Introduction to Deep Learning

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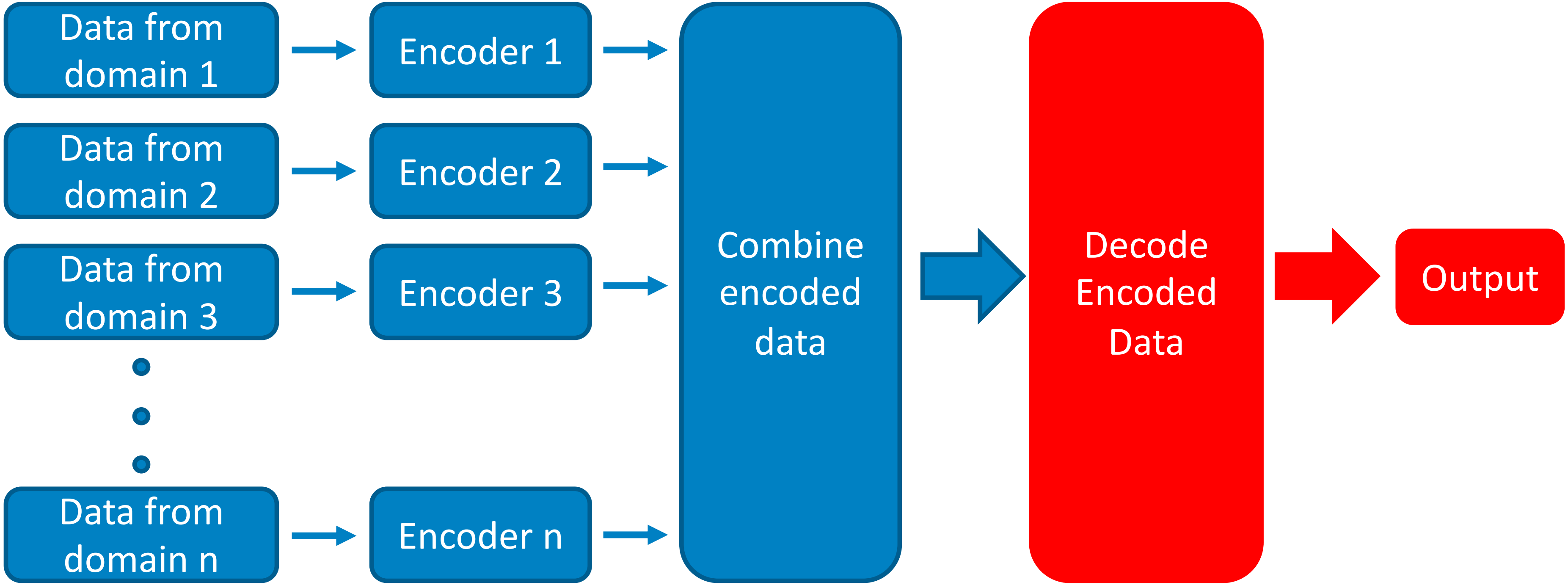
February 13 2019

Deep Learning: A few considerations

- Deep Learning is just another word for artificial neural network (ANN) (in general it has more layers than a standard ANN, hence “deep”)
- A Deep Neural Network is a universal function approximator that can be learned via standard(ish) gradient descent methods
- Other than the fact that operations within a DNN must be differentiable, there are very little a-priori assumptions about deep models
- Deep learning provides superior solutions over standard methods in **computer vision** and **natural language processing**
- Deep learning is very much an ***experimental*** science

(Almost) all Deep Learning Architectures



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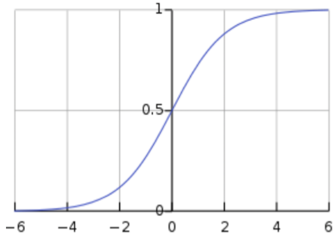
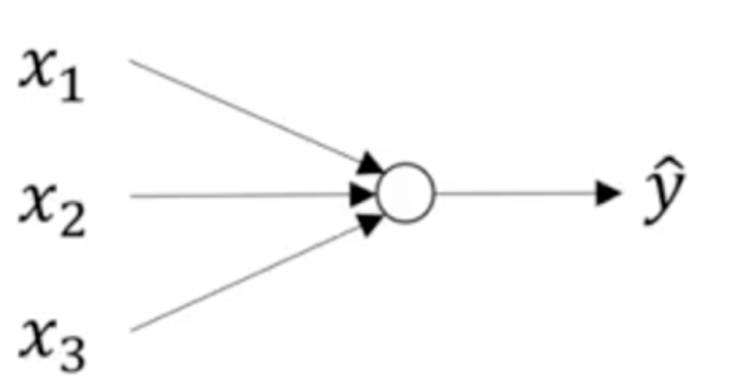
A familiar algorithm

