.x.r (256, 14, 14)
z.x.x.x.x.p (256, 14, 14)
z.x.x.x.x.b (256, 14, 14)
z.x.x.x.x.b.x.c (256, 14, 14)
z.x.x.x.x.b.x (256, 14, 14)
z.x.x.x.x.b.x. (256, 14, 14)
z.x.x.x.x.b.x._.x.c (256, 14, 14)
z.x.x.x.x.x.r (128, 28, 28)
z.x.x.x.x.x.p (128, 28, 28)
z.x.x.x.x.x.b (128, 28, 28)
z.x.x.x.x.x.b.x.c (128, 28, 28)
z.x.x.x.x.x.b.x (128, 28, 28)
z.x.x.x.x.x.b.x._ (128, 28, 28)
z.x.x.x.x.x.b.x._.x.c (128, 28, 28)
z.x.x.x.x.x.x.r (128, 28, 28)
z.x.x.x.x.x.x.p (128, 28, 28)
z.x.x.x.x.x.x.b (128, 28, 28)
z.x.x.x.x.x.x.b.x.c (128, 28, 28)
z.x.x.x.x.x.x.b.x (128, 28, 28)
z.x.x.x.x.x.x.b.x._ (128, 28, 28)
z.x.x.x.x.x.x.b.x._.x.c (128, 28, 28)
z.x.x.x.x.x.x.x.r (64, 56, 56)
z.x.x.x.x.x.x.x.x.p (64, 56, 56)
z.x.x.x.x.x.x.x.b (64, 56, 56)
z.x.x.x.x.x.x.x.b.x.c (64, 56, 56)
z.x.x.x.x.x.x.x.b.x (64, 56, 56)
z.x.x.x.x.x.x.x.b.x. (64, 56, 56)
z.x.x.x.x.x.x.x.b.x._.x.c (64, 56, 56)
z.x.x.x.x.x.x.x.x.x.r (64, 56, 56)
z.x.x.x.x.x.x.x.x.p (64, 56, 56)
z.x.x.x.x.x.x.x.b (64, 56, 56)
z.x.x.x.x.x.x.x.x.b.x.c (64, 56, 56)
z.x.x.x.x.x.x.x.b.x (64, 56, 56)
z.x.x.x.x.x.x.x.x.b.x._ (64, 56, 56)
z.x.x.x.x.x.x.x.x.b.x._.x.c (64, 56, 56)
z.x.x.x.x.x.x.x.x (64, 56, 56)
z.x.x.x.x.x.x.x.x (64, 112, 112)
z.x.x.x.x.x.x.x.x.x. (64, 112, 112)
z.x.x.x.x.x.x.s (128, 28, 28)
z.x.x.x.x.x.x.s.x.c (128, 28, 28)
z.x.x.x.x.s (256, 14, 14)
z.x.x.x.x.x.s.x.c (256, 14, 14)
z.x.x.x.s (512, 7, 7)
z.x.x.x.s.x.c (512, 7, 7)
errs ()
top5Errs ()
```

```
svg = C.logging.graph.plot(C.load_model(base_model['model_file']), "tmp.svg");
Warning: node 'ReLU1049', graph 'network_graph' size too small for label
Warning: node 'ReLU1018', graph 'network_graph' size too small for label
Warning: node 'ReLU1032', graph 'network_graph' size too small for label
Warning: node 'ReLU987', graph 'network_graph' size too small for label
Warning: node 'ReLU1001', graph 'network_graph' size too small for label
Warning: node 'ReLU956', graph 'network_graph' size too small for label
Warning: node 'ReLU942', graph 'network_graph' size too small for label
Warning: node 'ReLU911', graph 'network_graph' size too small for label
Warning: node 'ReLU925', graph 'network_graph' size too small for label
Warning: node 'ReLU880', graph 'network_graph' size too small for label
Warning: node 'ReLU866', graph 'network_graph' size too small for label
Warning: node 'ReLU835', graph 'network_graph' size too small for label
Warning: node 'ReLU849', graph 'network_graph' size too small for label
Warning: node 'ReLU804', graph 'network_graph' size too small for label
Warning: node 'ReLU790', graph 'network graph' size too small for label
Warning: node 'ReLU759', graph 'network_graph' size too small for label
Warning: node 'ReLU773', graph 'network_graph' size too small for label
Warning: node 'ReLU742', graph 'network_graph' size too small for label
Warning: node 'ReLU725', graph 'network_graph' size too small for label
display(SVG(filename="tmp.svg"))
Visualizing the network architecture is tough due to it's complexity and size. Kitties and puppies are simpler,
and more fun to visualize!
def plot_images(images, subplot_shape):
   plt.style.use('ggplot')
   fig, axes = plt.subplots(*subplot_shape)
   for image, ax in zip(images, axes.flatten()):
        ax.imshow(image.reshape(28, 28), vmin = 0, vmax = 1.0, cmap = 'gray')
        ax.axis('off')
   plt.show()
img = mpimg.imread(train_dogs[random.randint(0, len(train_dogs))])
plt.imshow(img)
<matplotlib.image.AxesImage at 0x7faf3058eb70>
img = mpimg.imread(train_cats[random.randint(0, len(train_cats))])
plt.imshow(img)
<matplotlib.image.AxesImage at 0x7faf306df4a8>
def show_pics(paths: list):
   f, ax = plt.subplots(1, len(paths))
   for i, path in enumerate(paths):
        ax[i].imshow(Image.open(path))
        ax[i].set_title(os.path.basename(path))
        ax[i].axis('off')
dog sample = train dogs[0:3]
cat_sample = train_cats[0:3]
```

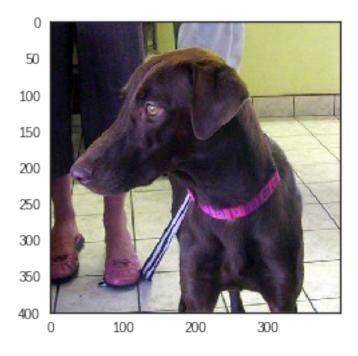


Figure 4.1: png

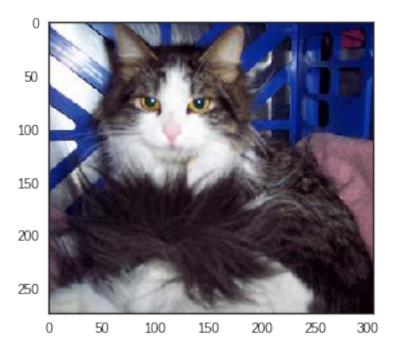


Figure 4.2: png

dog.628.jpg

dog.3083.jpg

Figure 4.3: png







Figure 4.4: png

```
show_pics(dog_sample)
show_pics(cat_sample)
```

4.7 Training the Transfer Model

Okay, back to our model. Let's take a look at those node labels again. The last labels are the cross-entropy term, errors, and top-5 errors. These are needed to define our full computational graph and for training through backpropagation. The last actual label is z, which maps to our class labels (1000 in this case, for the number of classes in ImageNet). The last activation layer prior to the dense mapping to ImageNet classes is $z \cdot x$.

