

Satellite Imagery Classification with Deep Learning

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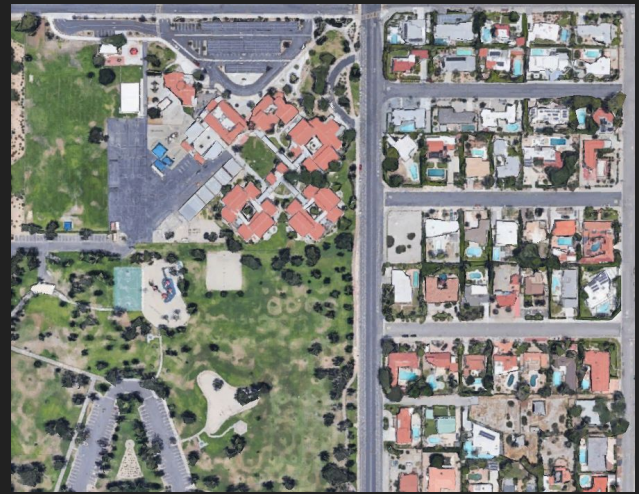
Completed as Capstone Assignment 2
Springboard Data Science Bootcamp

Overview

Satellite imagery

- Rapid growth in data acquisition
- Applications
 - Agriculture
 - Insurance
 - Disaster Response
 - Land Use Management
 - Environmental Management
- Common use-case: classify land uses within area of interest

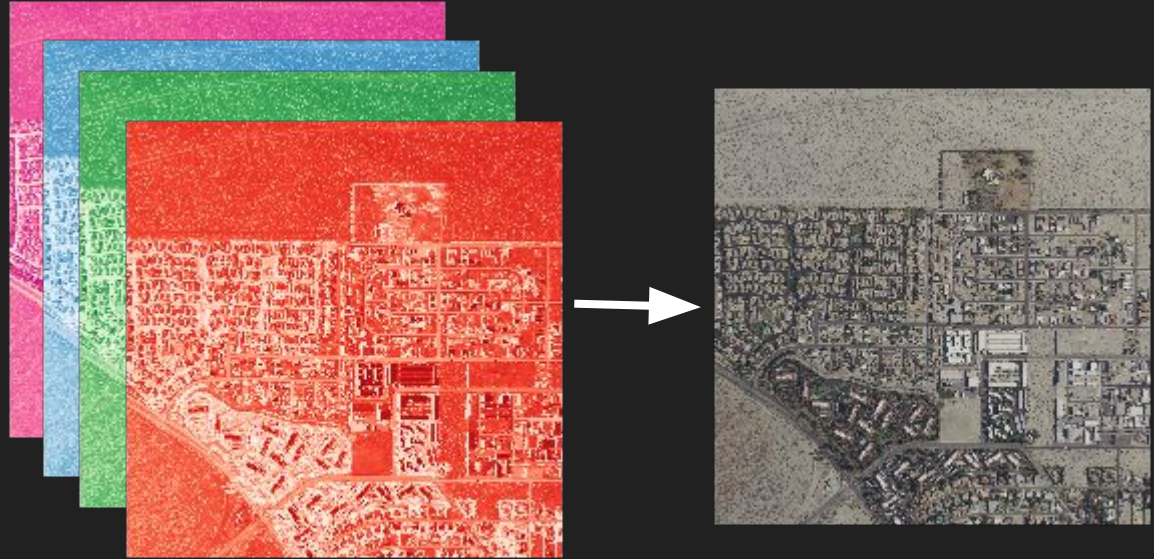
Raw data → Process → Interpret → Decisions