- Logistic regression
    - Prediction $\hat{y} = \text{Sigmoid}(Wx + b)$
    - Activation function $\text{Sigmoid}(z) = \dfrac{1}{1 + e^{-z}}$
    - Cost function $J(W, b) = y \log(\hat{y}) + (1 - y) \log(1 - \hat{y})$

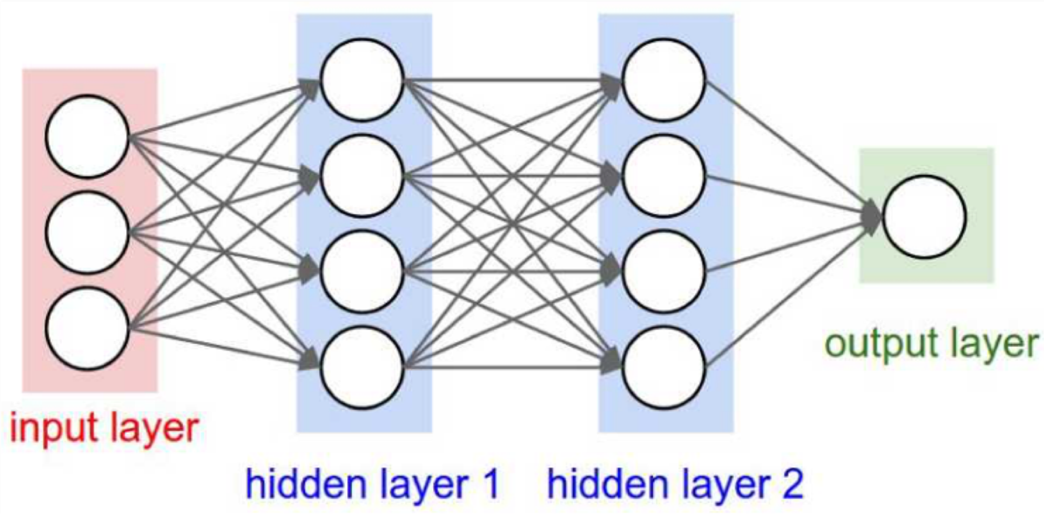


- Can be represented with

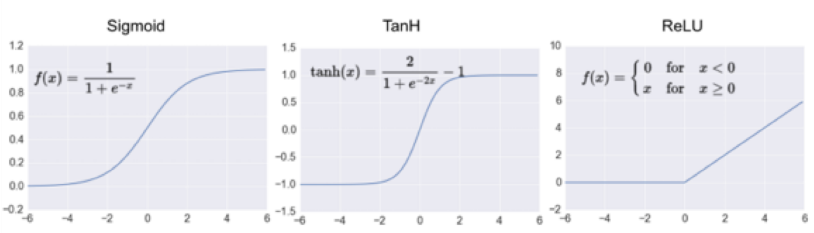


Deep Neural Networks

$$x = a^{[0]} \qquad\qquad a^{[\ell]} = g^{[\ell]}(W^{[\ell]}a^{[\ell-1]} + b^{[\ell]})$$

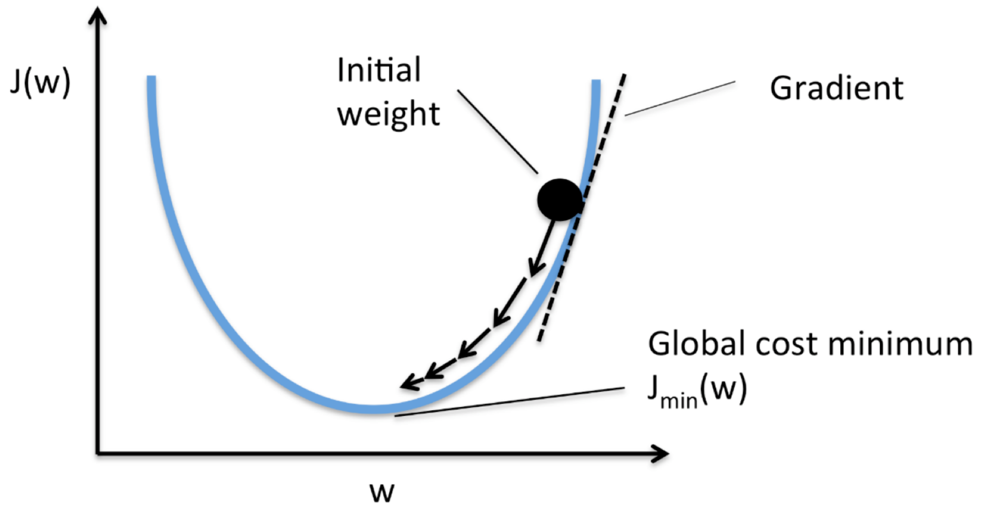


$$g(z) =$$



How do we learn?

