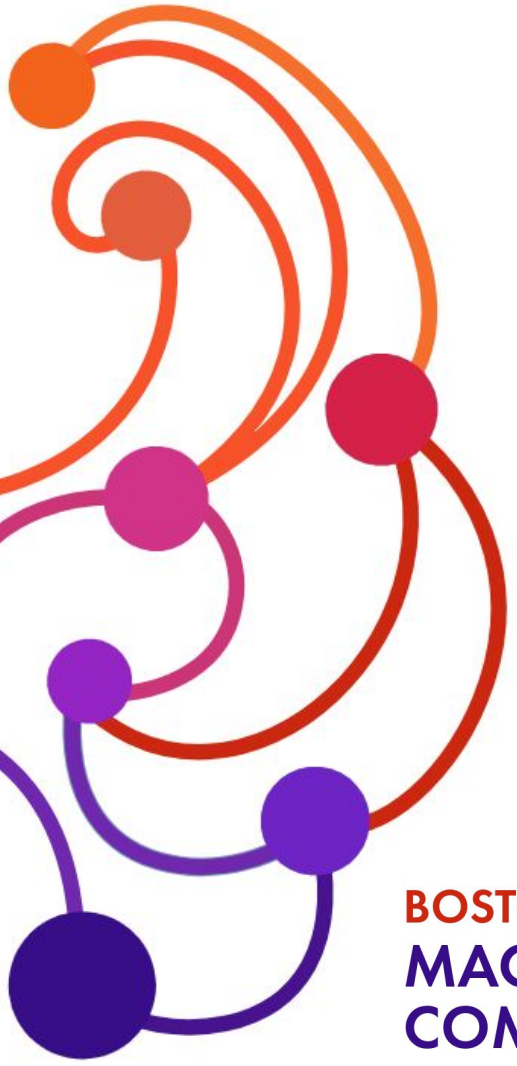

Style Transfer with TensorFlow™

BOSTON UNIVERSITY
MACHINE INTELLIGENCE COMMUNITY

Rachel Manzelli
3/28/18

https://goo.gl/bGiujV

Last Time

- ➔ Learned the concepts of TensorFlow 1.2
- ➔ Built and evaluated simple graphs
- ➔ “Trained” a linear model

https://github.com/bumic/TF-Workshops/tree/master/Workshop%201

Today's Plan

- ➔ *Begin project:* implementation of neural style transfer in TensorFlow (will last 3 workshops)
- ➔ *Concepts:* convolutional neural networks, VGG-19 architecture, neural style transfer
- ➔ *Implementations:* structure of a neural network implementation, skeleton code for NST

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What You Need For Today

- A computer & text editor
- Installations of Python 2 or 3, TensorFlow, numpy, scipy, and Pillow
- These can all be installed via `pip install`

```
>> pip install numpy

>> pip install scipy

>> pip install Pillow
```

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A Brief Overview of Neural Networks

- **Multilayer perceptrons:** the "plain vanilla" of machine learning
- In a fully connected network, each **neuron** (a tensor in TensorFlow) in the next layer is connected to all neurons in the previous layer, and **feeds forward** information to "activate" the next neuron
- What is this information?

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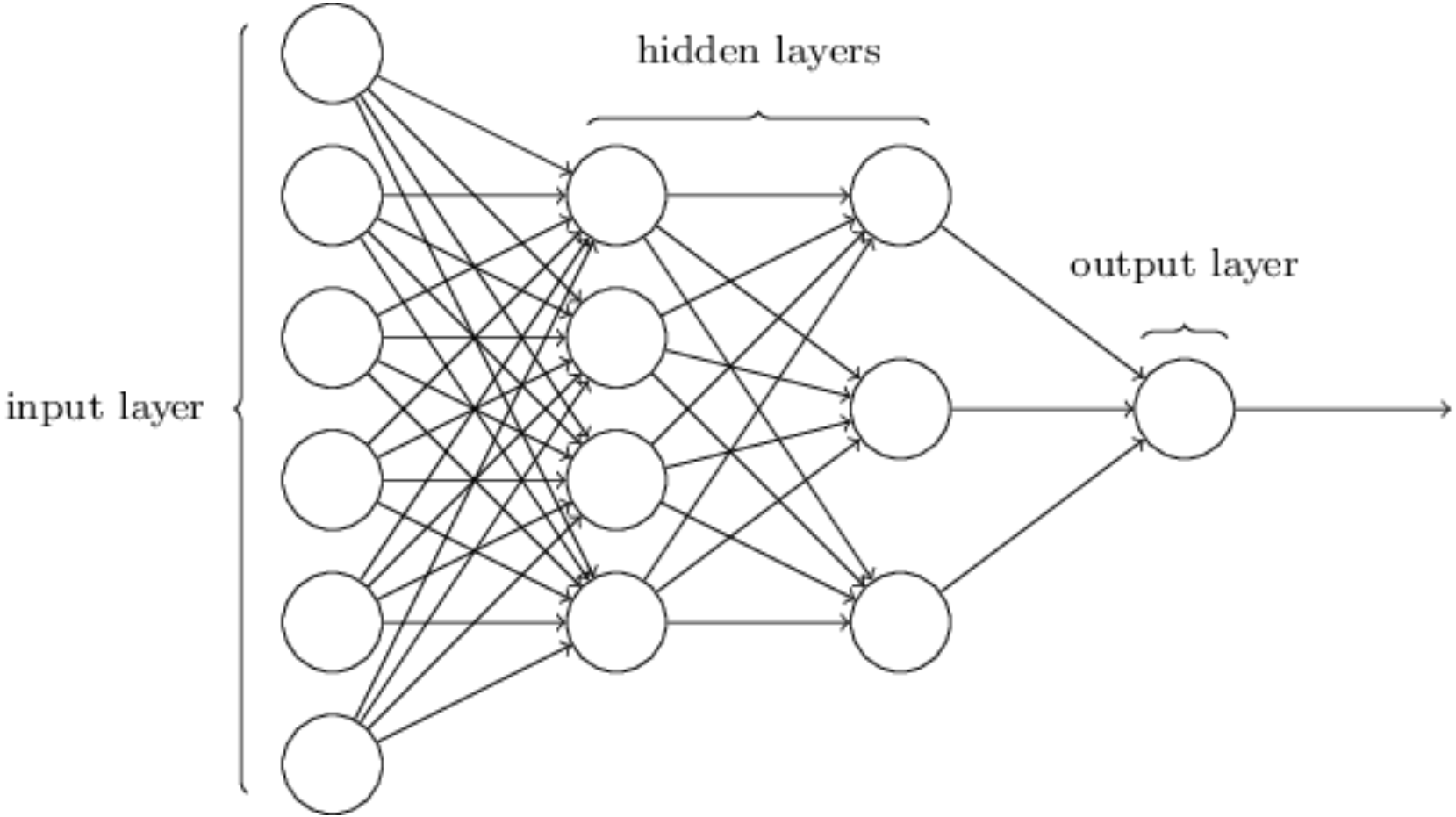
hidden layers
output layer
input layer