Screen captures from Google Earth

About Satellite Imagery

- Resolution
- Bands/Spectra
- Extent
- Temporal

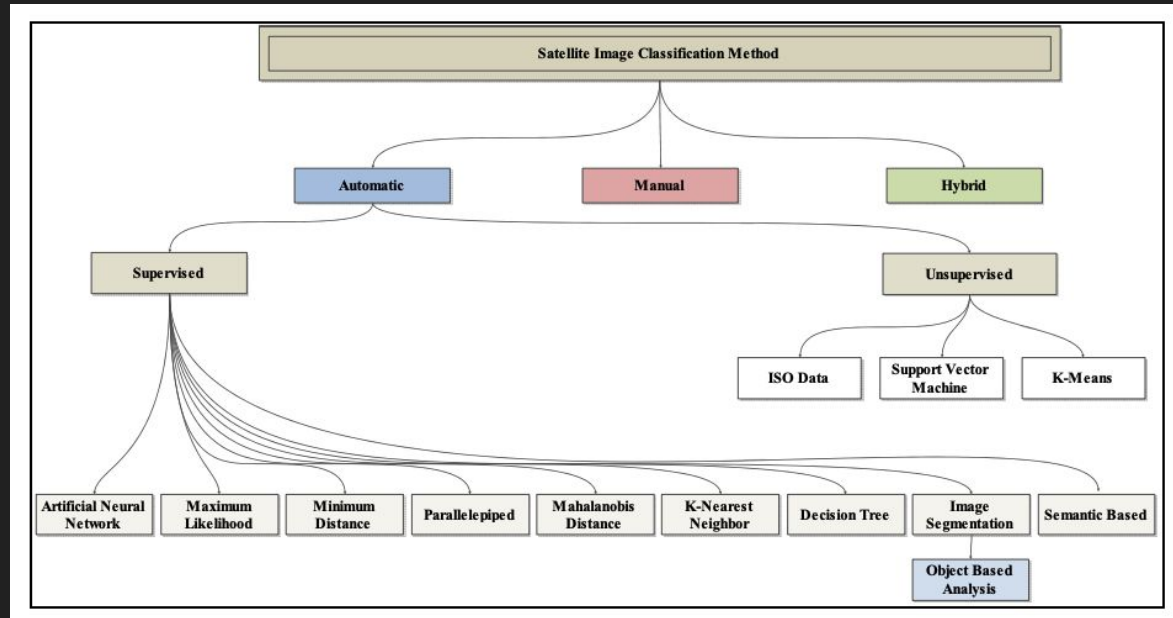


Satellite Imagery - Computer Vision Tasks

- Patch-based classification
- Semantic segmentation (per-pixel classification)
- Object counting
- Object detection (presence/absence, bounding box)
- Change detection

Satellite Image Classification with ML

GOAL: Group image pixels into meaningful categories



Satellite Imagery Analysis With ML

Challenges:

- Big data

- Significant intra-class variability

Why Deep Learning?

- Traditional supervised learning methods like random forest do not scale well to big data.

- CNNs can use the underlying structure in images for classification. Context.

DeepSat-6 (Basu et al, 2015)

Labelled satellite imagery dataset, used for benchmarking classification models

405,000 patches sampled from NAIP

No spatial context

28x28 pixel tiles

1 meter resolution

4 bands: R,G,B,IR

6 class labels: building, barren land, tree, grassland, road, water

Training: 324,000 tiles (80%), Test: 81,000 tiles (20%)



Deep Learning for Computer Vision

Convolutional Neural Network (CNN)

- Deep learning model widely used in computer vision applications

Convolution

- Small tensor multiplied over sections of a larger image, like a filter
- Learn local patterns
- Convolutional layer applies multiple convolutions to the input
- Training learns weights of the convolutions that are most informative

Computer Vision Approaches

- Basic Architecture
 - Convolutional Base
 - Dense Classifier
- Approaches
 - Build and train CNN from scratch
 - Transfer Learning
 - Repurpose pre-trained CNN base (VGG16, Resnet) + custom classifier
 - Training options:
 - Apply convolutional base to dataset, fit classifier to numpy array output
 - Attach classifier to frozen convolutional base, train classifier model
 - Like prior, also re-train top layers of base (fine-tuning)
 - Unfreeze base and retrain entire

