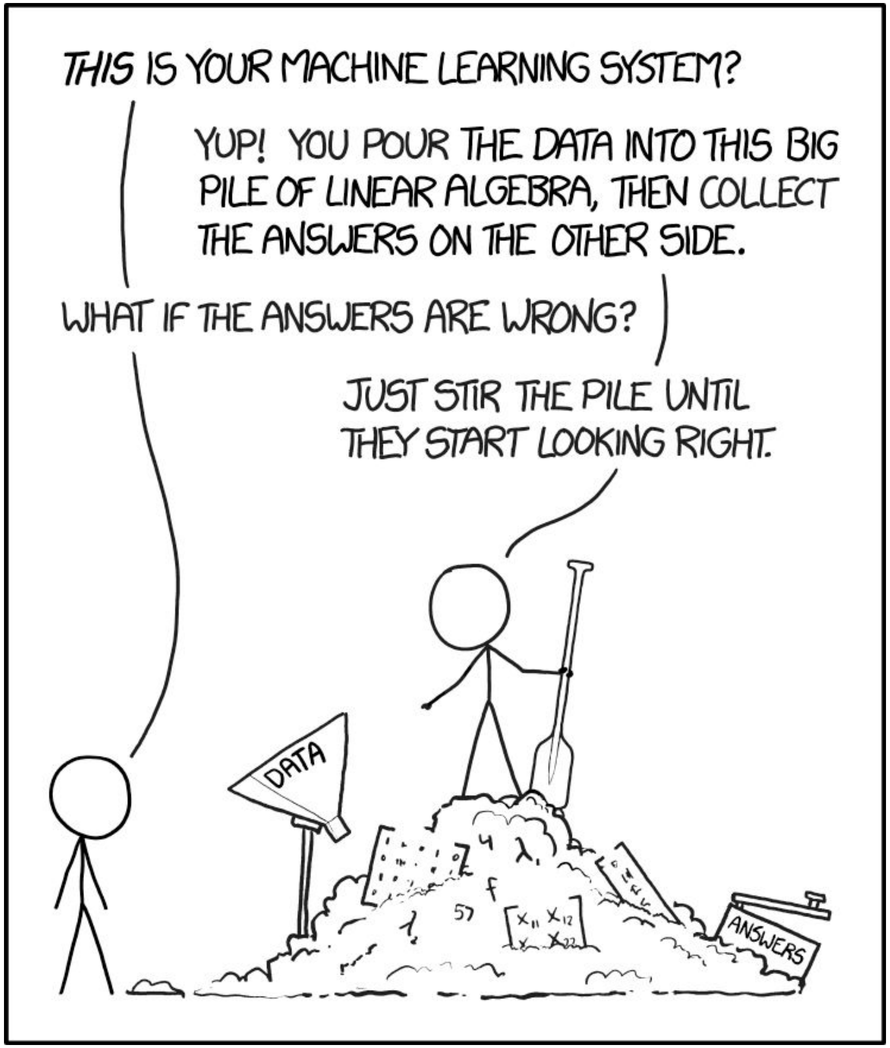
Neural Networks and Deep Learning for Space Physics



Source: xkcd

Asti Bhatt

CEDAR 2019 Tutorial

Neural Networks

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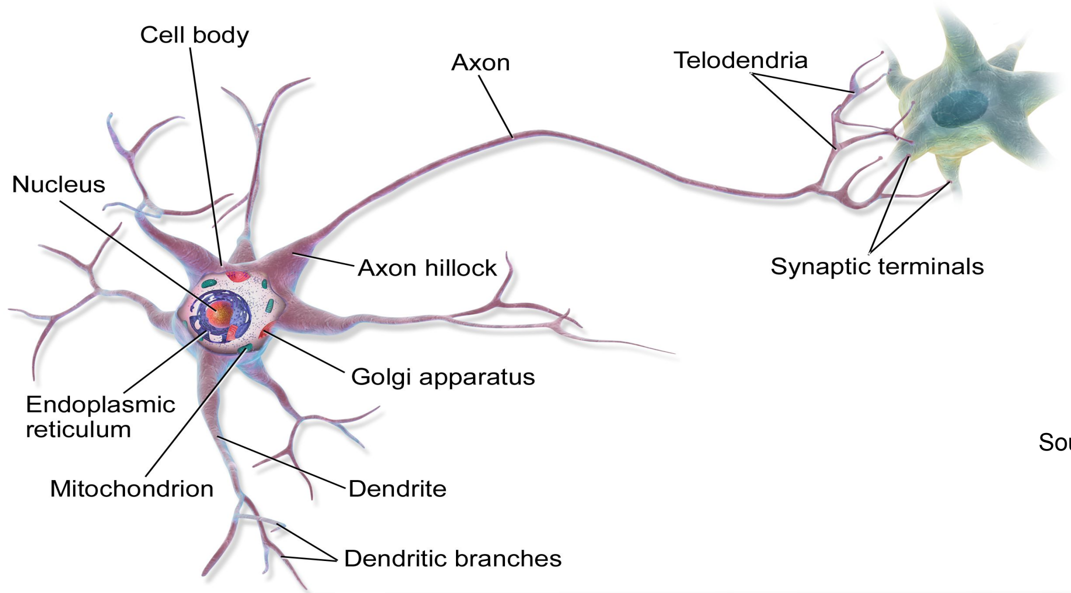
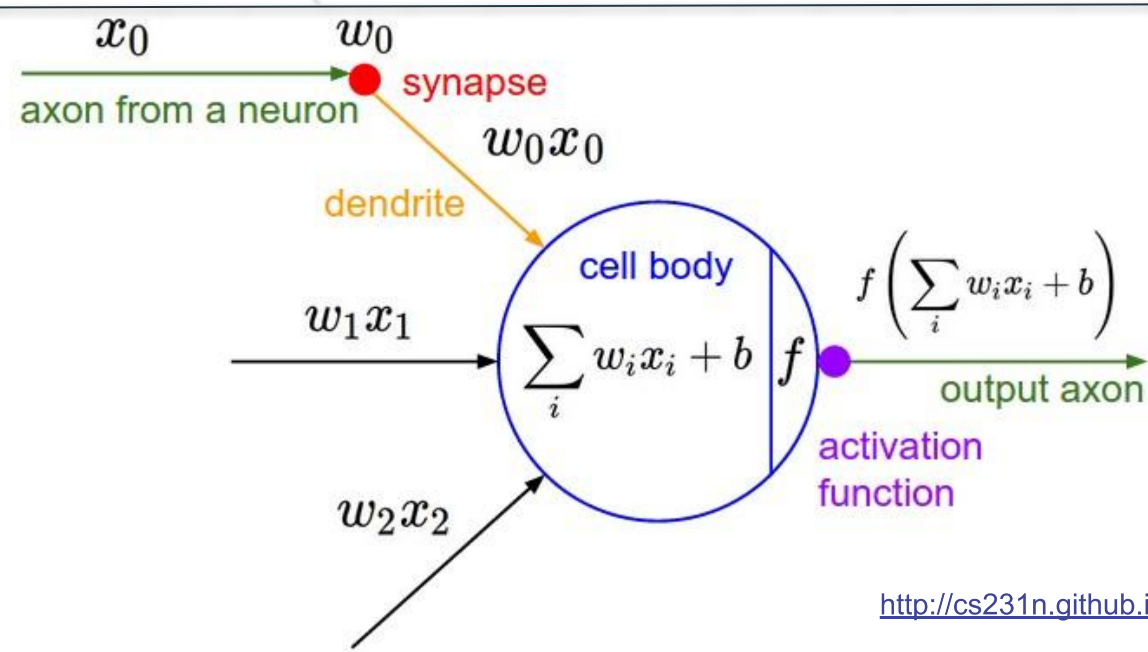
How does a neuron operate?