```
C.logging.get_node_outputs(C.load_model(base_model['model_file']))
```

```
[Output('ce', [], []),
Output('errs', [], []),
Output('top5Errs', [], []),
```

```
Output('z', [#, ], [1000]),
Output('ce', [], []),
Output('z', [#, ], [1000]),
Output('z.PlusArgs[0]', [#, ], [1000]),
Output('z.x', [#, ], [512 x 1 x 1]),
Output('z.x.x.r', [#, ], [512 x 7 x 7]),
Output('z.x.x.p', [#, ], [512 x 7 x 7]),
Output('z.x.x.b', [#, ], [512 x 7 x 7]),
Output('z.x.x.b.x.c', [#, ], [512 x 7 x 7]),
Output('z.x.x.b.x', [#, ], [512 x 7 x 7]),
Output('z.x.x.b.x._', [#, ], [512 x 7 x 7]),
Output('z.x.x.b.x._.x.c', [#, ], [512 x 7 x 7]),
Output('z.x.x.x.r', [#, ], [512 x 7 x 7]),
Output('z.x.x.x.p', [#, ], [512 x 7 x 7]),
Output('z.x.x.x.b', [#, ], [512 x 7 x 7]),
Output('z.x.x.x.b.x.c', [#, ], [512 x 7 x 7]),
Output('z.x.x.x.b.x', [#, ], [512 x 7 x 7]),
Output('z.x.x.x.b.x._', [#, ], [512 x 7 x 7]),
Output('z.x.x.x.b.x._.x.c', [#, ], [512 x 7 x 7]),
Output('_z.x.x.r', [#, ], [512 x 7 x 7]),
Output('_z.x.x.x.p', [#, ], [512 x 7 x 7]),
Output('_z.x.x.x.b', [#, ], [512 x 7 x 7]),
Output('_z.x.x.x.b.x.c', [#, ], [512 x 7 x 7]),
Output('_z.x.x.x.b.x', [#, ], [512 x 7 x 7]),
Output('_z.x.x.x.b.x._', [#, ], [512 x 7 x 7]),
Output('_z.x.x.x.b.x._.x.c', [#, ], [512 x 7 x 7]),
Output('z.x.x.x.r', [#, ], [256 x 14 x 14]),
Output('z.x.x.x.x.p', [#, ], [256 x 14 x 14]),
Output('z.x.x.x.x.b', [#, ], [256 x 14 x 14]),
Output('z.x.x.x.x.b.x.c', [#, ], [256 x 14 x 14]),
Output('z.x.x.x.x.b.x', [#, ], [256 x 14 x 14]),
Output('z.x.x.x.x.b.x._', [#, ], [256 x 14 x 14]),
Output('z.x.x.x.x.b.x._.x.c', [#, ], [256 x 14 x 14]),
Output('z.x.x.x.x.r', [#, ], [256 x 14 x 14]),
Output('z.x.x.x.x.x.p', [#, ], [256 x 14 x 14]),
Output('z.x.x.x.x.x.b', [#, ], [256 x 14 x 14]),
Output('z.x.x.x.x.x.b.x.c', [#, ], [256 x 14 x 14]),
Output('z.x.x.x.x.x.b.x', [#, ], [256 x 14 x 14]),
Output('z.x.x.x.x.x.b.x._', [#, ], [256 x 14 x 14]),
Output('z.x.x.x.x.x.b.x._.x.c', [#, ], [256 x 14 x 14]),
Output('z.x.x.x.x.x.r', [#, ], [128 x 28 x 28]),
Output('z.x.x.x.x.x.x.p', [#, ], [128 x 28 x 28]),
Output('z.x.x.x.x.x.x.b', [#, ], [128 x 28 x 28]),
Output('z.x.x.x.x.x.x.b.x.c', [#, ], [128 x 28 x 28]),
Output('z.x.x.x.x.x.x.b.x', [#, ], [128 x 28 x 28]),
Output('z.x.x.x.x.x.x.b.x._', [#, ], [128 x 28 x 28]),
Output('z.x.x.x.x.x.x.b.x._.x.c', [#, ], [128 x 28 x 28]),
Output('z.x.x.x.x.x.x.r', [#, ], [128 x 28 x 28]),
Output('z.x.x.x.x.x.x.x.p', [#, ], [128 x 28 x 28]),
Output('z.x.x.x.x.x.x.b', [#, ], [128 x 28 x 28]),
Output('z.x.x.x.x.x.x.x.b.x.c', [#, ], [128 x 28 x 28]),
Output('z.x.x.x.x.x.x.x.b.x', [#, ], [128 x 28 x 28]),
Output('z.x.x.x.x.x.x.x.b.x._', [#, ], [128 x 28 x 28]),
Output('z.x.x.x.x.x.x.x.b.x. .x.c', [#, ], [128 x 28 x 28]),
```