Baseline CNN - Architecture

Input

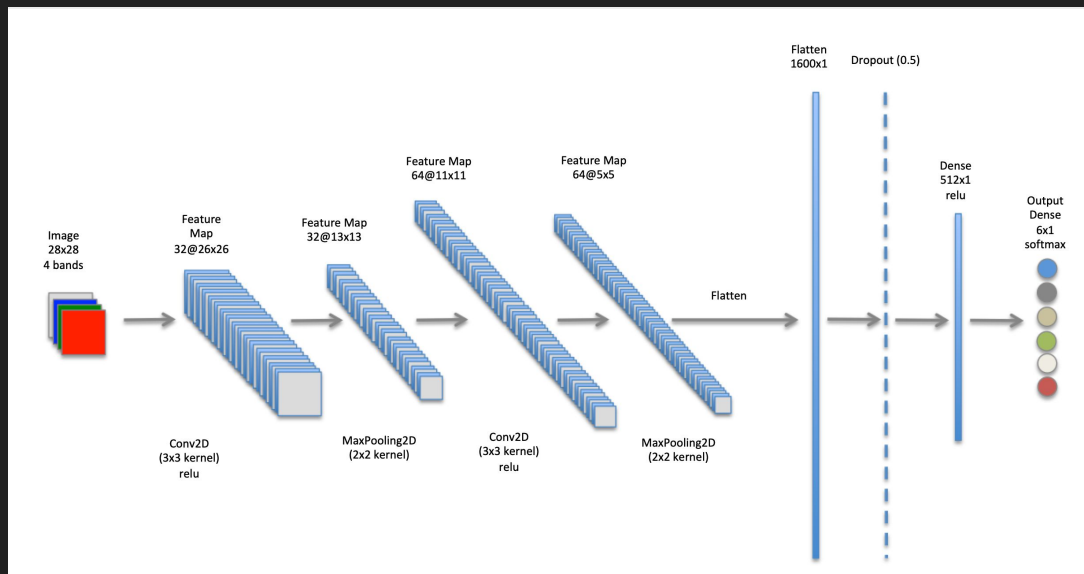
- ImageDataGenerator (train,val)

Convolutional Base

- Maxpooling - downsampling
- Relu - nonlinearity
- Learns patterns at different scales
- Translation invariant

Dense Classifier

- Learn global pattern
- Softmax
- Dropout
- Output classification



Baseline CNN - Training

Backpropagation - gradient descent from output to input

Loss Function	<i>How performance is measured on training data</i>	Categorical Cross-Entropy (Softmax Loss) -log(softmax(s)) for positive class
Optimizer	<i>How network parameters are updated during training</i>	SGD (lr=0.01)
Output Metrics	<i>What measures to record during training</i>	Accuracy

Deep Learning Platform: Keras on Colab

Keras

- High-level library for building deep learning models
- Multiple backend deep learning frameworks (Tensorflow, Theano, CNTK) for handling tensor operations
- Modular approach
- Leverage backend engine to compute on GPU

Colab

- Jupyter notebook environment running python in cloud
- Access to GPU resources
- Free

Building a CNN in Keras

```
# Set up the model
```

```
from tensorflow.keras import models, layers
```

```
model = models.Sequential()
```

```
model.add(layers.Conv2D(32, (3, 3), activation='relu', input_shape=(28, 28, 4))) # RGB+IR images.
```

```
model.add(layers.MaxPooling2D((2, 2)))
```

```
model.add(layers.Conv2D(64, (3, 3), activation='relu'))
```

```
model.add(layers.MaxPooling2D((2, 2)))
```

```
model.add(layers.Flatten()) #collapse to 1D
```

```
model.add(layers.Dropout(0.5)) #added to reduce overfitting
```

```
model.add(layers.Dense(512, activation='relu')) #reduce after flatten
```

```
model.add(layers.Dense(6, activation='softmax')) #final 6-way classification, predict class
```

```
model.summary()
```

```
# Compile the model
```