Neural Networks: Connections

- **Weights**: how "important" that neuron is
- **Bias**: how high the weighted sum needs to be for neuron to be meaningfully active
- Initialized randomly, then through training they are adjusted toward the correct value

$$Y = \sum (weight * input) + bias$$

```
linear_model = W * x + b
```

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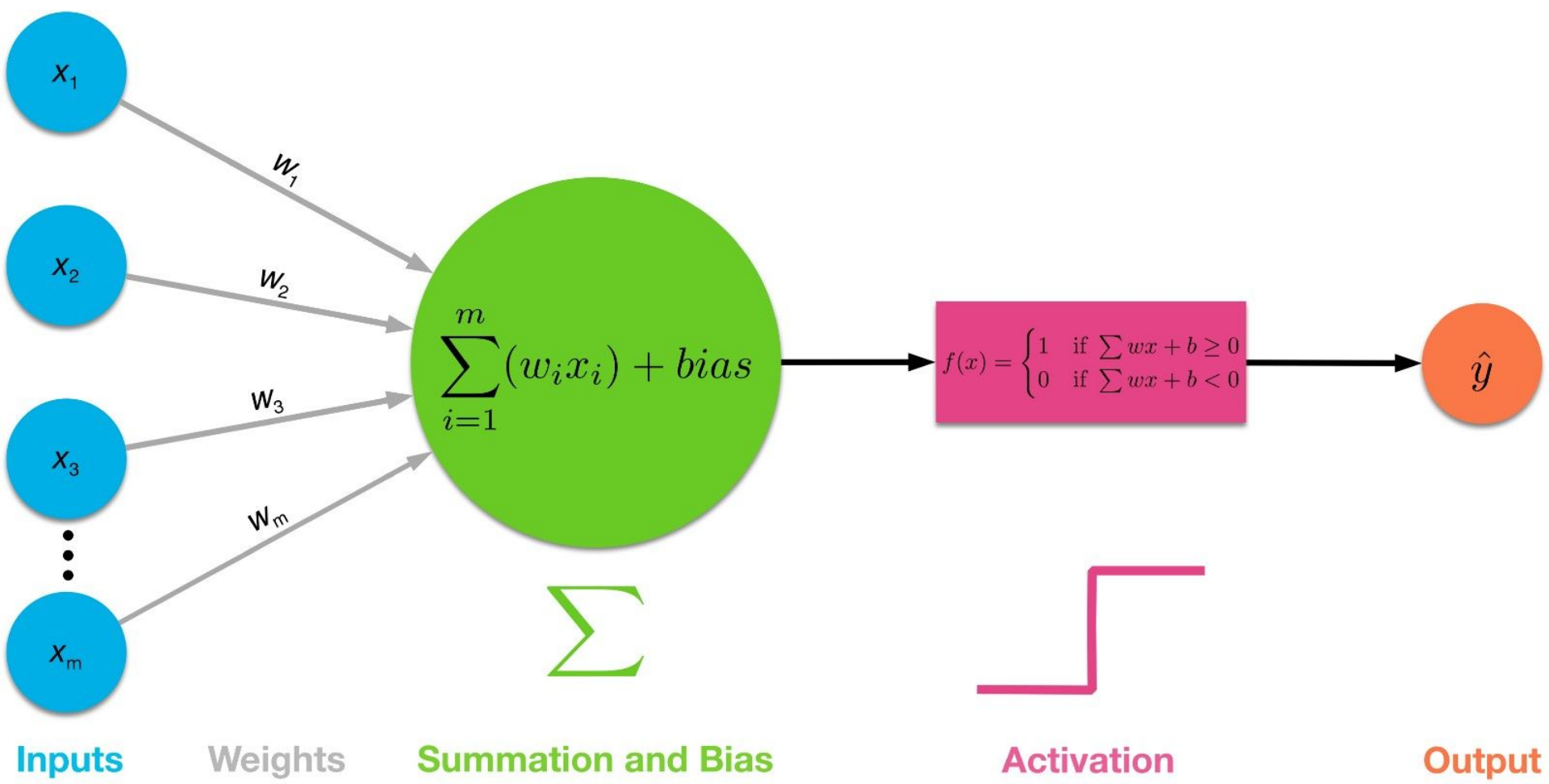
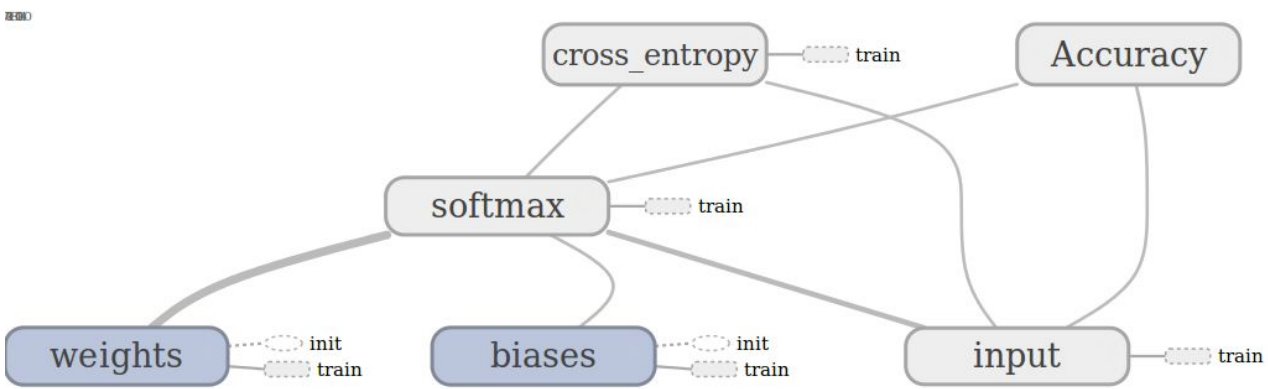
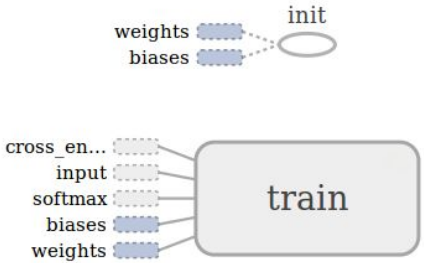