```
Output('z.x.x.x.x.x.x.x.r', [#, ], [64 x 56 x 56]),
Output('z.x.x.x.x.x.x.x.p', [#, ], [64 x 56 x 56]),
Output('z.x.x.x.x.x.x.x.b', [#, ], [64 x 56 x 56]),
Output('z.x.x.x.x.x.x.x.x.b.x.c', [#, ], [64 x 56 x 56]),
Output('z.x.x.x.x.x.x.x.b.x', [#, ], [64 x 56 x 56]),
Output('z.x.x.x.x.x.x.x.x.b.x._', [#, ], [64 x 56 x 56]),
Output('z.x.x.x.x.x.x.x.x.b.x._.x.c', [#, ], [64 x 56 x 56]),
Output('z.x.x.x.x.x.x.x.x.r', [#, ], [64 x 56 x 56]),
Output('z.x.x.x.x.x.x.x.x.r', [#, ], [64 x 56 x 56]),
Output('z.x.x.x.x.x.x.x.x.b', [#, ], [64 x 56 x 56]),
Output('z.x.x.x.x.x.x.x.x.x.b.x.c', [#, ], [64 x 56 x 56]),
Output('z.x.x.x.x.x.x.x.x.x.b.x', [#, ], [64 \times 56 \times 56]),
Output('z.x.x.x.x.x.x.x.x.b.x._', [#, ], [64 x 56 x 56]),
Output('z.x.x.x.x.x.x.x.x.x.b.x._.x.c', [#, ], [64 x 56 x 56]),
Output('z.x.x.x.x.x.x.x.x', [#, ], [64 x 56 x 56]),
Output('z.x.x.x.x.x.x.x.x.x', [#, ], [64 x 112 x 112]),
Output('z.x.x.x.x.x.x.x.x.x.x., [#, ], [64 x 112 x 112]),
Output('z.x.x.x.x.x.x.s', [#, ], [128 x 28 x 28]),
{\tt Output('z.x.x.x.x.x.x.x.x.x.s.x.c', [\#, ], [128 \ x \ 28 \ x \ 28]),}
Output('z.x.x.x.x.x.s', [#, ], [256 x 14 x 14]),
Output('z.x.x.x.x.x.s.x.c', [#, ], [256 x 14 x 14]),
Output('z.x.x.x.s', [#, ], [512 x 7 x 7]),
Output('z.x.x.x.s.x.c', [#, ], [512 x 7 x 7]),
Output('errs', [], []),
Output('top5Errs', [], [])]
```

We clone the model so that we can re-use the same trained model multiple times, trained for different things - it is not strictly necessary if you are just training it for a single task, but this is why we would not use CloneMethod.share, we want to learn new parameters. If freeze_weights is true, we will freeze weights on all layers we clone and only learn weights on the final new features layer. This can often be useful if you are cloning higher up the tree (e.g., cloning after the first convolutional layer to just get basic image features).

We find the final hidden layer (z.x) using find_by_name, clone it and all of its predecessors, then attach a new Dense layer for classification.

4.8 Define Minibatch Source

Now that we have our model defined, we have to also tell CNTK how to read in batches to train the model using backprop. Here we'll use the ImageDeserializer class, designed specifically for the data we have here.

4.9 Training

Now our setup is nearly complete. We have our network architecture defined, and our minibatch reader setup. The last step is defining the loss function for our optimization algorithm (in this case binary_cross_entropy, or cross_entropy_softmax if we had more than two classes). We'll use a specific learning routine with a momentum schedule, and simple ℓ_2 regularization penalty on our model's weight terms.

```
def train_model(model_details, num_classes, train_map_file,
                learning_params, max_images=-1):
    num_epochs = learning_params['max_epochs']
    epoch_size = sum(1 for line in open(train_map_file))
    if max_images > 0:
        epoch_size = min(epoch_size, max_images)
    minibatch_size = learning_params['mb_size']
    # Create the minibatch source and input variables
   minibatch_source = create_mb_source(train_map_file, model_details['image_dims'], num_classes)
    image_input = C.input_variable(model_details['image_dims'])
   label_input = C.input_variable(num_classes)
    # Define mapping from reader streams to network inputs
    input map = {
        image_input: minibatch_source['features'],
        label_input: minibatch_source['labels']
   }
    # Instantiate the transfer learning model and loss function
   tl_model = create_model(model_details, num_classes, image_input, freeze=learning_params['freeze_wei
    ce = C.binary_cross_entropy(tl_model, label_input)
   pe = C.classification_error(tl_model, label_input)
    # Instantiate the trainer object
   lr_schedule = C.learning_rate_schedule(learning_params['lr_per_mb'], unit=C.UnitType.minibatch)
    mm_schedule = C.momentum_schedule(learning_params['momentum_per_mb'])
    learner = C.momentum_sgd(tl_model.parameters, lr_schedule, mm_schedule,
                           12_regularization_weight=learning_params['12_reg_weight'])
    trainer = C.Trainer(tl_model, (ce, pe), learner)
    # Get minibatches of images and perform model training
    print("Training transfer learning model for {0} epochs (epoch_size = {1}).".format(num_epochs, epoc
```

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```
C.logging.log_number_of_parameters(tl_model)
    progress_printer = C.logging.ProgressPrinter(tag='Training', num_epochs=num_epochs)
    for epoch in range(num_epochs):
                                        # loop over epochs
        sample_count = 0
        while sample_count < epoch_size: # loop over minibatches in the epoch
            data = minibatch_source.next_minibatch(min(minibatch_size, epoch_size - sample_count), inpu
                                                                             # update model with it
            trainer.train_minibatch(data)
            sample_count += trainer.previous_minibatch_sample_count
                                                                            # count samples processed
            progress_printer.update_with_trainer(trainer, with_metric=True) # log progress
            if sample_count % (100 * minibatch_size) == 0:
                print ("Processed {0} samples".format(sample_count))
       progress_printer.epoch_summary(with_metric=True)
   return tl_model
force_retraining = True
max_training_epochs = 10
learning_params = {
    'max_epochs': max_training_epochs,
    'mb_size': 50,
    'lr_per_mb': [0.2]*10 + [0.1],
    'momentum_per_mb': 0.9,
    '12_reg_weight': 0.0005,
    'freeze_weights': True
kitty_doggo_model = {
    'model_file': os.path.join('DogsCats.model'),
    'results_file': os.path.join('predictions.txt'),
    'num_classes': 2
}
if os.path.isfile(kitty_doggo_model['model_file']):
    print("Reload stored model from %s", kitty_doggo_model['model_file'])
   trained_model = C.load_model(kitty_doggo_model['model_file'])
   print("Retraining model and saving to %s", kitty_doggo_model['model_file'])
    trained_model = train_model(base_model,
                              kitty_doggo_model['num_classes'],
                              base_model['training_map'],
                              learning_params)
Reload stored model from %s DogsCats.model
trained_model.save(kitty_doggo_model['model_file'])
print("Stored trained model at %s" % kitty_doggo_model['model_file'])
Stored trained model at DogsCats.model
# Evaluates a single image using the re-trained model
def eval_single_image(loaded_model, image_path, image_dims):
    # load and format image (resize, RGB -> BGR, CHW -> HWC)
   try:
```

```
img = Image.open(image_path)
        if image_path.endswith("png"):
            temp = Image.new("RGB", img.size, (255, 255, 255))
            temp.paste(img, img)
            img = temp
        resized = img.resize((image_dims[2], image_dims[1]), Image.ANTIALIAS)
        bgr image = np.asarray(resized, dtype=np.float32)[..., [2, 1, 0]]
        hwc_format = np.ascontiguousarray(np.rollaxis(bgr_image, 2))
        # compute model output
        arguments = {loaded_model.arguments[0]: [hwc_format]}
        output = loaded model.eval(arguments)
        # return softmax probabilities
        sm = C.softmax(output[0])
        return sm.eval()
    except FileNotFoundError:
       print("Could not open (skipping file): ", image_path)
        return ['None']
isFast = False # set to true if you want to evaluate fewer images
# Evaluates an image set using the provided model
def eval_test_images(loaded_model, output_file, test_map_file,
                     image_dims, max_images=-1, column_offset=0):
   num_images = sum(1 for line in open(test_map_file))
    if max_images > 0:
       num_images = min(num_images, max_images)
    if isFast:
       num_images = min(num_images, 300)
   print("Evaluating model output node '{0}' for {1} images.".format('prediction', num_images))
   pred count = 0
   correct_count = 0
   np.seterr(over='raise')
   with open(output_file, 'wb') as results_file:
        with open(test_map_file, "r") as input_file:
            for line in input file:
                tokens = line.rstrip().split('\t')
                img_file = tokens[0 + column_offset]
                probs = eval_single_image(loaded_model, img_file, image_dims)
                if probs[0] == 'None':
                    print("Eval not possible: ", img_file)
                    continue
                pred_count += 1
                true_label = int(tokens[1 + column_offset])
                predicted_label = np.argmax(probs)
                if predicted_label == true_label:
                    correct_count += 1
```