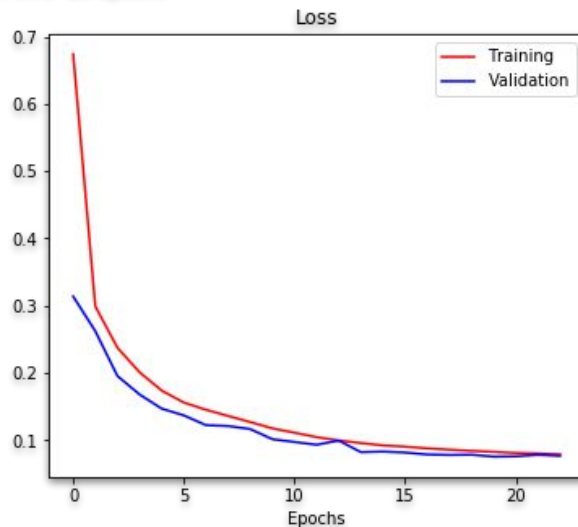
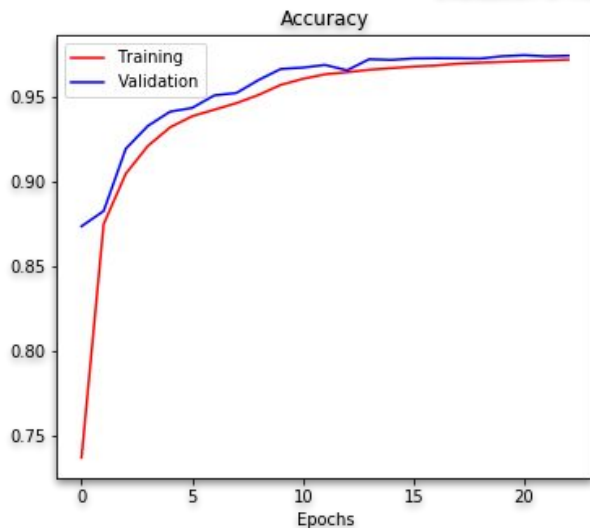
```
model.compile(loss='categorical_crossentropy', optimizer=optimizers.SGD(lr=0.01), metrics=['accuracy'])
```

```
# Train the model
```

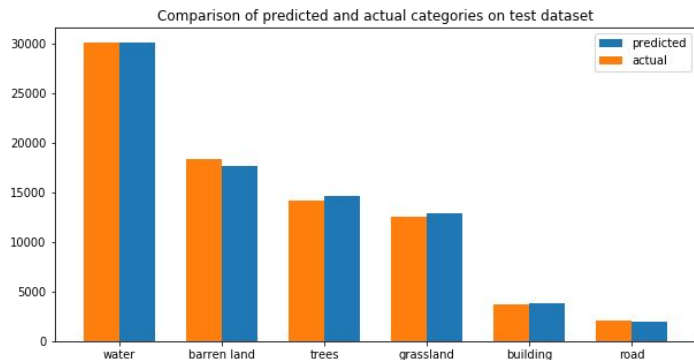
```
history = model.fit_generator(train_generator, steps_per_epoch=545, epochs=30, validation_data=val_generator, validation_steps=126, callbacks=[early_stop_monitor])
```

Baseline Model - Training Performance

Evaluation of Model Fit Over 23 Epochs



Baseline Model - Test Performance



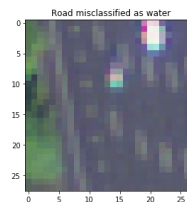
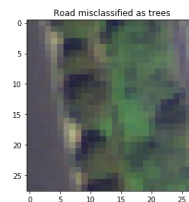
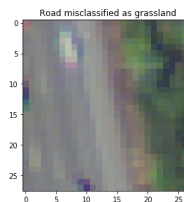
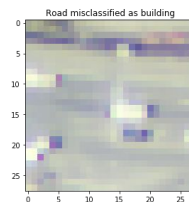
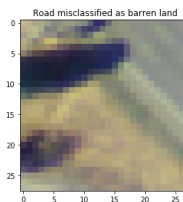
Confusion Matrix

	barren land	building	grassland	road	trees	water
barren land	17480	7	841	9	30	0
building	1	3598	1	101	2	11
grassland	223	0	11910	32	431	0
road	3	180	38	1800	10	39
trees	2	0	74	0	14109	0
water	0	0	0	0	0	30068
Actual \ Predicted	barren land	building	grassland	road	trees	water