x_1
x_2
x_3
x_m
w_1
w_2
w_3
w_m
$\sum_{i=1}^{m}(w_i x_i) + bias$
$f(x) = \begin{cases} 1 & \text{if } \sum wx + b \geq 0 \\ 0 & \text{if } \sum wx + b < 0 \end{cases}$
$\hat{y}$
$\sum$
Inputs
Weights
Summation and Bias
Activation
Output


cross_entropy
train
Accuracy
softmax
train
weights
init
train
biases
init
train
input
train


init
weights
biases
cross_en...
input
softmax
biases
weights
train

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Neural Networks: Loss functions

- **Loss functions** add a cost to the network's output, i.e. penalizing the network for performing poorly
  - Difference between output and desired output
  - We want to **minimize** this. There are many loss functions...

$$\text{MSE} = \frac{1}{n}\sum_{i=1}^{n} (y_i - \tilde{y}_i)^2$$

$$\mathcal{L}(y, \hat{y}) = -y \log \hat{y} - (1 - y) \log(1 - \hat{y})$$

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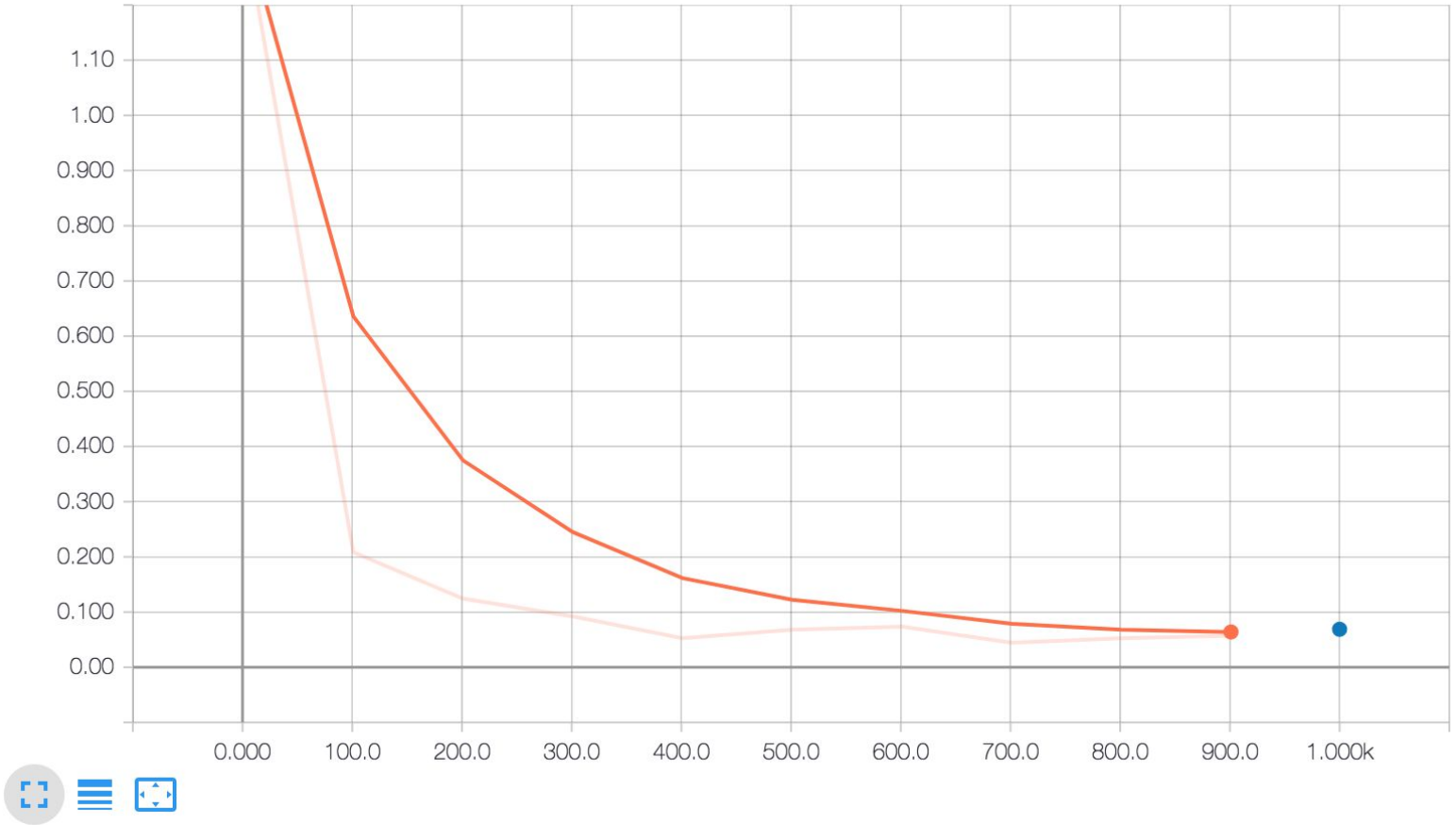
loss


1.10
1.00
0.900
0.800
0.700
0.600
0.500
0.400
0.300
0.200
0.100
0.00
0.000
100.0
200.0
300.0
400.0
500.0
600.0
700.0
800.0
900.0
1.000k


M I C

Neural Networks: Training

- ➔ **Training** a network means minimizing this cost function more and more with each step.
- ➔ **Gradient descent** is called an optimizer: it allows us to **adjust weights and biases** by telling them to increase or decrease to minimize the cost function
- ➔ There are many other optimizers...