- Start with randomly initialized parameters
- Compute output of network
- Use cost function to evaluate model performance
- Compute ***gradients*** of cost function via ***back propagation***
- Use ***stochastic gradient descent*** to update model parameters
- Deep learning libraries implement this training step for you!



$$w \Rightarrow w - \lambda \nabla J(w)$$

Deep Neural Networks Simple Keras Code

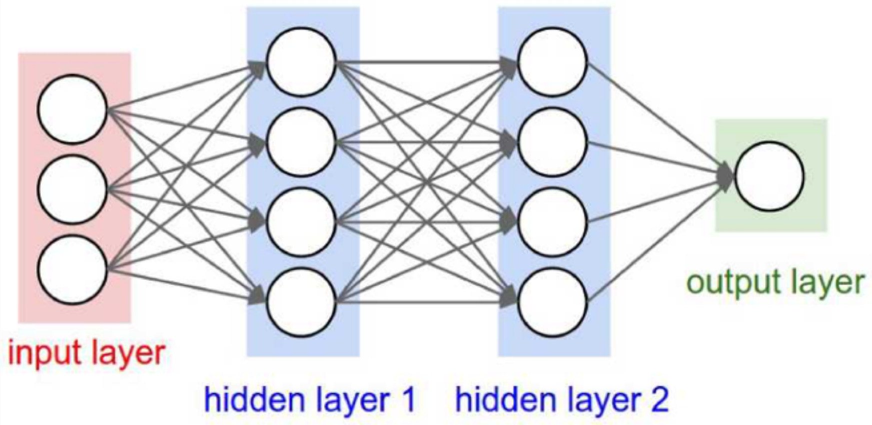
- With modern DL frameworks, most neural nets can be coded in <~ 100 lines

```
# create model
model = Sequential()
layer_sizes = [64, 128, 512, 512, 128, 64]
model.add(Dense(layer_sizes[0], input_dim=64, activation='relu'))
for ls in layer_sizes[1:]:
    model.add(Dense(ls, activation='relu'))
model.add(Dense(1, activation='sigmoid'))

# Compile model
model.compile(loss='binary_crossentropy', optimizer='adam', metrics=['accuracy'])

# Fit the model
model.fit(X, Y)
```

- Will work on CPU or GPU with no change to code!

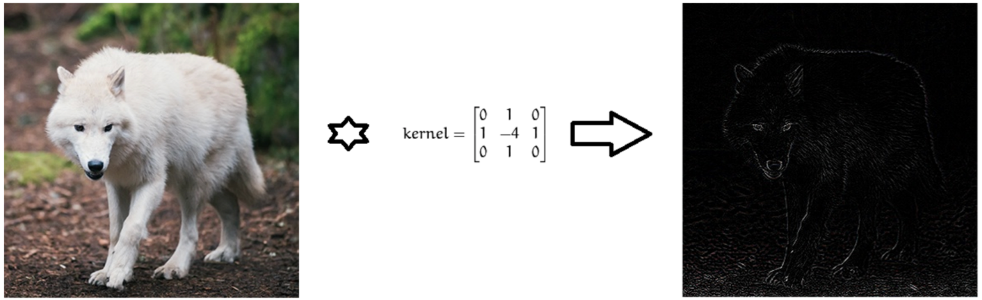
Can we use fully connected networks for images?

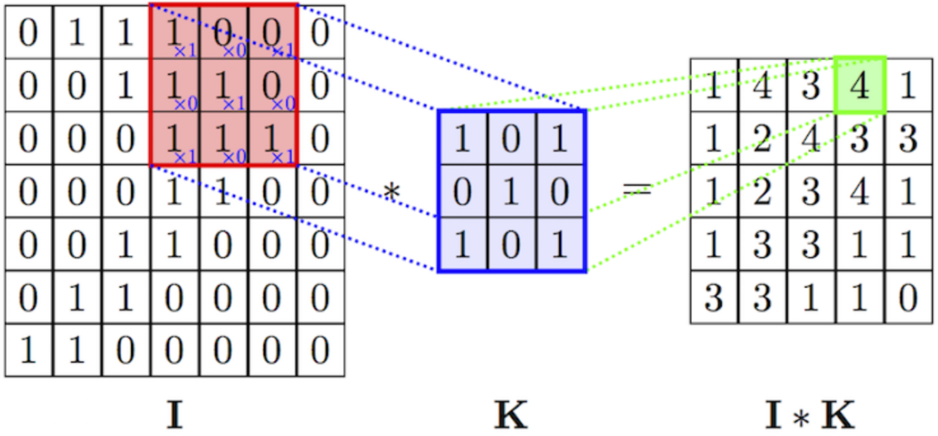
- Say image is 224 x 224 x 3 (RGB).
- Unroll to feature vector of size 150528
- For just the first hidden layer with 100 nodes we have over 15 million parameters. Not good