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```
np.savetxt(results_file, probs[np.newaxis], fmt="%.3f")
                if pred_count % 100 == 0:
                    print("Processed {0} samples ({1:.2%} correct)".format(pred_count,
                                                                            (float(correct_count) / pred
                if pred_count >= num_images:
   print ("{0} of {1} prediction were correct".format(correct_count, pred_count))
   return correct count, pred count, (float(correct count) / pred count)
mkdir val/cats
mkdir val/dogs
mv val/cat.*.jpg ./val/cats/
mv val/dog.*.jpg ./val/dogs
class_mapping = create_class_mapping_from_folder(os.path.abspath(path="val/"))
testing_map = create_map_file_from_folder("val/", class_mapping)
kitty_doggo_model
{'model_file': 'DogsCats.model',
 'num classes': 2,
 'results_file': 'predictions.txt'}
predict_correct, predict_total, predict_accuracy = \
   eval_test_images(trained_model, kitty_doggo_model['results_file'],
                    testing_map, base_model['image_dims'])
print("Done. Wrote output to %s" % kitty_doggo_model['results_file'])
Evaluating model output node 'prediction' for 5000 images.
Processed 100 samples (97.00% correct)
Processed 200 samples (97.50% correct)
Processed 300 samples (98.33% correct)
Processed 400 samples (98.25% correct)
Processed 500 samples (98.20% correct)
Processed 600 samples (98.50% correct)
Processed 700 samples (98.57% correct)
Processed 800 samples (98.62% correct)
Processed 900 samples (98.22% correct)
Processed 1000 samples (98.40% correct)
Processed 1100 samples (98.27% correct)
Processed 1200 samples (98.00% correct)
Processed 1300 samples (98.08% correct)
Processed 1400 samples (98.07% correct)
Processed 1500 samples (98.07% correct)
Processed 1600 samples (98.00% correct)
Processed 1700 samples (98.06% correct)
Processed 1800 samples (98.06% correct)
Processed 1900 samples (98.05% correct)
Processed 2000 samples (97.95% correct)
Processed 2100 samples (97.90% correct)
Processed 2200 samples (97.86% correct)
Processed 2300 samples (97.91% correct)
Processed 2400 samples (97.83% correct)
Processed 2500 samples (97.84% correct)
```

```
Processed 2600 samples (97.77% correct)
Processed 2700 samples (97.81% correct)
Processed 2800 samples (97.86% correct)
Processed 2900 samples (97.90% correct)
Processed 3000 samples (97.90% correct)
Processed 3100 samples (97.87% correct)
Processed 3200 samples (97.88% correct)
Processed 3300 samples (97.91% correct)
Processed 3400 samples (97.94% correct)
Processed 3500 samples (98.00% correct)
Processed 3600 samples (98.00% correct)
Processed 3700 samples (97.97% correct)
Processed 3800 samples (98.00% correct)
Processed 3900 samples (97.97% correct)
Processed 4000 samples (97.95% correct)
Processed 4100 samples (97.93% correct)
Processed 4200 samples (97.95% correct)
Processed 4300 samples (97.98% correct)
Processed 4400 samples (98.00% correct)
Processed 4500 samples (98.02% correct)
Processed 4600 samples (98.00% correct)
Processed 4700 samples (98.02% correct)
Processed 4800 samples (98.04% correct)
Processed 4900 samples (98.02% correct)
Processed 5000 samples (98.06% correct)
4903 of 5000 prediction were correct
Done. Wrote output to predictions.txt
# evaluate test images
with open(testing_map, 'r') as input_file:
   head = list(itertools.islice(input_file, 15))
    for line in head:
        tokens = line.rstrip().split('\t')
        img_file = tokens[0]
        true_label = int(tokens[1])
       probs = eval_single_image(trained_model, img_file, base_model['image_dims'])
       if probs[0] == 'None':
            continue
        class_probs = np.column_stack((probs, class_mapping)).tolist()
        class_probs.sort(key=lambda x: float(x[0]), reverse=True)
       predictions = ' '.join(['%s:%.3f' % (class_probs[i][1], float(class_probs[i][0])) \
                                for i in range(0, kitty_doggo_model['num_classes'])])
       true_class_name = class_mapping[true_label] if true_label >= 0 else 'unknown'
       print('Class: %s, predictions: %s, image: %s' % (true_class_name, predictions, img_file))
Class: cats, predictions: cats:1.000 dogs:0.000, image: val/cats/cat.10001.jpg
Class: cats, predictions: cats:1.000 dogs:0.000, image: val/cats/cat.10003.jpg
Class: cats, predictions: cats:1.000 dogs:0.000, image: val/cats/cat.10005.jpg
Class: cats, predictions: cats:1.000 dogs:0.000, image: val/cats/cat.10006.jpg
Class: cats, predictions: cats:1.000 dogs:0.000, image: val/cats/cat.10010.jpg
Class: cats, predictions: cats:1.000 dogs:0.000, image: val/cats/cat.10016.jpg
Class: cats, predictions: cats:1.000 dogs:0.000, image: val/cats/cat.10017.jpg
Class: cats, predictions: cats:1.000 dogs:0.000, image: val/cats/cat.1002.jpg
Class: cats, predictions: cats:1.000 dogs:0.000, image: val/cats/cat.10032.jpg
```

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```
Class: cats, predictions: cats:1.000 dogs:0.000, image: val/cats/cat.10033.jpg
Class: cats, predictions: cats:1.000 dogs:0.000, image: val/cats/cat.1004.jpg
Class: cats, predictions: cats:1.000 dogs:0.000, image: val/cats/cat.10047.jpg
Class: cats, predictions: cats:1.000 dogs:0.000, image: val/cats/cat.10054.jpg
Class: cats, predictions: cats:0.995 dogs:0.005, image: val/cats/cat.10058.jpg
Class: cats, predictions: cats:1.000 dogs:0.000, image: val/cats/cat.1006.jpg
def predictions_df(results=kitty_doggo_model['results_file'],
              key_maps = "val/map.txt"):
   preds = pd.read_csv(results, sep=" ", names=['cat', 'dog'])
   maps_df = pd.read_csv(key_maps, names=['path', 'label'], sep='\t')
   preds = pd.concat([preds, maps_df], axis=1)
   return preds
preds = predictions_df()
preds.iloc[0:5]
cat
 dog
 path
 label
>0
 1.0
 0.0
 val/cats/cat.10001.jpg
 0
1
 1.0
 0.0
 val/cats/cat.10003.jpg
 0
2
 1.0
 0.0
 val/cats/cat.10005.jpg
 0
3
 1.0
 0.0
 val/cats/cat.10006.jpg
 0
```