Biological →



Source:Wikipedia

Artificial →

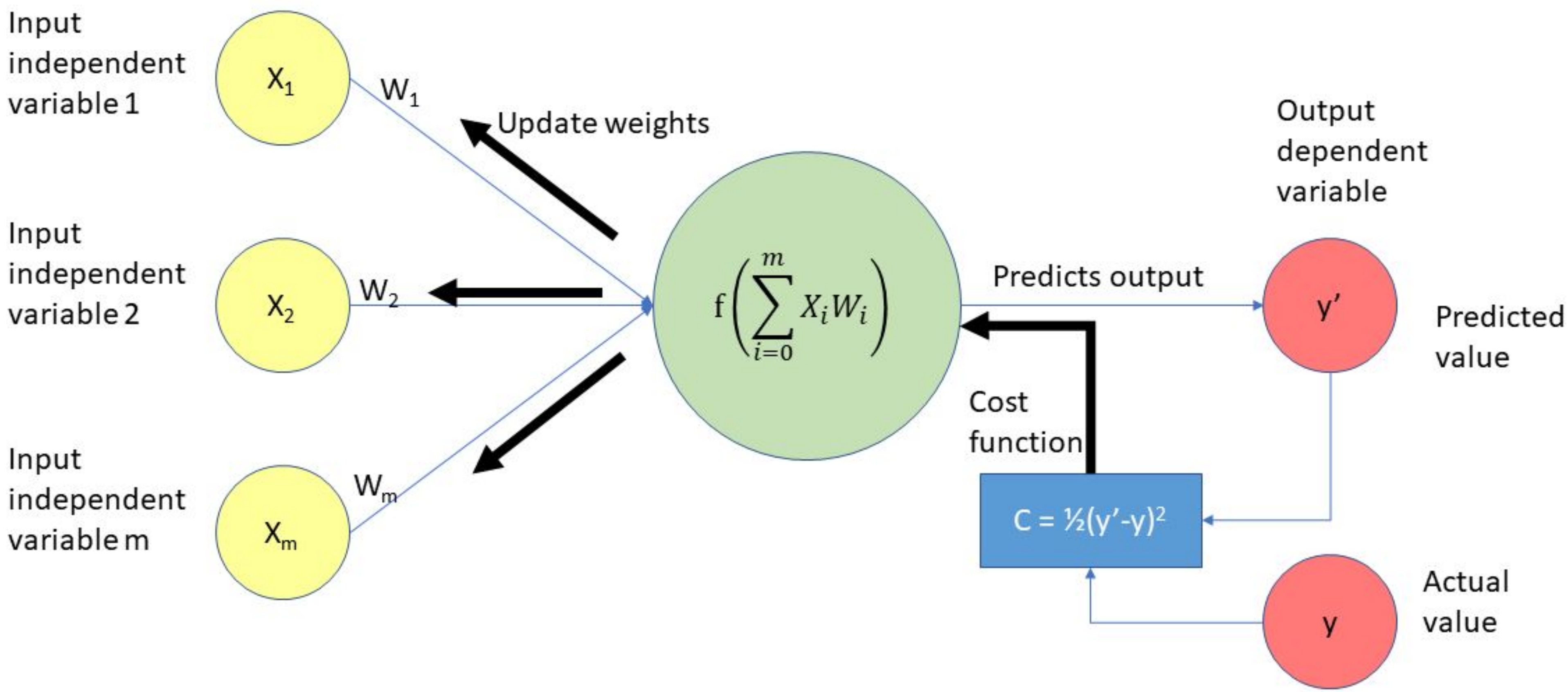


http://cs231n.github.io/neural-networks-1/

A brief history of neural networks

- In 1943, neurophysicist Warren McCulloch and the mathematician Walter Pitts proposed a simplified computational model of how biological neurons might work, but their model lacked a mechanism for learning
- In 1949, Donald Hebb published ‘Cells that fire together, wire together’
- In 1960, Frank Rosenblatt developed a ‘Perceptron’ - a simple neural network with a linear activation function - capable of classifying shapes
- Between 1960’s to 1980’s there were ups and downs in usage
- In recent times, the increase in computational power and data infrastructure has made it possible to use neural networks to their potential

How does a neural network learn?