Convolutions

- Convolution operator applies a “filter” or “kernel” to an input image
- Kernels can be designed to pull out features of images, edges, colors, shapes, etc
- **Very important**: The number of free parameters does not depend on the image size





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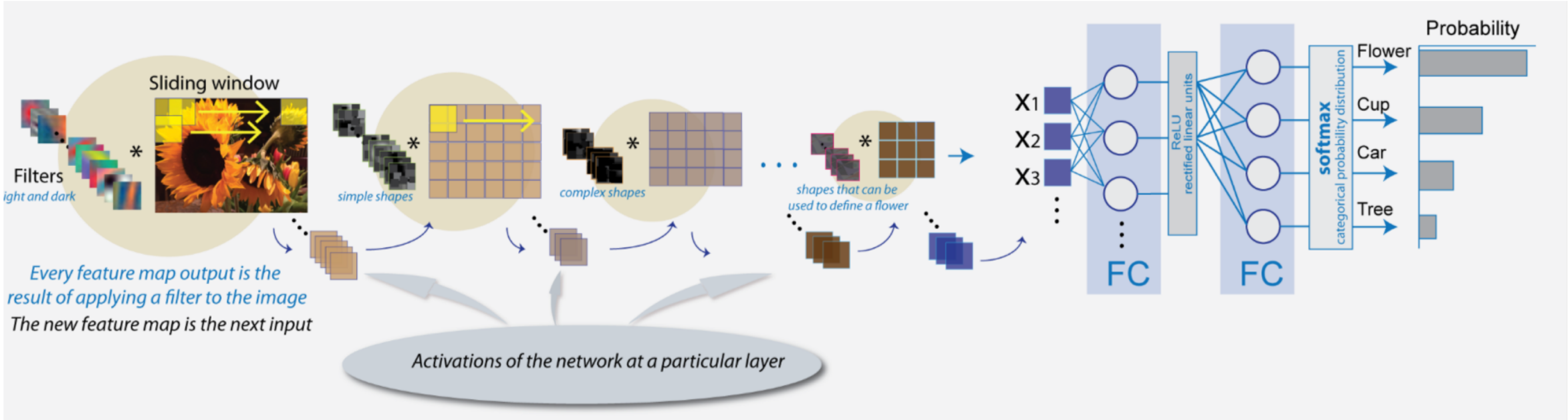
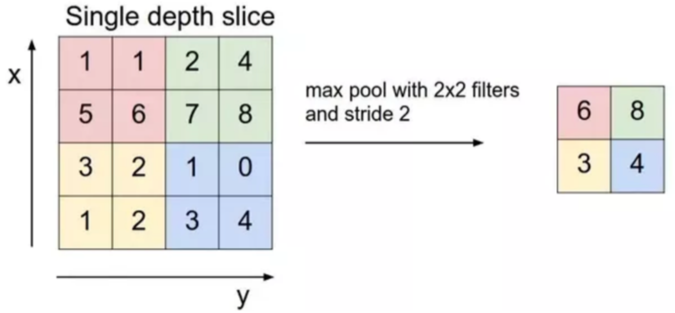
Convolutional Neural Networks (CNNs)

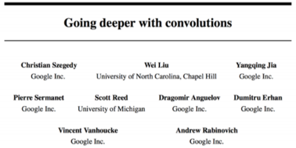


- Most CNNs have a pattern of some number of CONV layers followed by a POOL layer, ending in a FC layer