$$\mathbf{a}_{n+1} = \mathbf{a}_n - \gamma \nabla F(\mathbf{a}_n)$$

$$\theta_{t+1} = \theta_t - \frac{\eta}{\sqrt{\hat{v}_t} + \epsilon} \hat{m}_t$$

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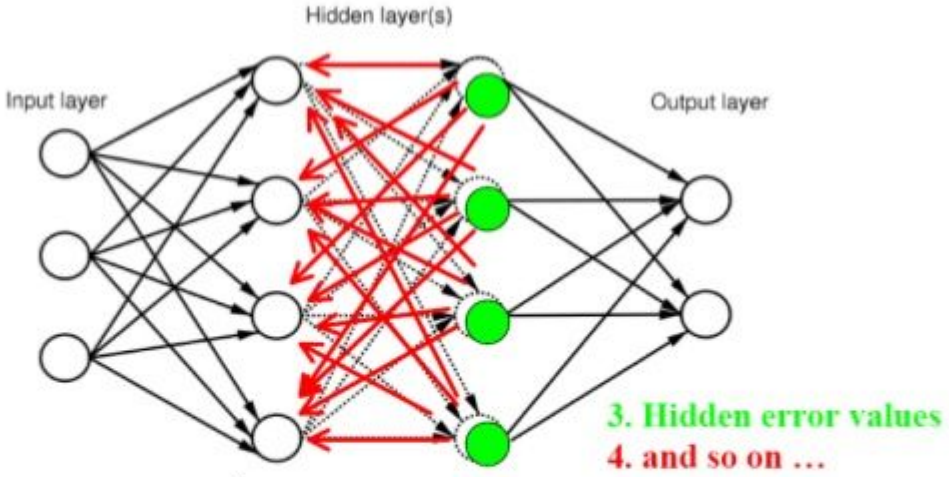
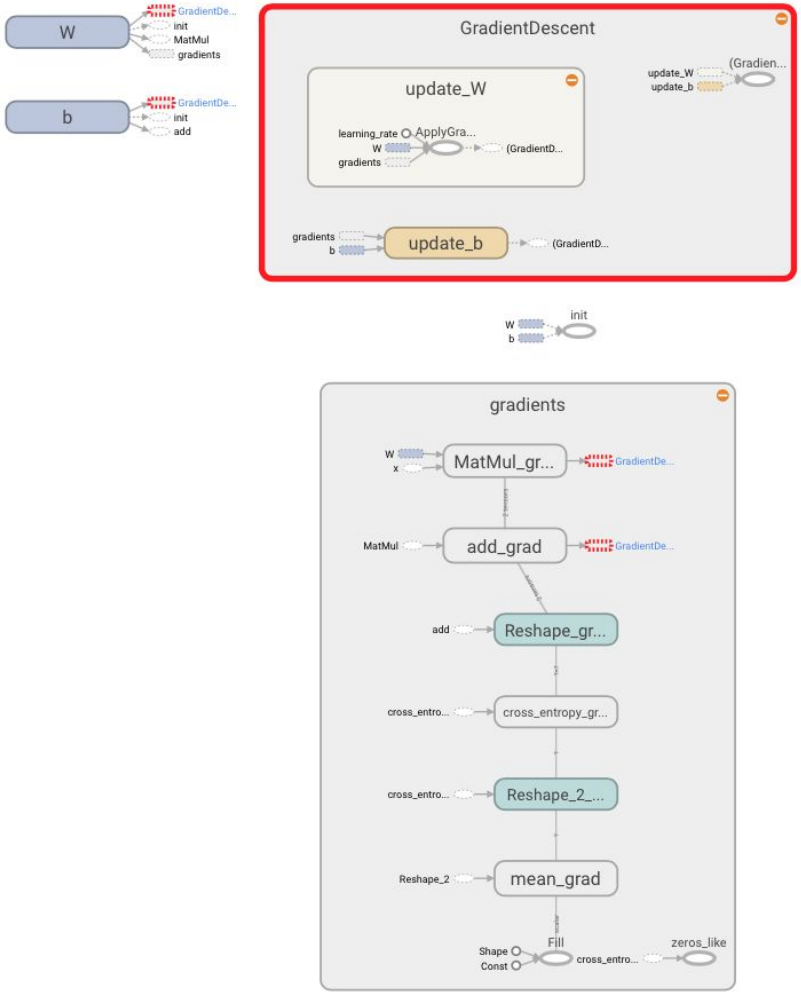
Visual: Backpropagation




W
GradientDe...
init
MatMul
gradients
b
GradientDe...
init
add
GradientDescent
update_W
learning_rate
W
gradients
ApplyGra...
(GradientD...
update_W
update_b
(Gradien...
gradients
b
update_b
(GradientD...
W
b
init
gradients
W
x
MatMul_gr...
GradientDe...
MatMul
add_grad
GradientDe...
add
Reshape_gr...
cross_entro...
cross_entropy_gr...
cross_entro...
Reshape_2_...
Reshape_2
mean_grad
Shape
Const
Fill
cross_entro...
zeros_like

François Chollet 

@fchollet

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"Neural networks" are a sad misnomer. They're neither neural nor even networks. They're chains of differentiable, parameterized geometric functions, trained with gradient descent (with gradients obtained via the chain rule). A small set of highschool-level ideas put together

11:58 AM - 12 Jan 2018

1,308 Retweets **3,413** Likes

116 1.3K 3.4K

François Chollet
@fchollet | 81,895 followers

Activity | Map | Analyse | Visualise | Alert

There's a point to be made that a neural network for food classification that can classify Tide pods as "not food" has already reached superhuman capabilities

