Recurrent Neural Networks

Deep Learning

- We’ve used Neural Networks to solve Classification and Regression problems, but we still haven’t seen how Neural Networks can deal with sequence information.
- For this we use Recurrent Neural Networks

Deep Learning

- RNN Theory
- Basic Manual RNN
- Vanishing Gradients
- LSTM and GRU Units
- Time Series with RNN
- Time Series Exercise / Solutions
- Word2Vec

Let’s get started!

Recurrent Neural Networks Theory

Deep Learning

- Examples of Sequences
  - Time Series Data (Sales)
  - Sentences
  - Audio
  - Car Trajectories
  - Music

Deep Learning

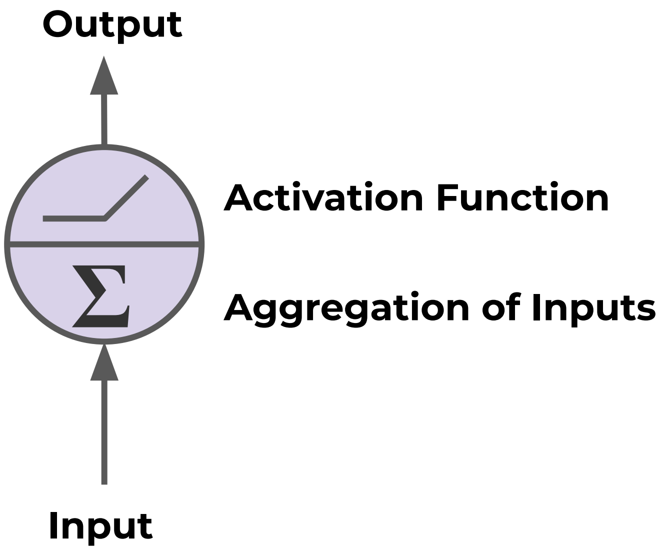
- Let’s imagine a sequence:
    - [1,2,3,4,5,6]
- Would you be able to predict a similar sequence shifted one time step into the future?
    - [2,3,4,5,6,7]

Deep Learning

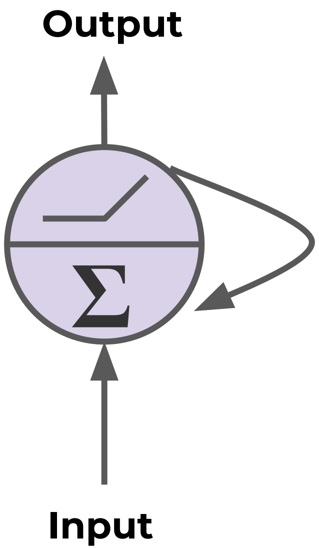
- Let’s imagine a sequence:
    - [1,2,3,4,5,6]
- Would you be able to predict a similar sequence shifted one time step into the future?
    - [2,3,4,5,6,7]