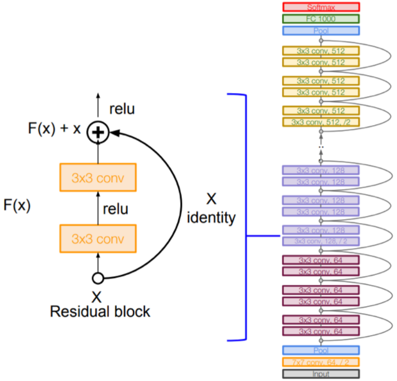
CNN Architecture

ZOO

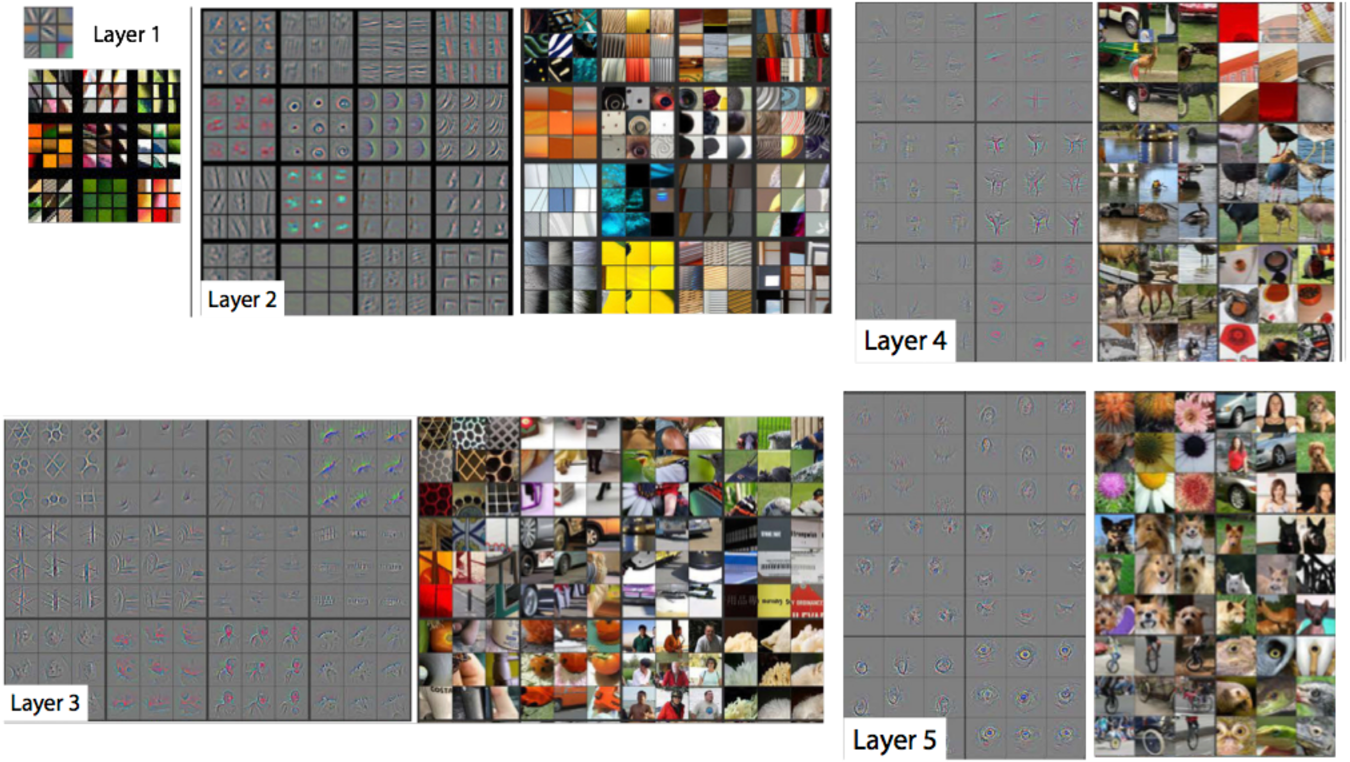


Going deeper with convolutions

Christian Szegedy
Google Inc.
Wei Liu
University of North Carolina, Chapel Hill
Yangqing Jia
Google Inc.
Pierre Sermanet
Google Inc.
Scott Reed
University of Michigan
Dragomir Anguelov
Google Inc.
Dumitru Erhan
Google Inc.
Vincent Vanhoucke
Google Inc.
Andrew Rabinovich
Google Inc.



What Does a CNN "see"



Zeiler & Fergus 2013, Visualizing and understanding convolutional networks

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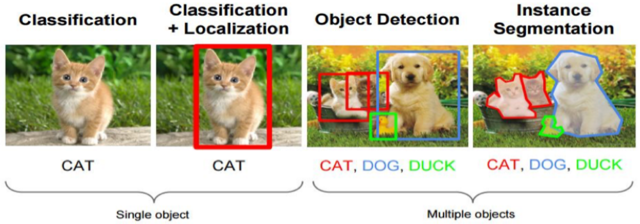
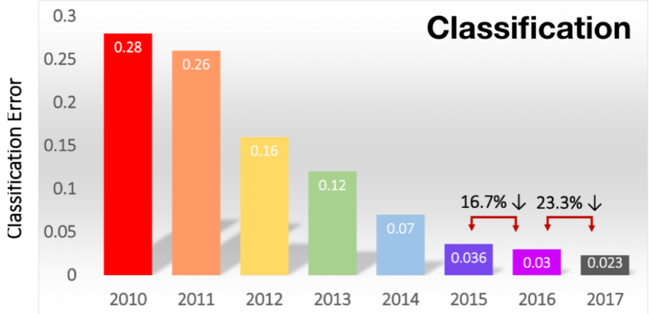
Computer Vision Tasks

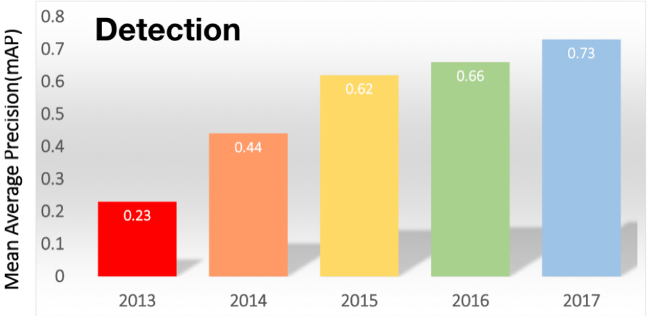
"the automatic extraction, analysis and understanding of useful information from a single image or a sequence of images."