Overall accuracy on test dataset: 0.975

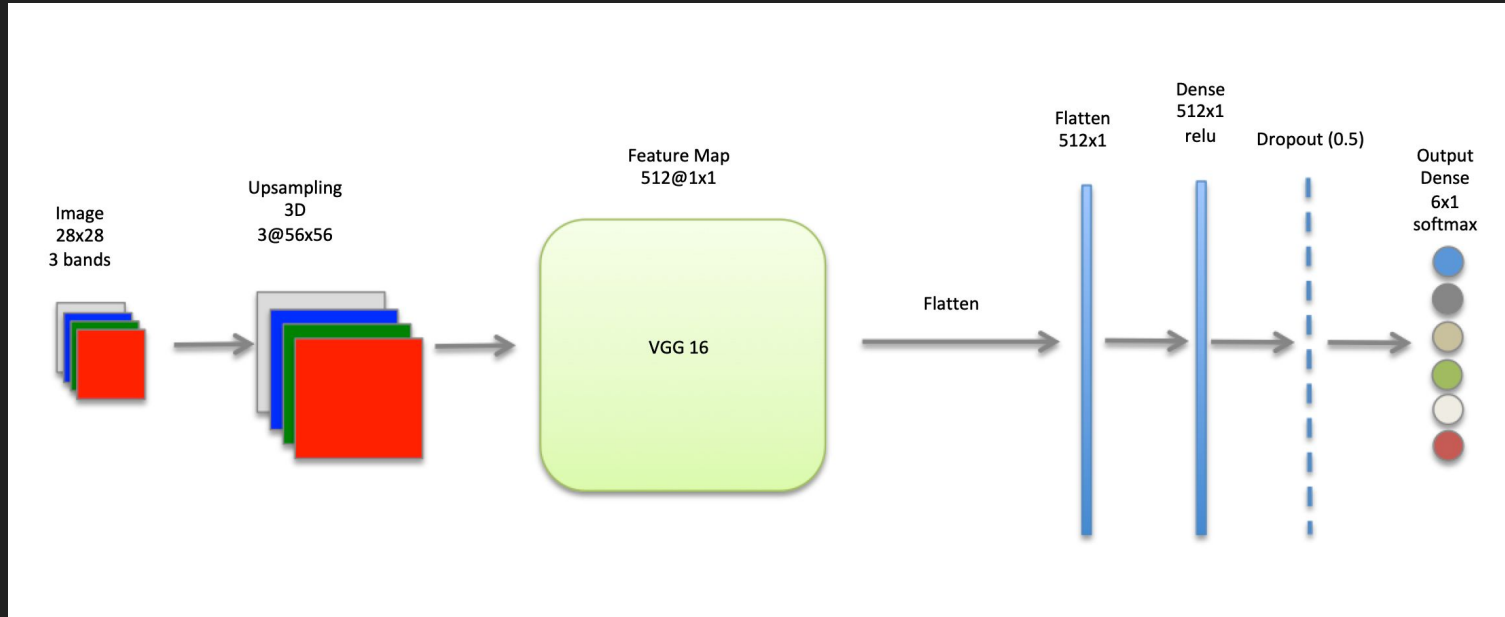
Classification Report:

	precision	recall	f1-score	support
barren land	0.99	0.95	0.97	18367
building	0.95	0.97	0.96	3714
grassland	0.93	0.95	0.94	12596
road	0.93	0.87	0.90	2070
trees	0.97	0.99	0.98	14185
water	1.00	1.00	1.00	30068
accuracy			0.97	81000
macro avg	0.96	0.96	0.96	81000
weighted avg	0.98	0.97	0.97	81000