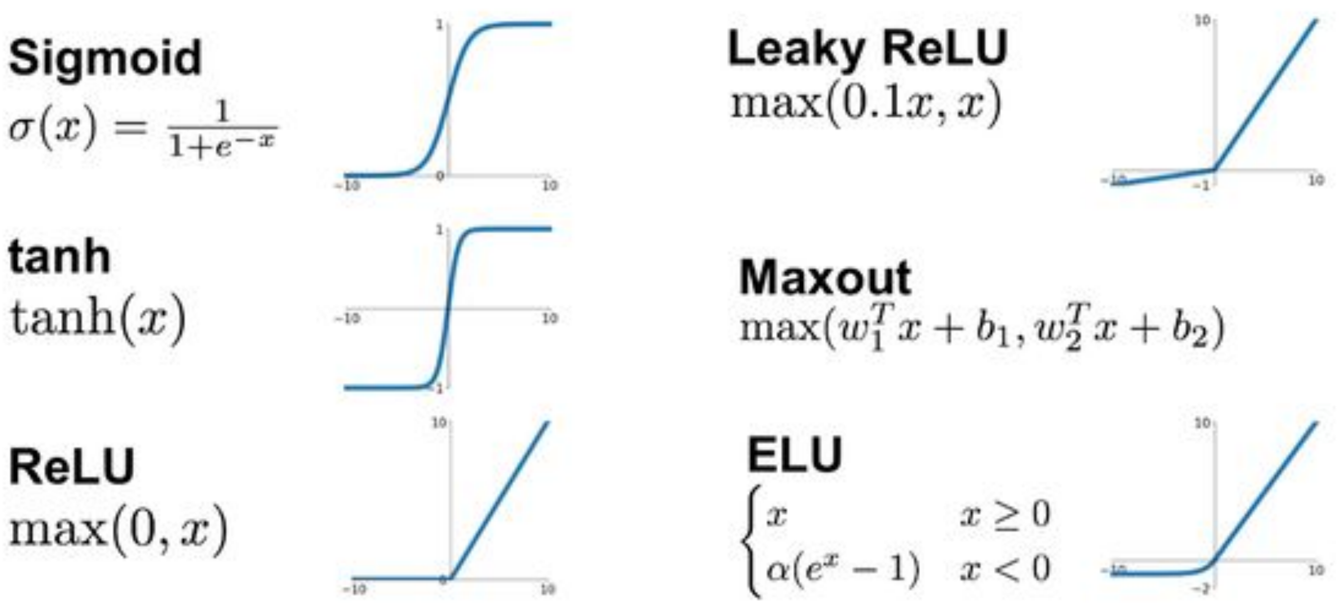


The goal is to minimize the cost function

http://www.thejavageek.com/2018/04/17/how-do-neural-networks-learn/

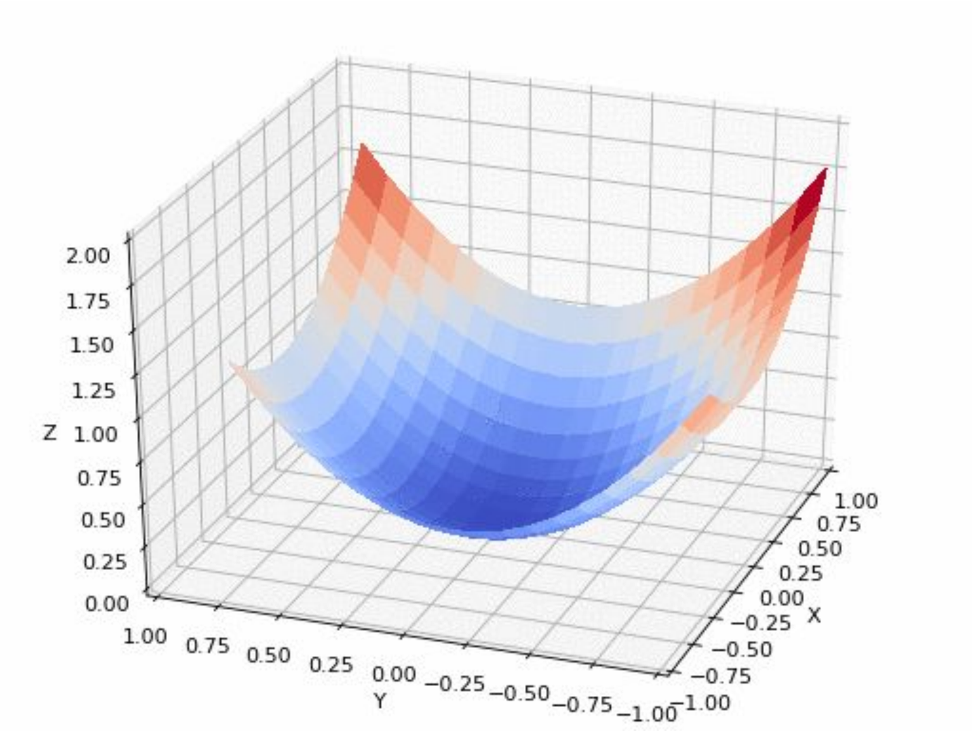
Activation functions

- Also known as ‘transfer function’ - calculates the weighted sum, and decides whether to ‘fire’ a neuron or not.
- Most common example - a step function.
- Non-linear activation functions help solve complex problems