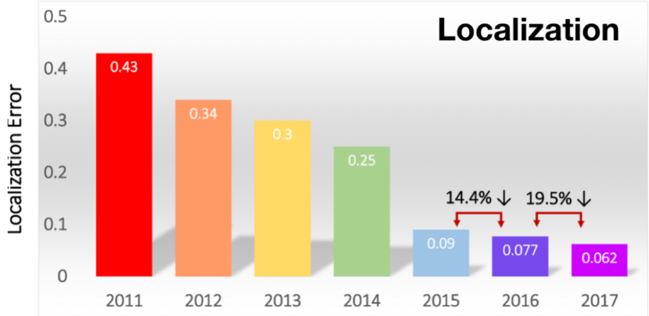
\- British Machine Vision Association



Source: Fei-Fei Li, Andrej Karpathy & Justin Johnson (2016) cs231n, Lecture 8 - Slide 8, *Spatial Localization and Detection* (01/02/2016). Available: http://cs231n.stanford.edu/slides/2016/winter1516_lecture8.pdf







Note: precision = True Positives / Predicted Positives

Source: http://image-net.org/challenges/talks_2017/ILSVRC2017_overview.pdf

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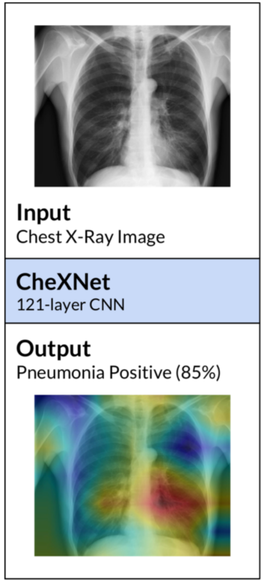
Medical Image Classification

- Can detect Pneumonia in chest X-rays with human level performance
- Model uses CNN pre-trained on ImageNet and replaces last layer with binary classifier
- Can also detect up to 13 other diseases from X-ray images
- Provides great opportunity to reduce health care costs and to help medical professionals in developing countries

CheXNet: Radiologist-Level Pneumonia Detection on Chest X-Rays with Deep Learning

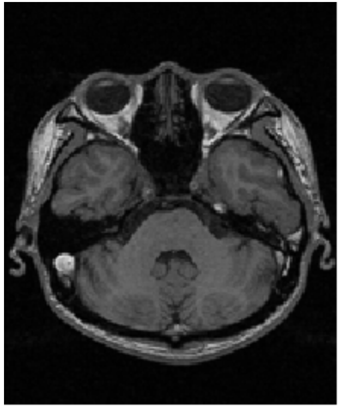
Pranav Rajpurkar[*1] Jeremy Irvin[*1] Kaylie Zhu[1] Brandon Yang[1] Hershel Mehta[1]
Tony Duan[1] Daisy Ding[1] Aarti Bagul[1] Robyn L. Ball[2] Curtis Langlotz[3] Katie Shpanskaya[3]
Matthew P. Lungren[3] Andrew Y. Ng[1]

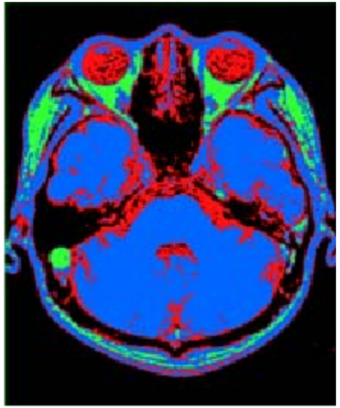
	F1 Score (95% CI)
Radiologist 1	0.383 (0.309, 0.453)
Radiologist 2	0.356 (0.282, 0.428)
Radiologist 3	0.365 (0.291, 0.435)
Radiologist 4	0.442 (0.390, 0.492)
Radiologist Avg.	0.387 (0.330, 0.442)
CheXNet	0.435 (0.387, 0.481)