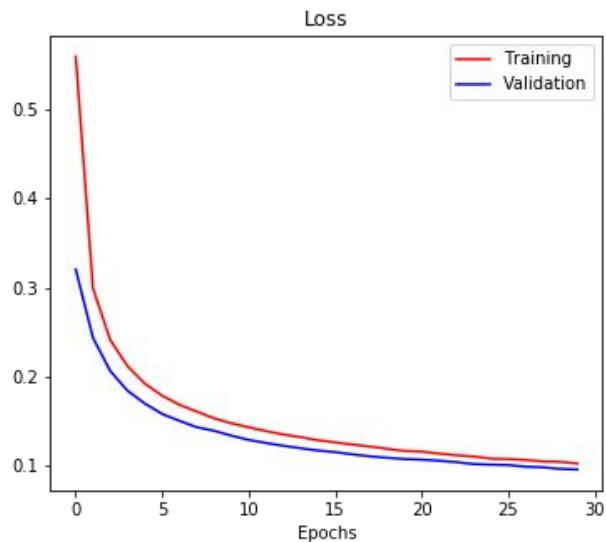
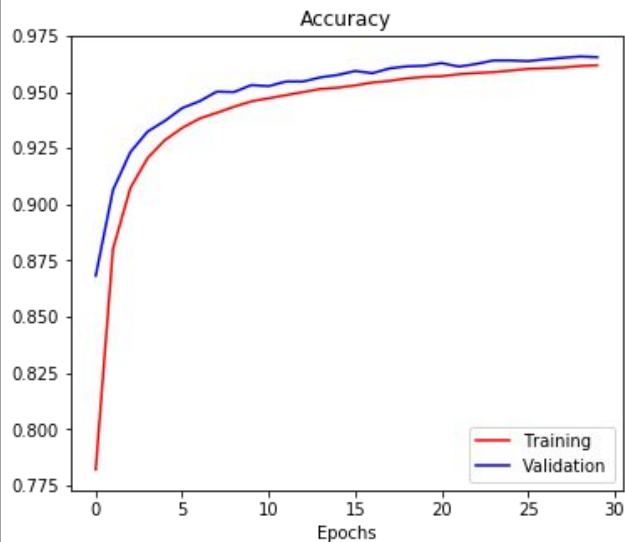
Transfer Learning with VGG16

Architecture:

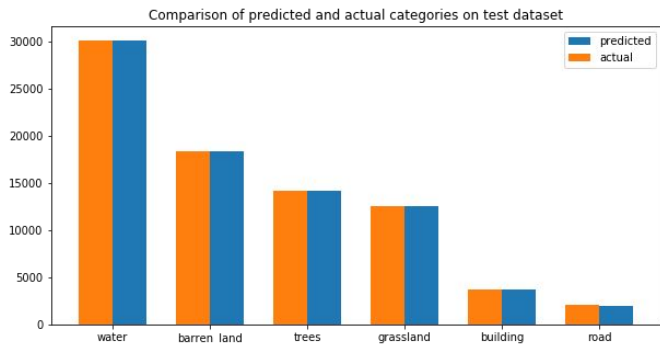


VGG16 - Training Performance

Evaluation of Model Fit Over 30 Epochs



VGG16 Model - Test Performance

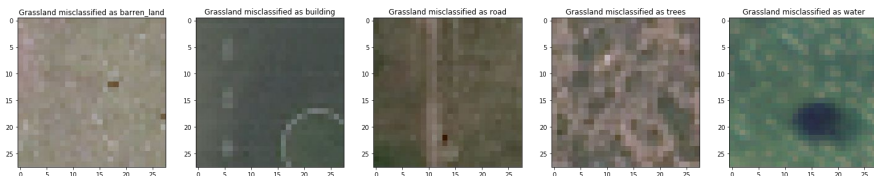


Confusion Matrix							
Actual	barren_land	17321	37	852	7	147	3
	building	63	3561	3	76	6	5
	grassland	887	14	11411	6	277	1
	road	15	121	8	1919	4	3
	trees	85	7	293	0	13779	21
	water	0	4	0	0	9	30055
		barren_land	building	grassland	road	trees	water

Overall accuracy on test dataset: 0.964

Classification Report:

	precision	recall	f1-score	support
barren_land	0.94	0.94	0.94	18367
building	0.95	0.96	0.95	3714
grassland	0.91	0.91	0.91	12596
road	0.96	0.93	0.94	2070
trees	0.97	0.97	0.97	14185
water	1.00	1.00	1.00	30068
accuracy			0.96	81000
macro avg	0.95	0.95	0.95	81000
weighted avg	0.96	0.96	0.96	81000