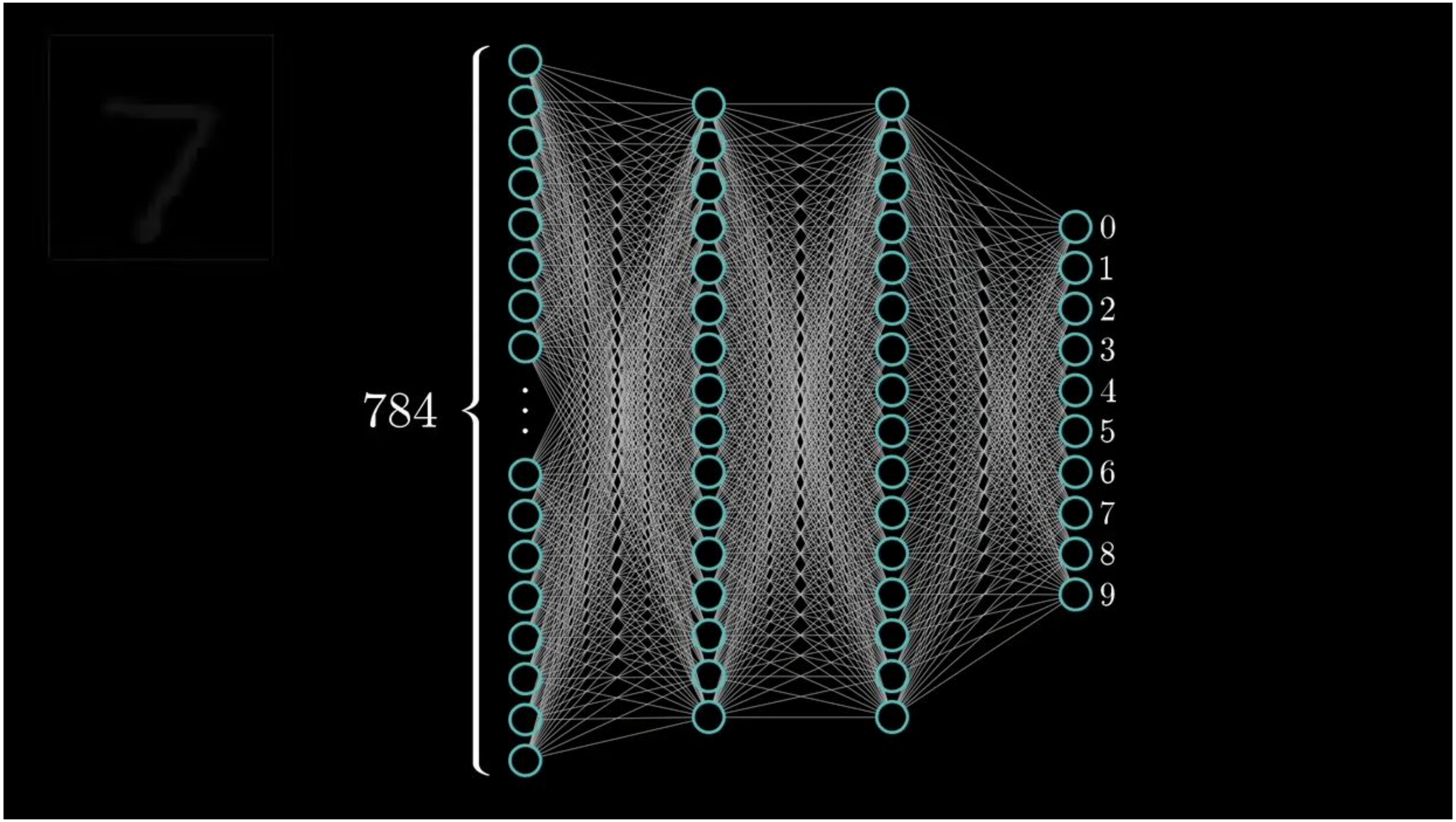
Cost function minimization

Most commonly used technique - **Gradient descent** is an optimization algorithm used to minimize some function by iteratively moving in the direction of steepest **descent** as defined by the negative of the **gradient**.



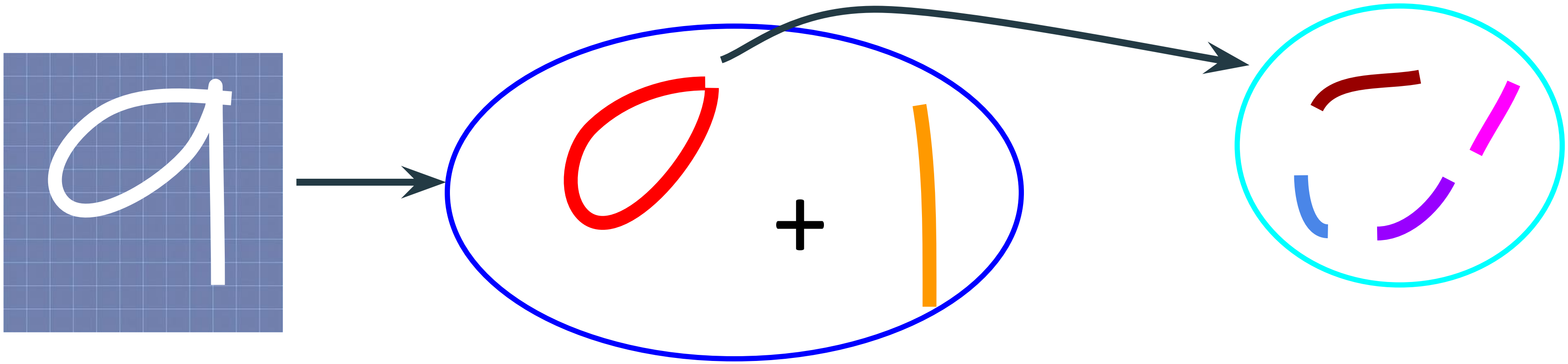
https://blog.paperspace.com/intro-to-optimization-in-deep-learning-gradient-descent/