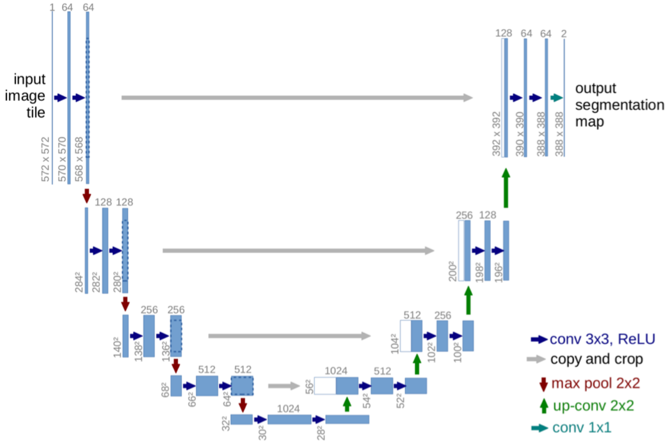


Medical Image Segmentation

- **Goal:** Input 2D (or 3D) medical image and output binary or multi-class map of desired segmentations (organs, abnormal areas, blood vessels, etc)
- **Solution:** Encode image via CNN and decode via up-sampling and convolutional operators







Object Detection

But maybe a better question is: "What are we going to do with these detectors now that we have them?" A lot of the people doing this research are at Google and Facebook. I guess at least we know the technology is in good hands and definitely won't be used to harvest your personal information and sell it to.... wait, you're saying that's exactly what it will be used for?? Oh.

Well the other people heavily funding vision research are the military and they've never done anything horrible like killing lots of people with new technology oh wait.....[1]

I have a lot of hope that most of the people using computer vision are just doing happy, good stuff with it, like counting the number of zebras in a national park [13], or tracking their cat as it wanders around their house [19]. But computer vision is already being put to questionable use and as researchers we have a responsibility to at least consider the harm our work might be doing and think of ways to mitigate it. We owe the world that much.

In closing, do not @ me. (Because I finally quit Twitter).

So, how does on "do" Deep Learning

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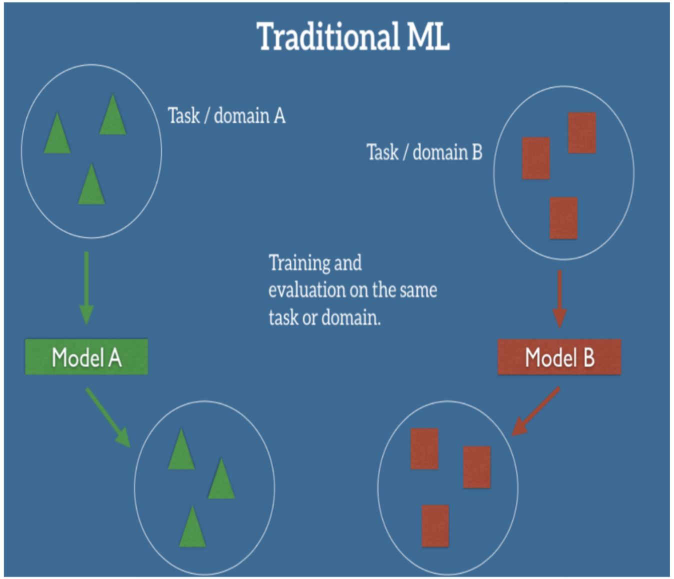
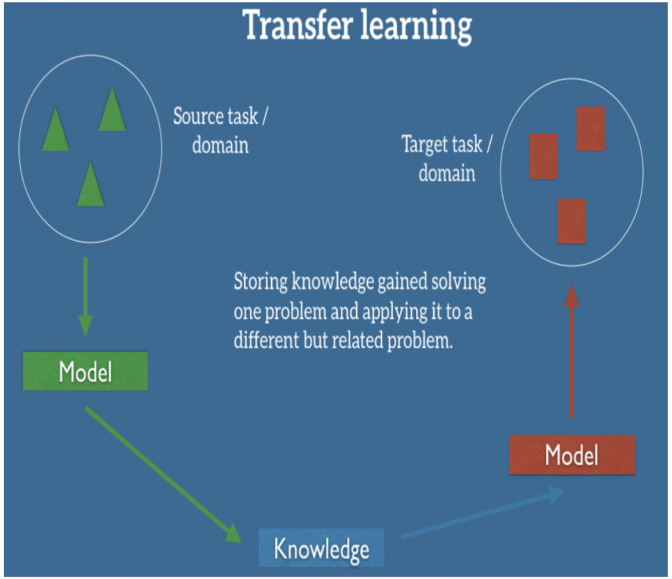
Transfer Learning