Figure 4.5: png



Figure 4.6: png

```
4
 1.0
 0.0
 val/cats/cat.10010.jpg
 0
def worst_preds(results = preds,
            kitties = 0):
   results = results[results['label'] == kitties]
   if kitties == 0:
       results = results.sort_values(by="cat", ascending=True)
       results = results.sort_values(by="dog", ascending=True)
   return results
worst_kitties = worst_preds(kitties = 0)
worst_pups = worst_preds(kitties = 1)
show_pics(worst_kitties['path'].iloc[0:5])
show_pics(worst_pups['path'].iloc[0:5])
```

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Fashion MNIST 4.10

import matplotlib.pyplot as plt

pixels = $x_{train}[10].reshape((28, 28))$

%matplotlib inline

plt.imshow(pixels)

plt.show()

A MNIST-like dataset for fashion items. See the original repository for more information and visualization

```
examples.
import os
os.environ['KERAS_BACKEND'] = "cntk"
import sys
import urllib
from keras.layers import Dense, Dropout, Flatten
from keras.layers import Conv2D, MaxPooling2D
from keras.layers.normalization import BatchNormalization
from keras.models import Sequential
from keras.utils import to_categorical
from keras.callbacks import ModelCheckpoint, TensorBoard
from keras import optimizers
from keras import losses
from fashion_import import load_data
import numpy as np
from PIL import Image
from io import BytesIO
Using CNTK backend
(x_train, y_train), (x_test, y_test) = load_data()
Downloading data from http://fashion-mnist.s3-website.eu-central-1.amazonaws.com/train-labels-idx1-ubyte
16384/29515 [=======>:......] - ETA: OsDownloading data from http://fashion-mnist.s3-websit
23953408/26421880 [==============>...] - ETA: OsDownloading data from http://fashion-mnist.s3-
Downloading data from http://fashion-mnist.s3-website.eu-central-1.amazonaws.com/t10k-images-idx3-ubyte.
3260416/4422102 [==========>.....] - ETA: Os
x_{train} = x_{train.reshape}(60000, 28, 28, 1)
x_{test} = x_{test.reshape}(10000, 28, 28, 1)
x_train = x_train.astype('float32')
x_test = x_test.astype('float32')
x_train /= 255
x_test /= 255
# convert class vectors to binary class matrices
y_train = to_categorical(y_train, 10)
y_test = to_categorical(y_test, 10)
```

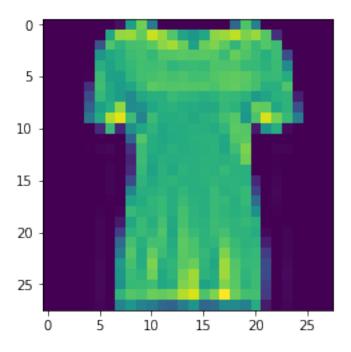


Figure 4.7: png

```
batch_size = 256
num_classes = 10
epochs = 10
img_rows, img_cols = 28, 28
input_shape = (img_rows, img_cols, 1)
model = Sequential()
model.add(Conv2D(32, kernel_size=(3, 3),
                 activation='relu',
                 kernel_initializer='he_normal',
                 input_shape=input_shape))
model.add(MaxPooling2D((2, 2)))
model.add(Dropout(0.25))
model.add(Conv2D(64, (3, 3), activation='relu'))
model.add(MaxPooling2D(pool_size=(2, 2)))
model.add(Dropout(0.25))
model.add(Conv2D(128, (3, 3), activation='relu'))
model.add(Dropout(0.4))
model.add(Flatten())
model.add(Dense(128, activation='relu'))
model.add(Dropout(0.3))
model.add(Dense(num_classes, activation='softmax'))
model.compile(loss=losses.categorical_crossentropy,
              optimizer=optimizers.Adam(),
              metrics=['accuracy'])
model.summary()
```

4.10. FASHION MNIST

Layer (type)	_	=	
conv2d_1 (Conv2D)			320
max_pooling2d_1 (MaxPooling2			
dropout_1 (Dropout)			
conv2d_2 (Conv2D)	(None,	11, 11, 64)	18496
max_pooling2d_2 (MaxPooling2	(None,	5, 5, 64)	0
dropout_2 (Dropout)			0
conv2d_3 (Conv2D)			
dropout_3 (Dropout)			
flatten_1 (Flatten)	(None,		0
dense_1 (Dense)	(None,		147584
dropout_4 (Dropout)		128)	0
dense_2 (Dense)			
Total params: 241,546 Trainable params: 241,546 Non-trainable params: 0			
history = model.fit(x_train, batch_size=batc	• –	n,	

Epoch 1/10

epochs=epochs)

/home/mugen/.conda/envs/cntk-py35/lib/python3.5/site-packages/cntk/core.py:361: UserWarning: your data is (sample.dtype, var.uid, str(var.dtype)))

```
60000/60000 [===========] - 10s - loss: 0.8519 - acc: 0.6817

Epoch 2/10
60000/60000 [===========] - 7s - loss: 0.5029 - acc: 0.8138

Epoch 3/10
60000/60000 [=============] - 7s - loss: 0.4330 - acc: 0.8406

Epoch 4/10
60000/60000 [===================] - 7s - loss: 0.3867 - acc: 0.8575

Epoch 5/10
60000/60000 [=======================] - 7s - loss: 0.3595 - acc: 0.8675

Epoch 6/10
```

```
60000/60000 [============= ] - 7s - loss: 0.3365 - acc: 0.8777
Epoch 7/10
Epoch 8/10
Epoch 9/10
Epoch 10/10
60000/60000 [============] - 7s - loss: 0.2889 - acc: 0.8936
test_val = model.evaluate(x_test, y_test)
1312/10000 [==>.....] - ETA: 1s
/anaconda/envs/cntk-22/lib/python3.5/site-packages/cntk/core.py:361: UserWarning: your data is of type "fl
  (sample.dtype, var.uid, str(var.dtype)))
9856/10000 [===========>.] - ETA: Os
print("Model's Accuracy on Test Set = "
     + "{0:.2f}%".format(test_val[1] * 100))
Model's Accuracy on Test Set = 90.14%
import matplotlib.pyplot as plt
%matplotlib inline
accuracy = history.history['acc']
# val_accuracy = history.history['val_acc']
loss = history.history['loss']
# val loss = history.history['val loss']
epochs = range(len(accuracy))
plt.plot(epochs, accuracy, 'bo', label='Training accuracy')
plt.title('Training accuracy')
plt.legend()
plt.figure()
plt.plot(epochs, loss, 'bo', label='Training loss')
plt.title('Training loss')
plt.legend()
plt.show()
test_{im} = x_{train}[3]
plt.imshow(test_im.reshape(28,28), cmap='gray', interpolation='none')
plt.show()
from keras import models
layer_outputs = [layer.output for layer in model.layers[:8]]
activation_model = models.Model(input=model.input, output=layer_outputs)
activations = activation_model.predict(test_im.reshape(1,28,28,1))
first layer activation = activations[0]
plt.matshow(first_layer_activation[0, :, :, 4], cmap='gray')
```