2 months ago · *Twitter Web Client* · *en*

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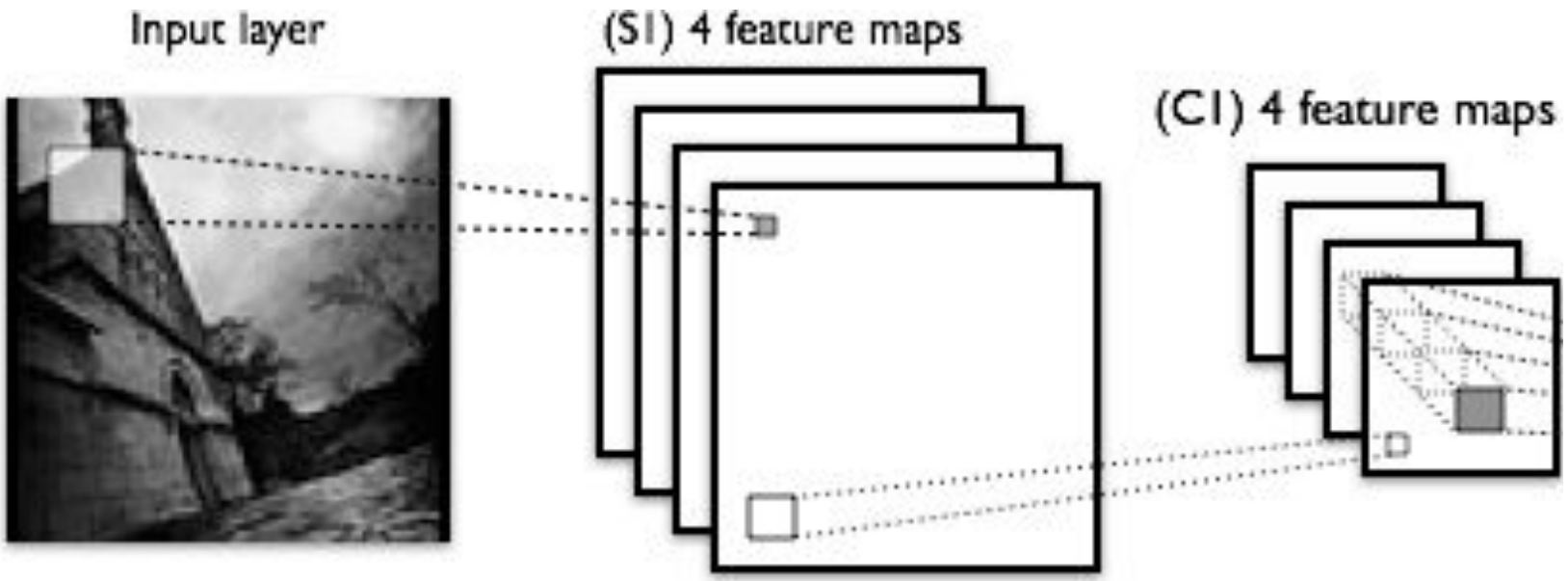
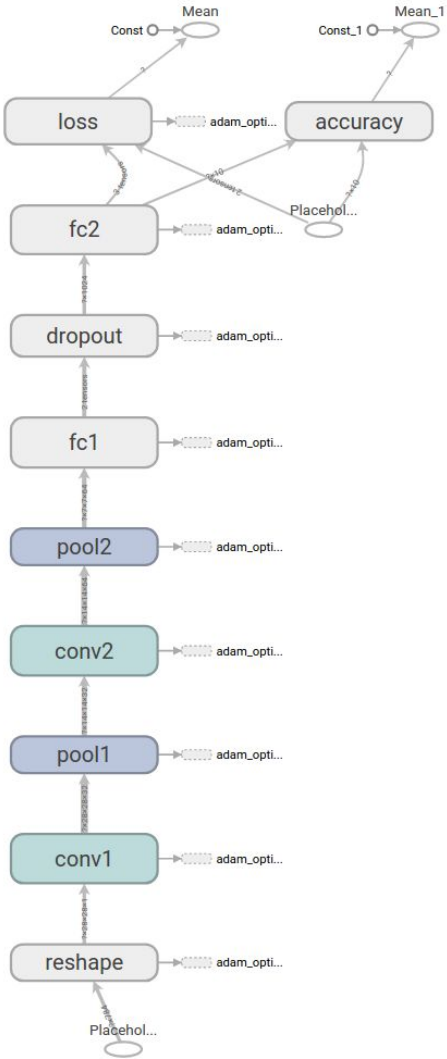
Convolutional Neural Networks

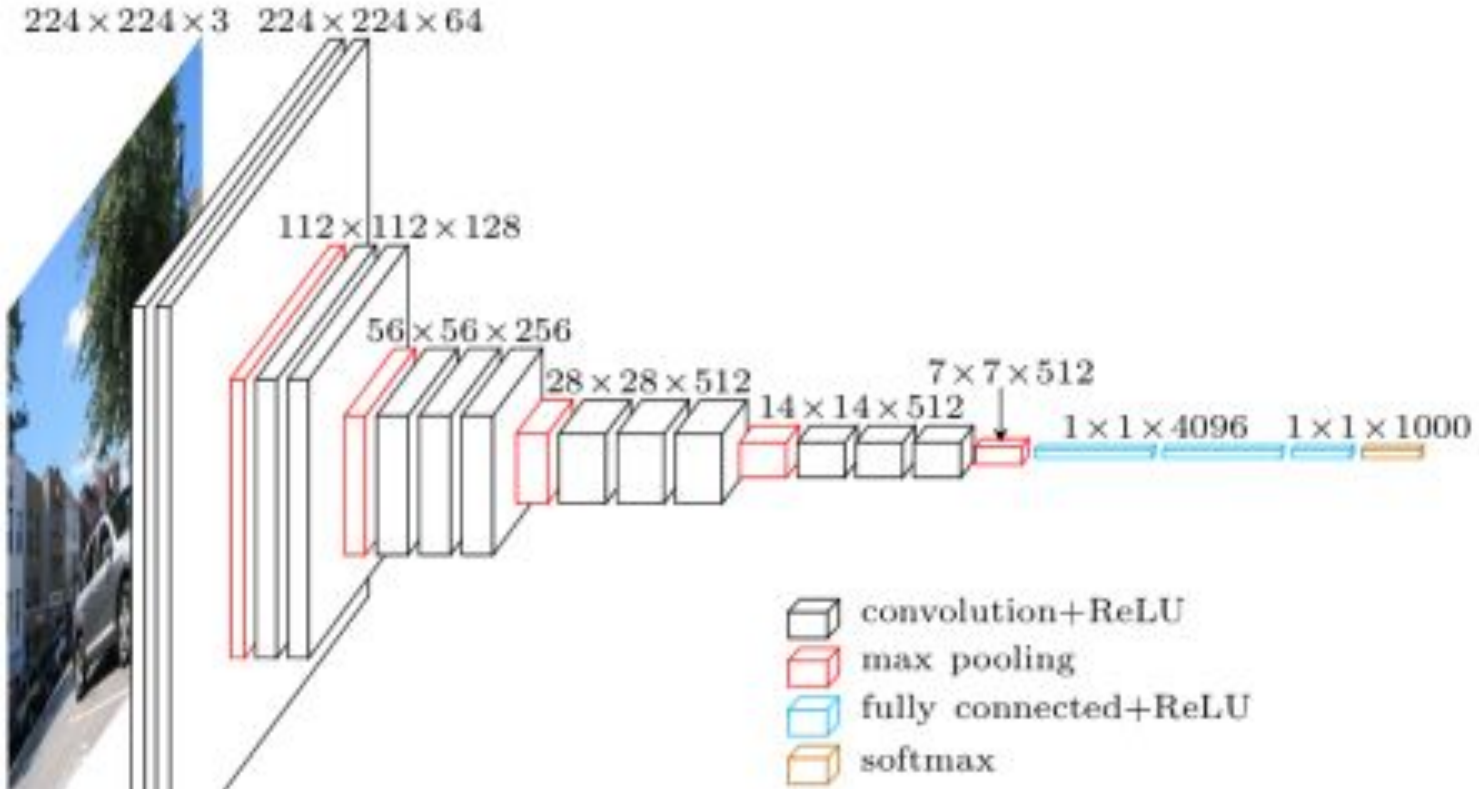
- Neural networks with **convolutional layers**: use convolutions instead of matrix multiplications to produce output in hidden layers
- Each convolution layer takes an input image and produces a set of **feature maps** by **filtering**
  - Each filter is “convolved” across the width and height of the input volume, producing a 2-dimensional activation map of that filter.