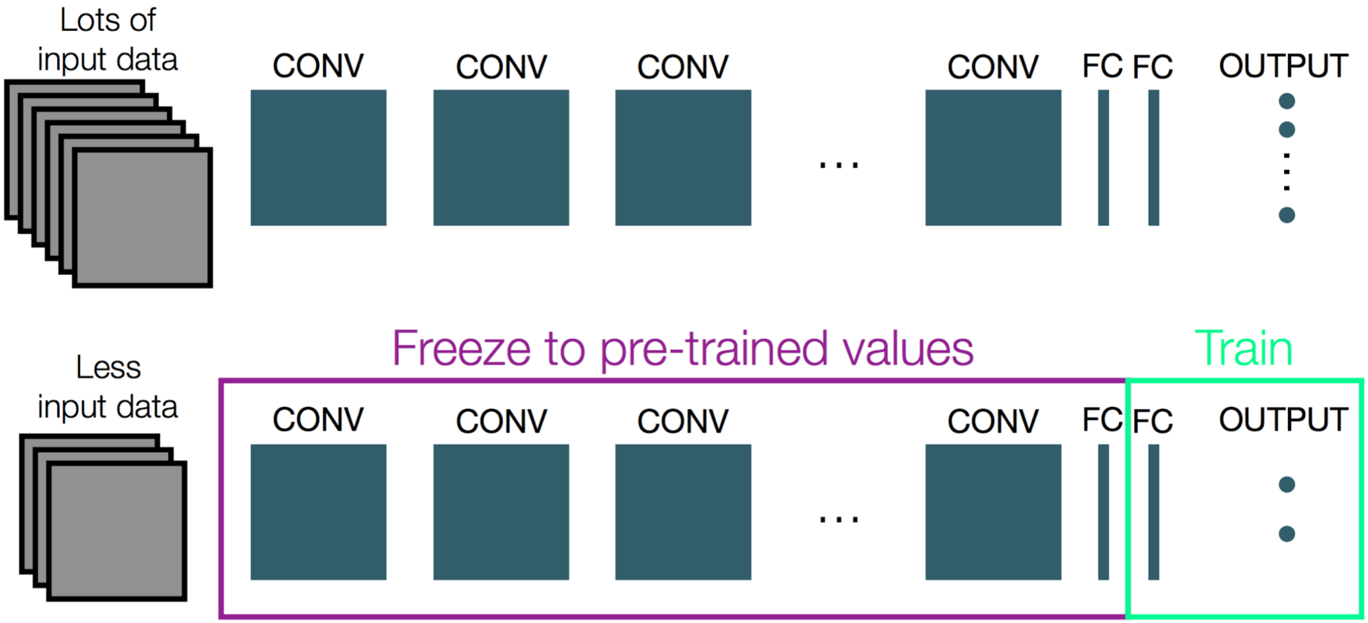
- Use “knowledge” from pre-trained network and “fine-tune” to new task





Transfer Learning in Computer Vision

- First train data on large available data set (i.e. imagnet) or better yet, download the pre-trained weights for a specific CNN architecture



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State of the Art in One Slide

```
# Pre-trained ResNet 50 models with last softmax dense layer removed
base_model = ResNet50(weights='imagenet', include_top=False)

# add Dense layer and sigmoid output layer
x = base_model.output
x = GlobalAveragePooling2D()(x)
x = Dense(1024, activation='relu')(x)
predictions = Dense(1, activation='sigmoid')(x)

# freeze convolution weights and compile model with cross-entropy loss for cat/dog
model = Model(inputs=base_model.input, outputs=predictions)
for layer in base_model.layers: layer.trainable = False
optim = adam(lr=1e-4, decay=1e-6)
model.compile(optimizer=optim, loss='binary_crossentropy', metrics=['accuracy'])

# Run pre-trained model for a few epochs
history = LossHistory()
model.fit_generator(train_generator, train_generator.n // batch_size, epochs=3, workers=4,
                    validation_data=validation_generator,
                    validation_steps=validation_generator.n // batch_size)
```

```
# re-train last convolutional layer
split_at = 157
for layer in model.layers[:split_at]: layer.trainable = False
for layer in model.layers[split_at:]: layer.trainable = True
model.compile(optimizer=optim, loss='binary_crossentropy', metrics=['accuracy'])
```

```
# fit for one epoch
model.fit_generator(train_generator, train_generator.n // batch_size, epochs=1, workers=3,
                    validation_data=validation_generator,
                    validation_steps=validation_generator.n // batch_size)
```

```
Epoch 1/1
359/359 [==============================] - 223s 620ms/step - loss: 0.0617 - acc: 0.9781 - val_loss: 0.0416 - val_acc:
0.9864
```

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Summary

- Deep learning is an experimental science
- Deep learning is not a complete black box and can be interpretable
- Deep learning results are state of the art in computer vision and NLP but are infringing on more traditional methods for sales and structured data
- Deep learning methods are able to perform at human level performance on some medical imaging tasks and offer huge opportunities for applications in developing countries
- Many large companies (Pinterest, Amazon, Google, Facebook,) are using deep learning for product recommendation