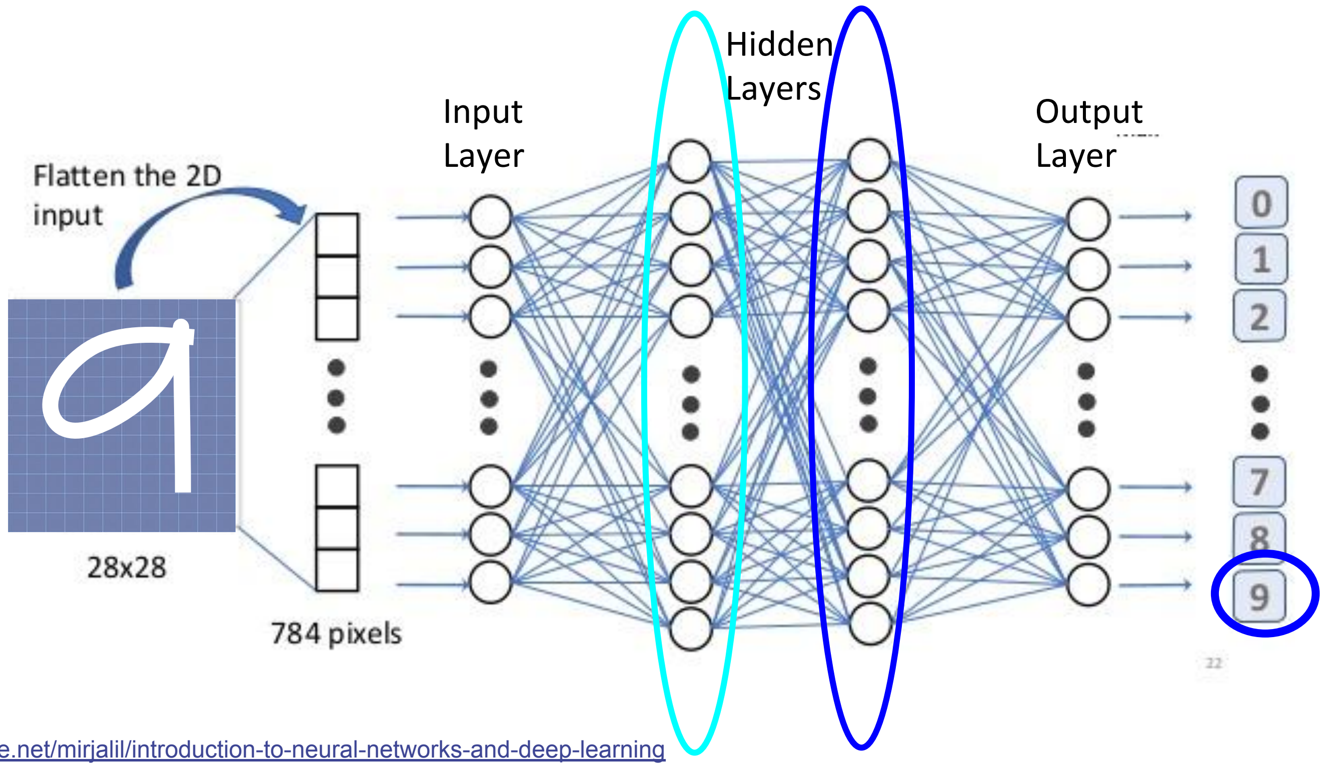
Supervised learning



https://www.youtube.com/watch?v=aircAruvnKk

How does a neural network 'recognize' a pattern?



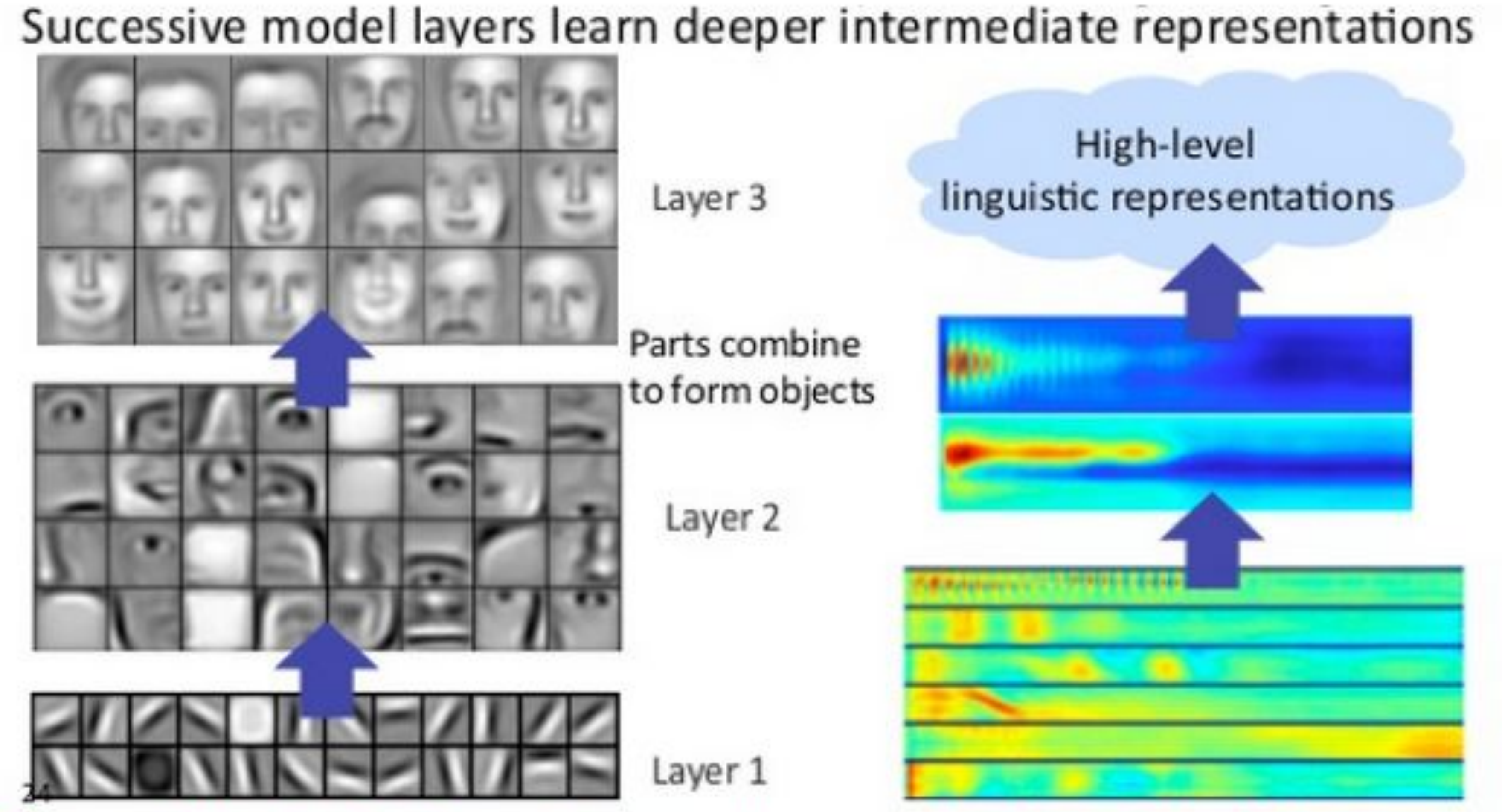


https://www.slideshare.net/mirjalil/introduction-to-neural-networks-and-deep-learning