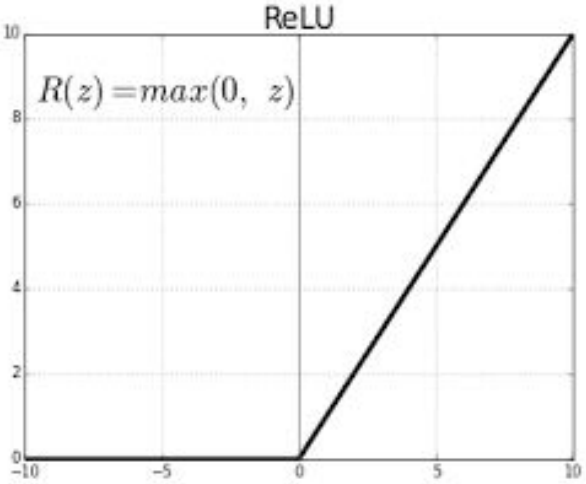

Input layer
(S1) 4 feature maps
(C1) 4 feature maps


Mean
Const
Mean_1
Const_1
loss
adam_opti...
accuracy
Placehol...
fc2
adam_opti...
dropout
adam_opti...
fc1
adam_opti...
pool2
adam_opti...
conv2
adam_opti...
pool1
adam_opti...
conv1
adam_opti...
reshape
adam_opti...
Placehol...

VGG-19

- A specific version of VGGNet with **19 weight layers**
- VGGNet is a convolutional neural network originally used for image classification
  - uses **3×3 convolutional layers** stacked on top of each other
  - reducing volume size is handled by **max pooling**
  - Two **fully-connected** layers, each with 4,096 nodes are followed by a **softmax classifier**.
- Original VGGNet paper: https://arxiv.org/abs/1409.1556

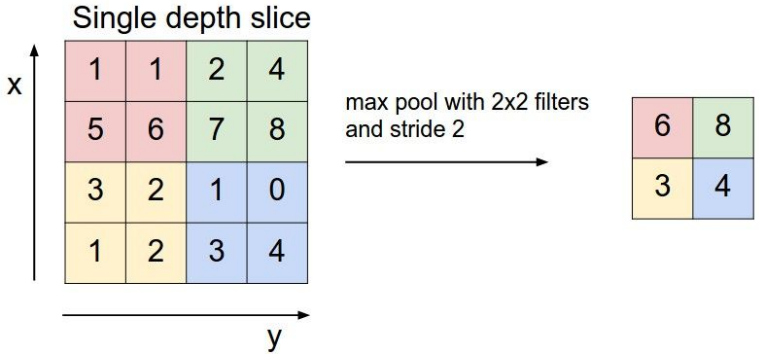

224×224×3
224×224×64
112×112×128
56×56×256
28×28×512
14×14×512
7×7×512
1×1×4096
1×1×1000
convolution+ReLU
max pooling
fully connected+ReLU
softmax



Softmax

$$\sigma(x_j) = \frac{e^{x_j}}{\sum_i e^{x_i}}$$

Max pooling



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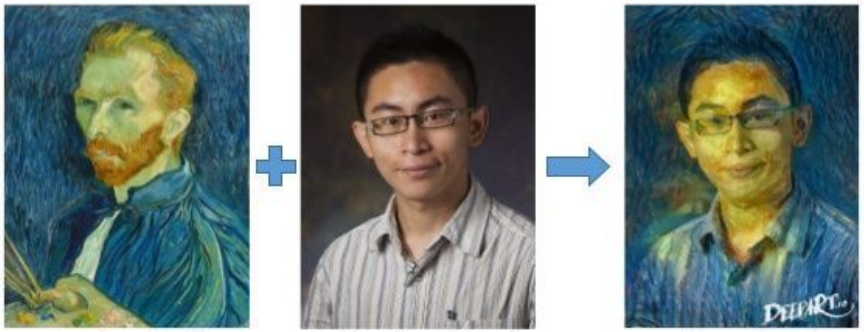
What is Neural Style Transfer?

- ➔ Representations of style and content can be isolated and manipulated separately from a convolutional NN!
- ➔ Contains three main components:
  - ◆ **Content image, style image, pastiche**



Source image (**Style**) Target image (**Content**) Output (deepart)

A Neural Algorithm of Artistic Style [Gatys et al. 2015]

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Content image:
Picture we want to transfer style onto

Style image:
Artwork whose style we want to transfer

Pastiche:
Final stylized image (Initialized to random/white noise)

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Content image: loss and reconstruction

- **Content Loss** - Mean Squared Error between feature maps for a given convolutional layer l
  - P_{ij}^{l}: Feature map of **original image**
  - F_{ij}^{l} : Feature map of **image content to be generated**

- Gradient descent is used to minimize the content loss

$$L_{content}(\overrightarrow{p}, \overrightarrow{x}, l) = \frac{1}{2} \sum_{ij} (F_{ij}^{l} - P_{ij}^{l})^2$$