/anaconda/envs/cntk-22/lib/python3.5/site-packages/ipykernel/__main__.py:3: UserWarning: Update your `Mod app.launch_new_instance()

4.10. FASHION MNIST

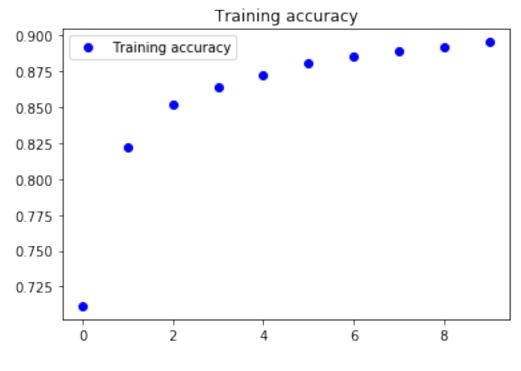


Figure 4.8: png

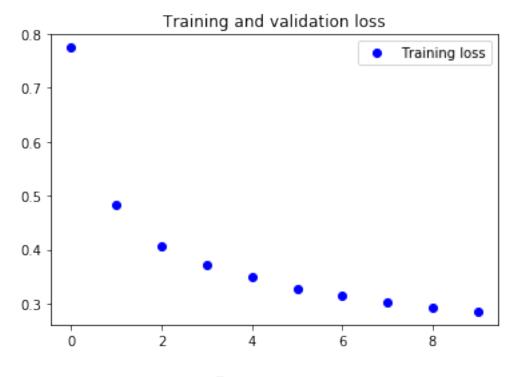


Figure 4.9: png

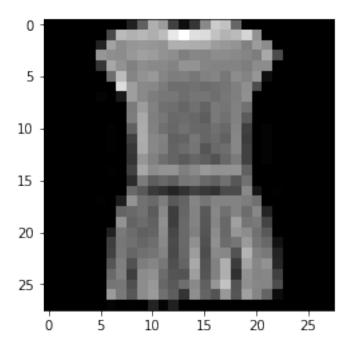


Figure 4.10: png

<matplotlib.image.AxesImage at 0x7f08c0f78278>

```
layer_names = []
for layer in model.layers[:-1]:
    if isinstance(layer, Conv2D):
        layer_names.append(layer.name)
images_per_row = 16
for layer_name, layer_activation in zip(layer_names, activations):
   n_features = layer_activation.shape[-1]
   size = layer_activation.shape[1]
   n_cols = n_features / images_per_row
   n_cols = int(n_cols)
   display_grid = np.zeros((size * n_cols, images_per_row * size))
   for col in range(n_cols):
        for row in range(images_per_row):
            channel_image = layer_activation[0,:, :, col * images_per_row + row]
            channel_image -= channel_image.mean()
            channel_image /= channel_image.std()
            channel_image *= 64
            channel_image += 128
            channel_image = np.clip(channel_image, 0, 255).astype('uint8')
            display_grid[col * size : (col + 1) * size,
                         row * size : (row + 1) * size] = channel_image
    scale = 1. / size
   plt.figure(figsize=(scale * display_grid.shape[1],
```

4.10. FASHION MNIST

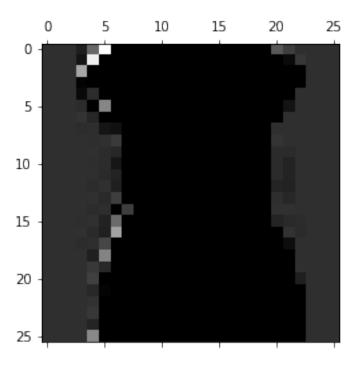


Figure 4.11: png

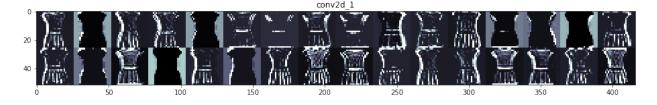


Figure 4.12: png

```
scale * display_grid.shape[0]))
plt.title(layer_name)
plt.grid(False)
plt.imshow(display_grid, aspect='auto', cmap='bone')
```

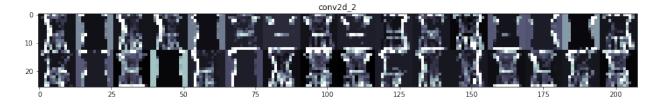


Figure 4.13: png

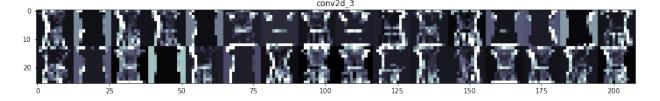


Figure 4.14: png

Chapter 5

Neural Style Transfer

This tutorial shows how to transfer the style / texture of one image to another. This allows us to take our ordinary photos and render them in the style of famous images or paintings.

Apart from creating nice looking pictures, in this tutorial you will learn how to load a pretrained VGG model into CNTK, how to get the gradient of a function with respect to an input variable (rather than a parameter), and how to use the gradient outside of CNTK.

We will follow the approach of Gatys et. al. with some of the improvements in Novak and Nikulin. While faster techniques exist, these are limited to transfering a particular style.

We begin by importing the necessary packages. In addition to the usual suspects (numpy, scipy, and cntk) we will need PIL to work with images, requests to download a pretrained model and h5py to read in the weights of the pretrained model.

```
from __future__ import print_function
import numpy as np
from scipy import optimize as opt
import cntk as C
from PIL import Image
import requests
import h5py
import os
%matplotlib inline
import matplotlib.pyplot as plt
# Select the right target device when this notebook is being tested:
if 'TEST DEVICE' in os.environ:
    if os.environ['TEST_DEVICE'] == 'cpu':
        C.device.try_set_default_device(C.device.cpu())
   else:
        C.device.try_set_default_device(C.device.gpu(0))
```