Deep Learning

- The higher the number of ‘hidden’ layers, the ‘deeper’ the network goes.
- A neural net with two or more hidden layers is qualified as ‘deep’
- Each layer in a ‘deep’ network trains on a distinct set of features based on the output from previous layer
- Deeper the net, more complex are the features it can recognize

Deep Learning Examples



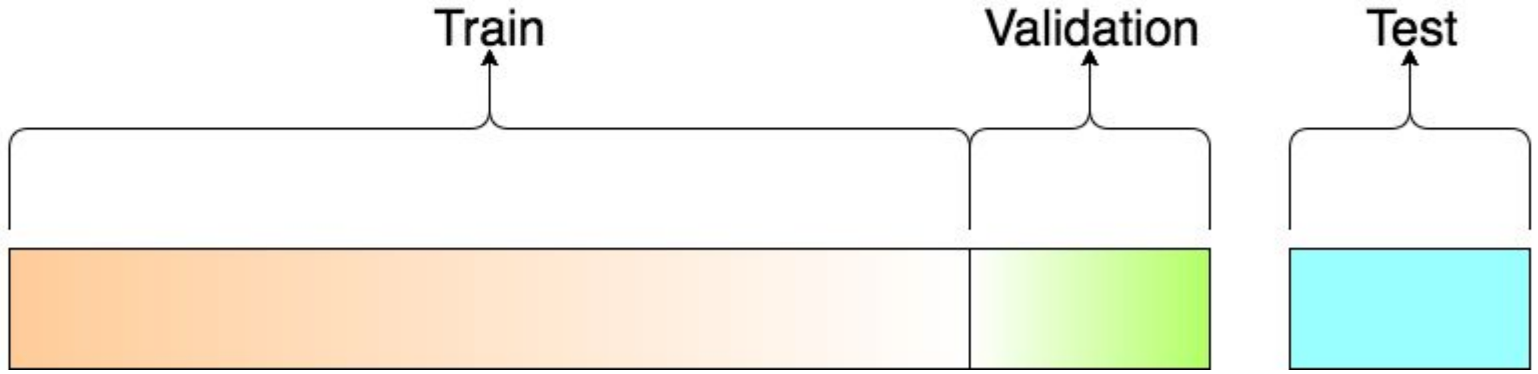
https://skymind.ai/wiki/neural-network

Training, Validation, Testing Neural Nets

Training Dataset: The sample of data used to fit the model. (*Largest*)

Validation Dataset: The sample of data used to provide an unbiased evaluation of a model fit on the training dataset while tuning model hyperparameters. The evaluation becomes more biased as skill on the validation dataset is incorporated into the model configuration.

Test Dataset: The sample of data used to provide an unbiased evaluation of a final model fit on the training dataset. (*Something that the model has never seen*)



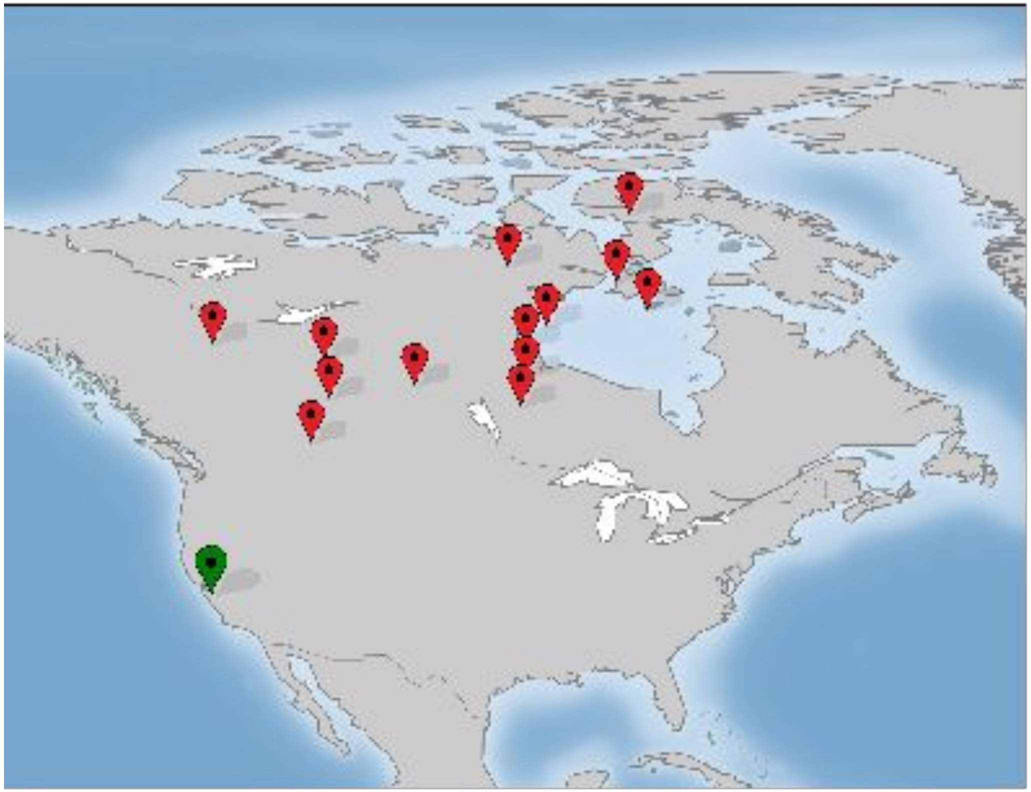
https://towardsdatascience.com/train-validation-and-test-sets-72cb40cba9e7