Original image

Generated image

Style image: loss function

- Style Loss
  - **Gram Matrix**: inner product between two vectorised features maps *i* and *j*
  - Computes correlations between different features

$$G_{ij}^{l} = \sum_{k} F_{ik}^{l} F_{jk}^{l}$$

  - Minimize mean-squared distance between entries of Gram matrix of style image and generated image

$$E_l = \frac{1}{4N_l^2 M_l^2} \sum_{i,j} (G_{ij}^{l} - A_{ij}^{l})^2$$

Style image: reconstruction

- **Total Style Loss** across multiple layers
  - Weighted sum of styles losses across all layers of the convolutional network

$$L_{style}(\overrightarrow{a}, \overrightarrow{x}) = \sum_{l=0}^{L} w_l E_l$$

Original image

Generated image

Layer contribution weight

Total Loss Function for NST

- **Total Loss** - Jointly minimize error of a white noise image from
  - Content representation of **content image** $\vec{p}$
  - Style representation of **style image** $\vec{a}$

$$L_{total}(\vec{p}, \vec{a}, \vec{x}) = \alpha L_{content}(\vec{p}, \vec{x}) + \beta L_{style}(\vec{a}, \vec{x})$$

- α, β : weighting factors for content and style reconstruction respectively

$$\mathbf{x}^* = \underset{\mathbf{x}}{\operatorname{argmin}} \left(\alpha \mathcal{L}_{\text{content}}(\mathbf{c}, \mathbf{x}) + \beta \mathcal{L}_{\text{style}}(\mathbf{s}, \mathbf{x}) \right)$$

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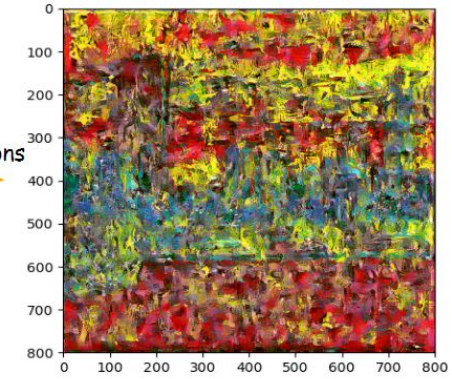
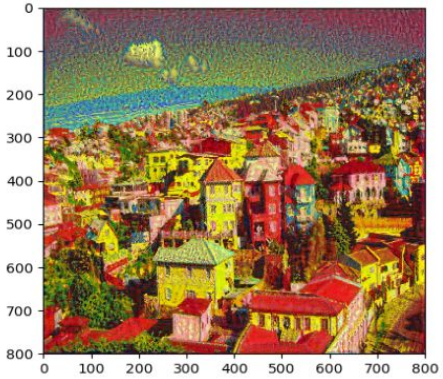
+

1000 iterations →



+

1000 iterations →



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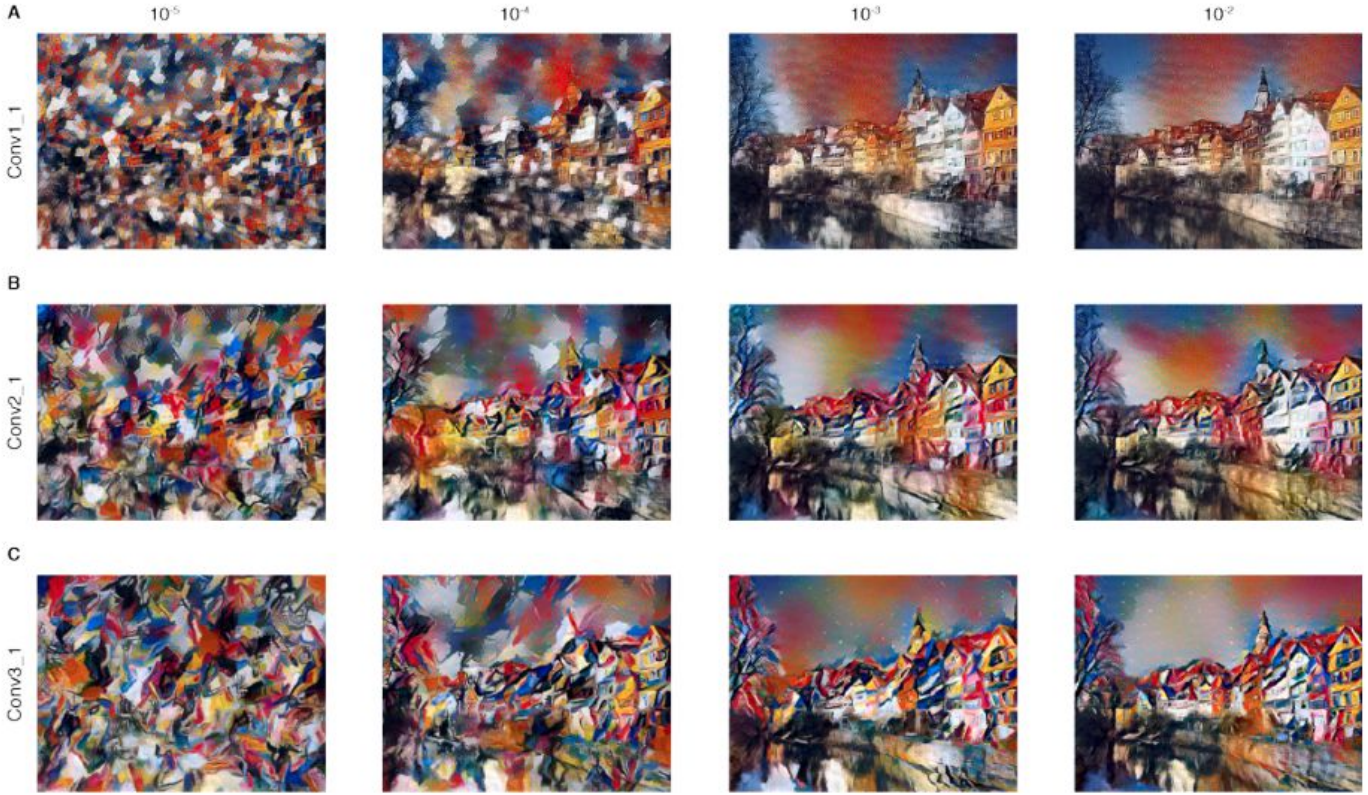
Style emphasis ← α/β ratio → Content emphasis

VGG content layer



Implementation of Neural Style Transfer

- The implementation of neural style we will be using is located here:

https://goo.gl/M1pBRx

- Let's go to it and play around!