The pretrained model is a VGG network which we originally got from this page. We host it in a place which permits easy downloading. Below we download it if it is not already available locally and load the weights into numpy arrays.

```
def download(url, filename):
    response = requests.get(url, stream=True)
    with open(filename, 'wb') as handle:
        for data in response.iter_content(chunk_size=2**20):
            if data: handle.write(data)
```

```
def load_vgg(path):
   f = h5py.File(path)
   layers = []
   for k in range(f.attrs['nb_layers']):
        g = f['layer_{}'.format(k)]
       n = g.attrs['nb_params']
        layers.append([g['param_{{}}'.format(p)][:] for p in range(n)])
   f.close()
   return layers
# Check for an environment variable defined in CNTK's test infrastructure
envvar = 'CNTK_EXTERNAL_TESTDATA_SOURCE_DIRECTORY'
def is_test(): return envvar in os.environ
path = 'vgg16_weights.bin'
url = 'https://cntk.ai/jup/models/vgg16_weights.bin'
# We check for the model locally
if not os.path.exists(path):
    # If not there we might be running in CNTK's test infrastructure
   if is test():
       path = os.path.join(os.environ[envvar], 'PreTrainedModels', 'Vgg16', 'v0', path)
    else:
        #If neither is true we download the file from the web
        print('downloading VGG model (~0.5GB)')
        download(url, path)
layers = load_vgg(path)
print('loaded VGG model')
```

downloading VGG model (~0.5GB) loaded VGG model

Next we define the VGG network as a CNTK graph.

```
# A convolutional layer in the VGG network
def vggblock(x, arrays, layer_map, name):
   f = arrays[0]
   b = arrays[1]
   k = C.constant(value=f)
   t = C.constant(value=np.reshape(b, (-1, 1, 1)))
   y = C.relu(C.convolution(k, x, auto_padding=[False, True, True]) + t)
   layer_map[name] = y
   return y
# A pooling layer in the VGG network
def vggpool(x):
    return C.pooling(x, C.AVG_POOLING, (2, 2), (2, 2))
# Build the graph for the VGG network (excluding fully connected layers)
def model(x, layers):
   model_layers = {}
   def convolutional(z): return len(z) == 2 and len(z[0].shape) == 4
   conv = [layer for layer in layers if convolutional(layer)]
```

```
cnt = 0
num_convs = {1: 2, 2: 2, 3: 3, 4: 3, 5: 3}
for outer in range(1,6):
    for inner in range(num_convs[outer]):
        x = vggblock(x, conv[cnt], model_layers, 'conv%d_%d' % (outer, 1+inner))
        cnt += 1
        x = vggpool(x)

return x, C.combine([model_layers[k] for k in sorted(model_layers.keys())])
```

5.0.1 Defining the loss function

The interesting part in this line of work is the definition of a loss function that, when optimized, leads to a result that is close to both the content of one image, as well as the style of the other image. This loss contains multiple terms some of which are defined in terms of the VGG network we just created. Concretely, the loss takes a candidate image x and takes a weighted sum of three terms: the content loss, the style loss and the total variation loss:

$$L(x) = \alpha C(x) + \beta S(x) + T(x)$$

where α and β are weights on the content loss and the style loss, respectively. We have normalized the weights so that the weight in front of the total variation loss is 1. How are each of these terms computed?

- The total variation loss T(x) is the simplest one to understand: It measures the average sum of squared differences among adjacent pixel values and encourages the result x to be a smooth image. We implement this by convolving the image with a kernel containing (-1,1) both horizontally and vertically, squaring the results and computing their average.
- The content loss is measuring the squared difference between the content image and x. We can measure this difference on the raw pixels or at various layers inside the VGG network. While we write the content loss as C(x) it implicitly depends on the content image we provide. However since that image is fixed we do not write this dependence explicitly.
- The style loss S(x) is similar to the content loss in that it also implicitly depends on another image. The main idea of Gatys et. al. was to define the style as the correlations among the activations of the network and measure the style loss as the squared difference between these correlations. In particular for a particular layer we compute a covariance matrix among the output channels averaging across all positions. The style loss is just the squared error between the covariance matrix induced by the style image and the covariance matrix induced by x. We are deliberately vague here as to which layer of the network is used for creating the covariance loss. Different implementations do this differently and below we will use a weighted sum of all the style losses of all layers.

Below we define these loss functions:

```
def flatten(x):
    assert len(x.shape) >= 3
    return C.reshape(x, (x.shape[-3], x.shape[-2] * x.shape[-1]))

def gram(x):
    features = C.minus(flatten(x), C.reduce_mean(x))
    return C.times_transpose(features, features)

def npgram(x):
    features = np.reshape(x, (-1, x.shape[-2]*x.shape[-1])) - np.mean(x)
    return features.dot(features.T)
```

```
def style_loss(a, b):
    channels, x, y = a.shape
   assert x == y
   A = gram(a)
   B = npgram(b)
   return C.squared_error(A, B)/(channels**2 * x**4)
def content_loss(a,b):
    channels, x, y = a.shape
    return C.squared_error(a, b)/(channels*x*y)
def total_variation_loss(x):
   xx = C.reshape(x, (1,)+x.shape)
    delta = np.array([-1, 1], dtype=np.float32)
   kh = C.constant(value=delta.reshape(1, 1, 1, 1, 2))
   kv = C.constant(value=delta.reshape(1, 1, 1, 2, 1))
   dh = C.convolution(kh, xx, auto_padding=[False])
    dv = C.convolution(kv, xx, auto padding=[False])
    avg = 0.5 * (C.reduce_mean(C.square(dv)) + C.reduce_mean(C.square(dh)))
    return avg
```