Misclassifications - Class Probabilities

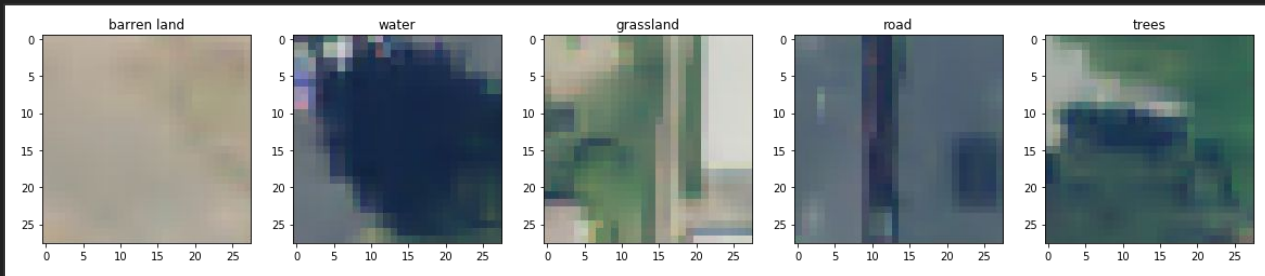
Class Probabilities							
building	barren_land	trees	grassland	road	water	Actual	Predicted
0.482	0.505	0.000	0.012	0.001	0.000	building	barren_land
0.000	0.151	0.022	0.827	0.000	0.000	barren_land	grassland
0.000	0.598	0.001	0.402	0.000	0.000	grassland	barren_land
0.000	0.125	0.003	0.872	0.000	0.000	barren_land	grassland
0.000	0.119	0.001	0.881	0.000	0.000	barren_land	grassland
0.101	0.891	0.000	0.000	0.007	0.000	building	barren_land
0.000	0.816	0.002	0.182	0.000	0.000	grassland	barren_land
0.763	0.000	0.000	0.000	0.237	0.000	road	building
0.000	0.113	0.059	0.828	0.000	0.000	trees	grassland
0.001	0.257	0.003	0.740	0.000	0.000	barren_land	grassland

Apply Baseline Model to New Image

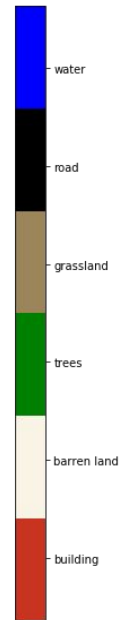
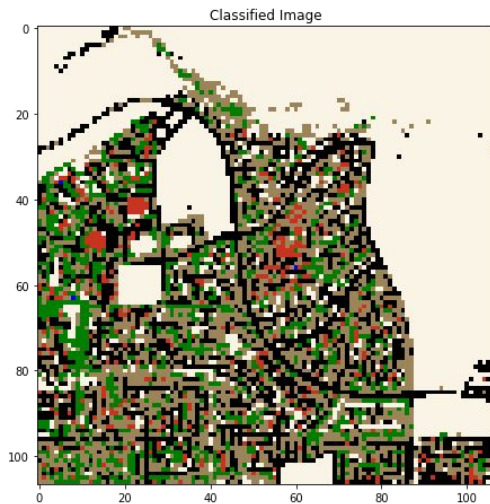
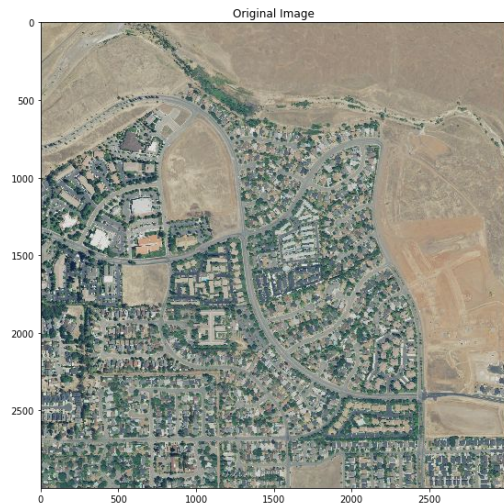
Download new NAIP image

Split into tiles, Reshape to channels-first ndarray

Input to `model.predict()`



Reassemble Classified Image



Summary of Results

- Applied Deep Learning with CNN to classify satellite image tiles
- Used DeepSat6 benchmarking dataset
- Two methods:
 - Simple Baseline CNN (97.5% accuracy)
 - Transfer learning with VGG16 (96.4% accuracy)
- Applied Baseline CNN to new NAIP imagery

Follow-on Work

- Additional testing on NAIP tiles
- Georeference output tile for additional spatial analysis
- Address resolution loss
 - Classify overlapping tiles, assign class to central pixels
 - Image segmentation with U-Net