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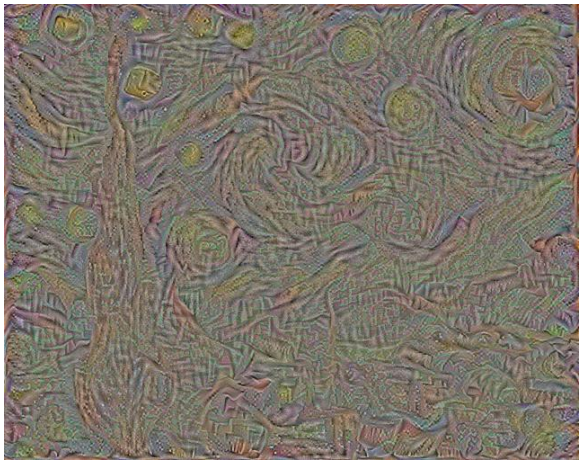
Implementation of Neural Style Transfer



Iteration 10

Iteration 300

Iteration 990

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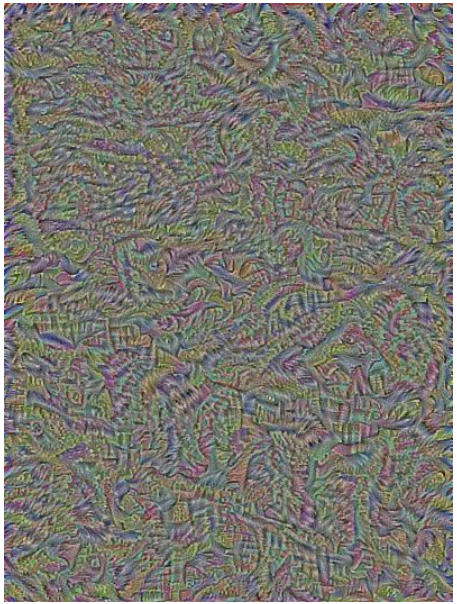
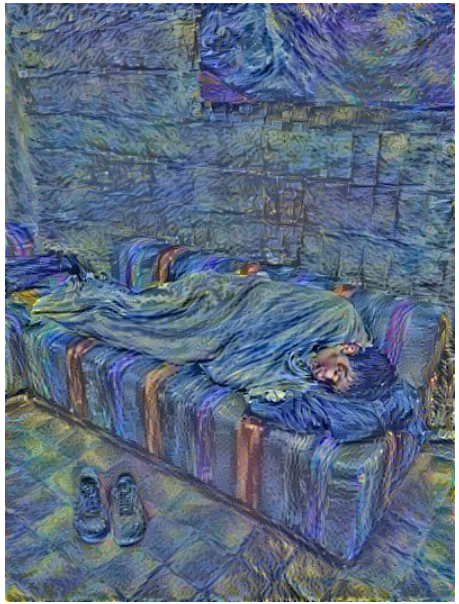
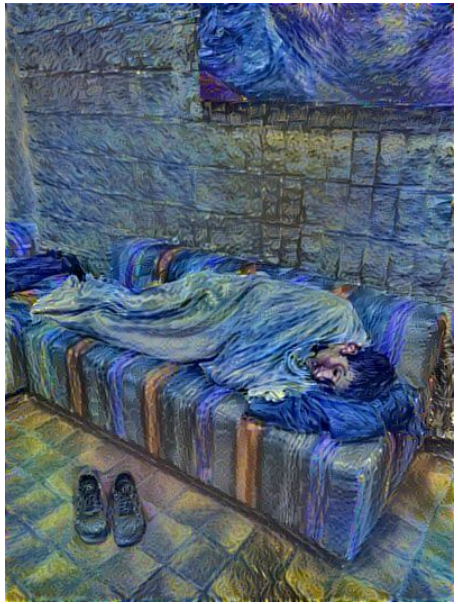
Implementation of Neural Style Transfer



Iteration 10



Iteration 300



Iteration 990

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Let's (finally) start building it!

- ➔ Go to https://github.com/anishathalye/neural-style
- ➔ This is the NST implementation we will be rebuilding.
- ➔ Download the file at the bottom:

```
imagenet-vgg-verydeep-19.mat
```

- ➔ This is our pretrained VGGNet that we will be using in our implementation. (pre-training a convnet is time-consuming!)

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The Pre-trained Network

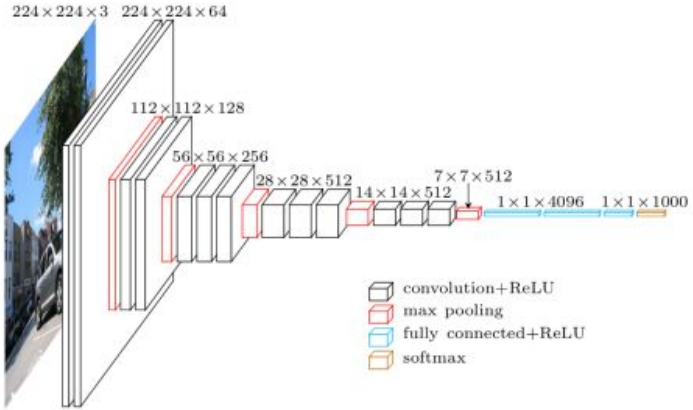
- ➔ This network was trained on ImageNet (it can presumably classify images)
- ➔ Open the file in MATLAB
- ➔ If you don't have MATLAB, that's ok - Python to come!

Implementing a Neural Network

- ➔ *Architecting*: constructing the architecture of the neural network
- ➔ *Preprocessing*: preprocessing the data so that it is in a form we can train on
- ➔ *Training*: getting those perfect weights
- ➔ *Testing/generating*: using the trained network to generate a result

Implementation: Architecture

- ➔ Open a new file. This will be our initialization of the architecture of the network.
- ➔ First, we will initialize a dictionary of keys to refer back to the weight layers of our network, based on the .mat file.



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Upcoming Events with BUMIC

- ➔ Impact of AI discussion group: 4/4/18
- ➔ Next TensorFlow session: 4/11/18 @ 7pm
  - ◆ Continuing NST: Finishing architecture and training the network

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