Commonly used Neural Networks

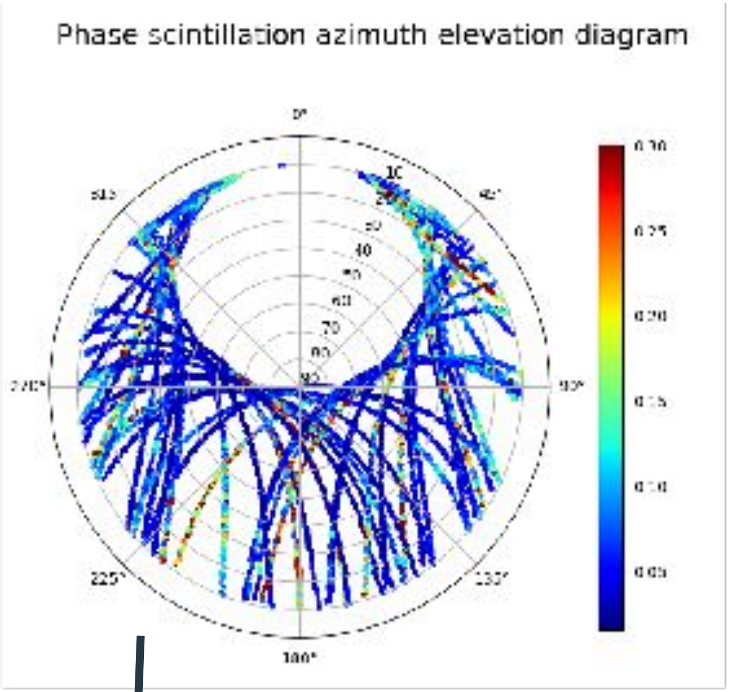
- Feed forward - Multilayer Perceptron (MLP)
- Convolutional Neural Networks (CNN): Commonly used for image analysis
- Recurrent Neural Networks (RNN): Commonly used for temporal sequence analysis

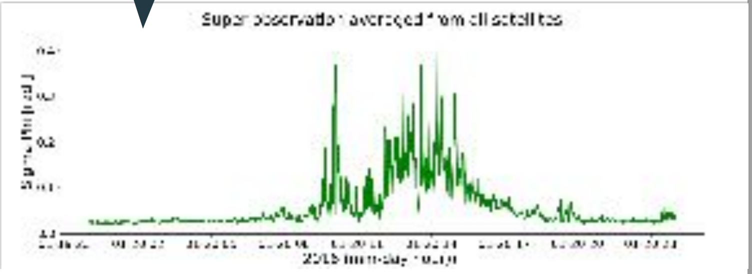
Applications in space science: GPS Scintillation Prediction

DATA



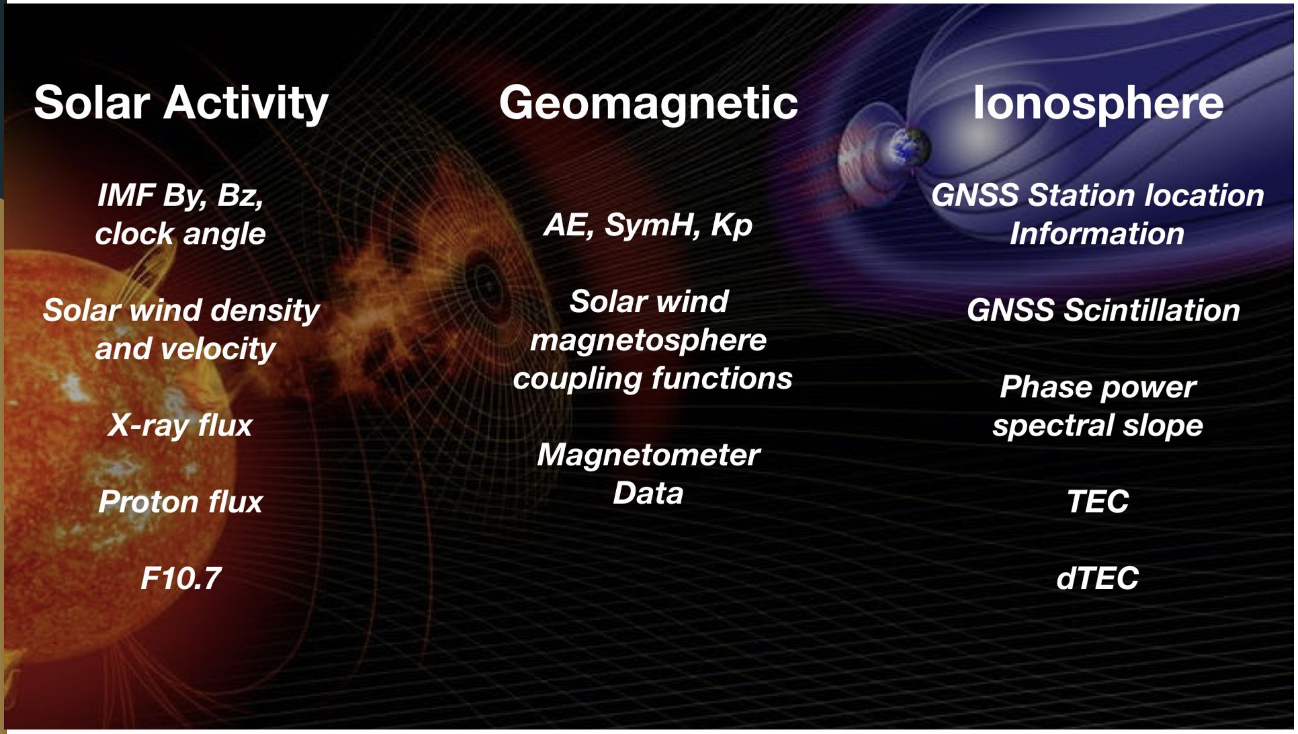
Canadian High Arctic Ionospheric Network (CHAIN)