5.0.2 Instantiating the loss

Now we are ready to instantiate a loss with two particular images. We will use an image of Portland's landscape and The Starry Night by Vincent van Gogh. We first define a few tuning parameters whose explanation is below: - Depending on whether the code runs on a GPU or a CPU we resize the images to 300 x 300 or 64 x 64 respectively and adjust the number of iterations of optimization to speed up the process and for ease of experimentation. You can use a larger size if you like the results. If you only have a CPU you will have to wait a while. - The content weight and style weight are the main parameters that affect the quality of the resulting image. - The decay factor is a number in (0,1) which decides how to weigh the contribution of each layer. Following Novak and Nikulin, all layers contribute to both the content loss and the style loss. The content loss weighs the input more heavily and each later layer in the VGG network contributes with a weight that is exponentially smaller with its distance from the input. The style loss weighs the output of the VGG network more heavily and each earlier layer in the VGG network contributes with a weight that is exponentially smaller with its distance from the output. As in Novak and Nikulin we use a decay factor of 0.5. - The inner and outer parameters define how we are going to obtain our final result. We will take outer snapshots during our search for the image that minimizes the loss. Each snapshot will be taken after inner steps of optimization. - Finally, a very important thing to know about our pretrained network is how it was trained. In particular, a constant vector was subtracted from all input images that contained the average value for the red, green, and blue channels in the training set. This makes the inputs zero centered which helps the training procedure. If we do not subtract this vector our images will not look like the training images and this will lead to bad results. This vector is referred to as SHIFT below.

```
style_path = 'style.jpg'
content_path = 'azthinksR.jpg'

start_from_random = False
content_weight = 5.0
style_weight = 1.0
```

```
decay = 0.5
if is_test():
   outer = 2
    inner = 2
   SIZE = 64
else:
   outer = 10
   inner = 20
   SIZE = 300
SHIFT = np.reshape([103.939, 116.779, 123.68], (3, 1, 1)).astype('f')
def load image(path):
    with Image.open(path) as pic:
       hw = pic.size[0] / 2
       hh = pic.size[1] / 2
        mh = min(hw,hh)
        cropped = pic.crop((hw - mh, hh - mh, hw + mh, hh + mh))
        array = np.array(cropped.resize((SIZE,SIZE), Image.BICUBIC), dtype=np.float32)
        return np.ascontiguousarray(np.transpose(array, (2,0,1)))-SHIFT
def save_image(img, path):
   sanitized_img = np.maximum(0, np.minimum(255, img+SHIFT))
   pic = Image.fromarray(np.uint8(np.transpose(sanitized_img, (1, 2, 0))))
   pic.save(path)
def ordered_outputs(f, binding):
    _, output_dict = f.forward(binding, f.outputs)
   return [np.squeeze(output_dict[out]) for out in f.outputs]
# download the images if they are not available locally
for local_path in content_path, style_path:
    if not os.path.exists(local_path):
        download('https://cntk.ai/jup/%s' % local_path, local_path)
# Load the images
style = load_image(style_path)
content = load_image(content_path)
# Display the images
for img in content, style:
   plt.figure()
   plt.imshow(np.asarray(np.transpose(img+SHIFT, (1, 2, 0)), dtype=np.uint8))
# Push the images through the VGG network
# First define the input and the output
y = C.input_variable((3, SIZE, SIZE), needs_gradient=True)
z, intermediate_layers = model(y, layers)
# Now get the activations for the two images
content_activations = ordered_outputs(intermediate_layers, {y: [[content]]})
style_activations = ordered_outputs(intermediate_layers, {y: [[style]]})
style_output = np.squeeze(z.eval({y: [[style]]}))
```

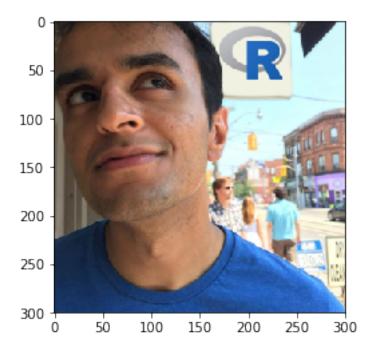


Figure 5.1: png

5.0.3 Optimizing the loss

Now we are finally ready to find the image that minimizes the loss we defined. We will use the optimization package in scipy and in particular the LBFGS method. LBFGS is a great optimization procedure which is very popular when computing the full gradient is feasible as is the case here.

Notice that we are computing the gradient with respect to the input. This is quite different from most other use cases where we compute the gradient with respect to the network parameters. By default, input variables do not ask for gradients, however we defined our input variable as

```
y = C.input_variable((3, SIZE, SIZE), needs_gradient=True)
```

which means that CNTK will compute the gradient with respect to this input variable as well.

The rest of the code is straightforward and most of the complexity comes from interacting with the scipy optimization package: - The optimizer works only with vectors of double precision so img2vec takes a (3,SIZE,SIZE) image and converts it to a vector of doubles - CNTK needs the input as an image but scipy

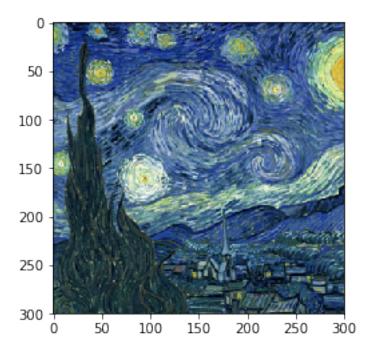


Figure 5.2: png

is calling us back with a vector - CNTK computes a gradient as an image but scipy wants the gradient as a vector

Besides these complexities we just start from the content image (or a random image), perform our optimization and display the final result.

```
# utility to convert a vector to an image
def vec2img(x):
   d = np.round(np.sqrt(x.size / 3)).astype('i')
   return np.reshape(x.astype(np.float32), (3, d, d))
# utility to convert an image to a vector
def img2vec(img):
   return img.flatten().astype(np.float64)
# utility to compute the value and the gradient of f at a particular place defined by binding
def value_and_grads(f, binding):
    if len(f.outputs) != 1:
        raise ValueError('function must return a single tensor')
   df, valdict = f.forward(binding, [f.output], set([f.output]))
   value = list(valdict.values())[0]
   grads = f.backward(df, {f.output: np.ones_like(value)}, set(binding.keys()))
   return value, grads
# an objective function that scipy will be happy with
def objfun(x, loss):
   y = vec2img(x)
   v, g = value_and_grads(loss, {loss.arguments[0]: [[y]]})
   v = np.reshape(v, (1,))
   g = img2vec(list(g.values())[0])
```

```
return v, g
# the actual optimization procedure
def optimize(loss, x0, inner, outer):
    bounds = [(-np.min(SHIFT), 255-np.max(SHIFT))]*x0.size
    for i in range(outer):
        s = opt.minimize(objfun, img2vec(x0), args=(loss,), method='L-BFGS-B',
                         bounds=bounds, options={'maxiter': inner}, jac=True)
       print('objective : %s' % s.fun[0])
       x0 = vec2img(s.x)
       path = 'output_%d.jpg' % i
        save_image(x0, path)
    return x0
np.random.seed(98052)
if start_from_random:
    x0 = np.random.randn(3, SIZE, SIZE).astype(np.float32)
else:
    x0 = content
xstar = optimize(loss, x0, inner, outer)
plt.imshow(np.asarray(np.transpose(xstar+SHIFT, (1, 2, 0)), dtype=np.uint8))
objective : 70194.4
objective : 60445.3
objective: 57855.2
objective: 56728.0
objective : 56166.7
objective : 55840.4
objective : 55627.4
objective: 55493.8
objective: 55395.1
objective : 55325.0
```

<matplotlib.image.AxesImage at 0x7fe962aa0e10>

```
# For testing purposes
objfun(xstar, loss)[0][0]
```

55325.039

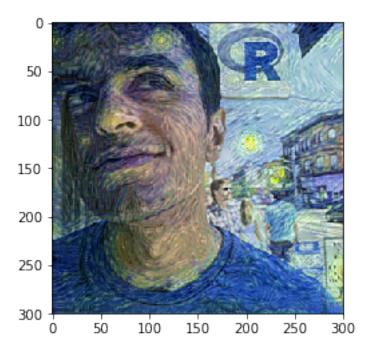


Figure 5.3: png

Bibliography