Applications in space science: GPS Scintillation Prediction

Building a predictive model GNSS scintillations using inputs from solar activity, magnetospheric coupling and ionosphere



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41 Input features

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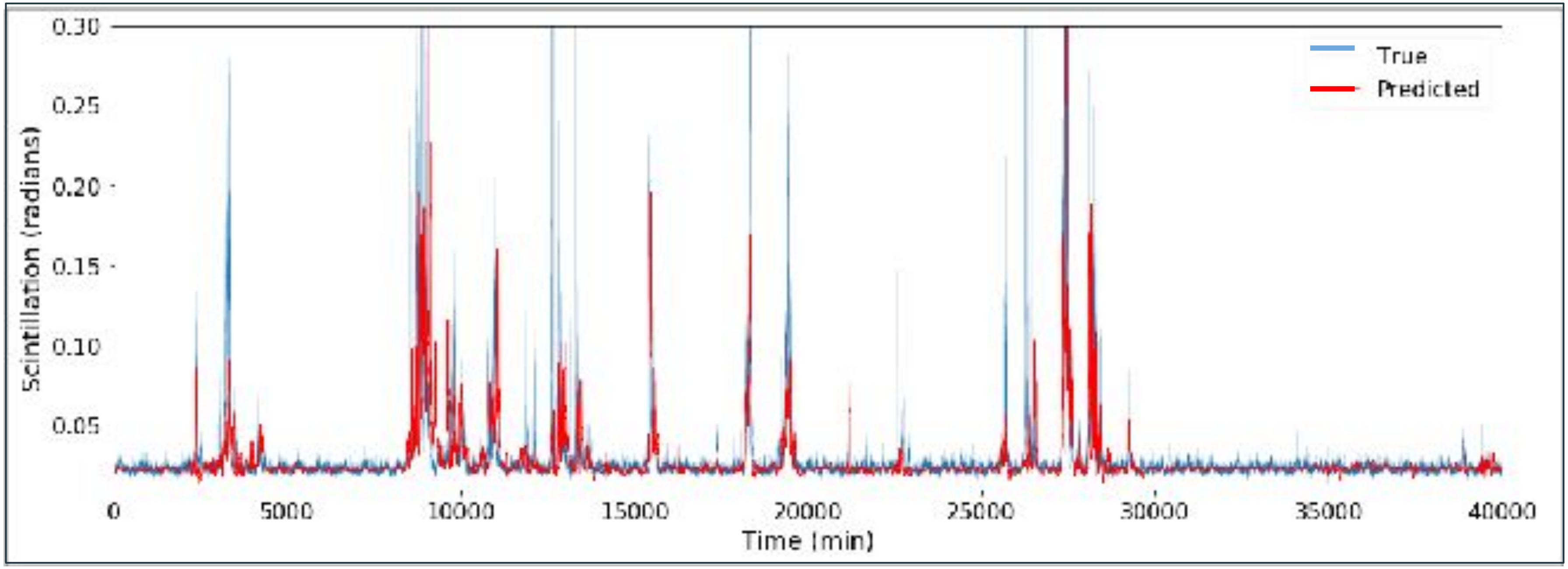
Predicted Scintillation

Applications in space science: GPS Scintillation Prediction

- **Training data**: 2015-2016 | Test on: 2017
- **Model**: Multilayer perceptron - 4 hidden layers and 128 nodes in each layer
- **Activation function**: Exponential Linear Unit (ELU)
- **Optimizer**: Adam (extension of gradient descent)



Applications in space science: GPS Scintillation Prediction

- 96% True results over all predicted results (‘Recall’)
- Localized model performed much better than a model developed for all sites together - Why?
- Adding co-located magnetometer data improved the prediction accuracy - Why?

So, should you use Deep Learning?

Advantages

- Massive amounts of data available
- Computational power to match the available massive amounts of data
- Advances in algorithms that make them much faster to run and access more data than before
- Ability to outperform nearly every other ML algorithms

Disadvantages

- Black Box - what are underlying rules that gave you the output you did
- While libraries with simplified functions exist, more complex challenges require longer development and resources
- Your neural network is only as good as your training data - requires massive amount to train properly
- More computationally expensive

Tools to explore deep learning

Deep Learning for Computer Vision.ipynb

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CODE TEXT CELL CELL CONNECT EDITING

Deep Learning for Computer Vision

This chapter introduces convolutionval neural networks.

```
[ ] :om keras import layers
    :om keras import models

    ›del = models.Sequential()
    ›del.add(layers.Conv2D(32, (3, 3), activation='relu', input_shape=(28, 28
    ›del.add(layers.MaxPooling2D((2, 2)))
    ›del.add(layers.Conv2D(64, (3, 3), activation='relu'))
    ›del.add(layers.MaxPooling2D((2, 2)))
    ›del.add(layers.Conv2D(64, (3, 3), activation='relu'))
```

A convnet is a stack of `Conv2D` and `MaxPooling2D` layers. A convnet takes as input tensors of shape `(image_hight, image_width, image_channels)`.

```
[ ] model.summary()
```

Opportunities that combine Space Physics and Machine Learning

What to do next?

- Go through CEDAR and identify long standing questions with enough relevant data, where ML approaches can be used
- Take a statistics course at your university
- Look up simple web-based ML tutorials
- Learn Python - play with canned tutorials on tools like Google Colab - or install Scikit-Learn on your machine
- Familiarize yourselves with geospace Python tools that help you access data - attend sessions and hackathons planned during CEDAR -
    - Python session and Hackathon on Monday
    - Integrated Geoscience Observatory workshop on Wednesday
    - Geospace Data Science on Thursday

Additional Resources

- Hands-On Machine Learning with Scikit-Learn & TensorFlow - O'reilly book by Aurelien Geron
- http://www.scs.ryerson.ca/~aharley/neural-networks/

- Coursera Course on Machine Learning by Andrew Ng