Deep Learning

- Normal Neuron in Feed Forward Network

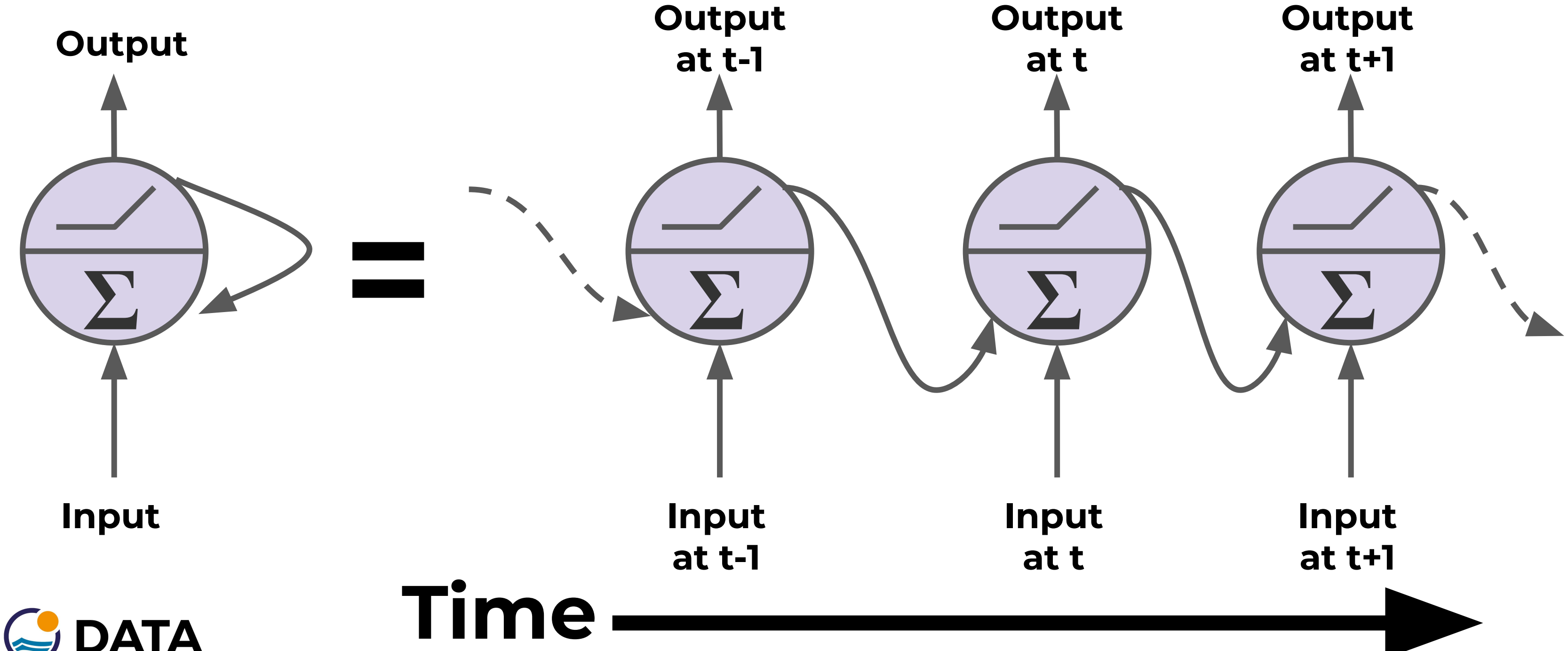


- Recurrent Neuron
  - Sends output back to itself!
  - Let's see what this looks like over time!



Deep Learning

- Recurrent Neuron



Deep Learning

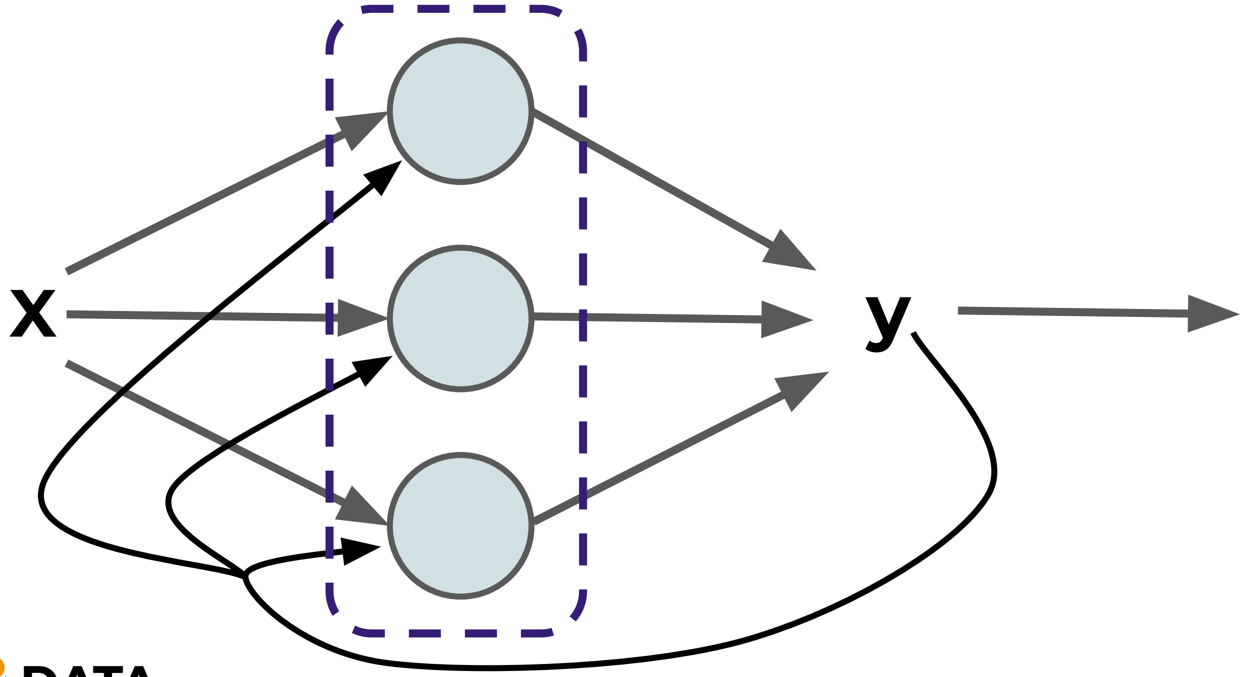
- Cells that are a function of inputs from previous time steps are also known as *memory cells.*
- RNN are also flexible in their inputs and outputs, for both sequences and single vector values.

Deep Learning

- We can also create entire layers of Recurrent Neurons...

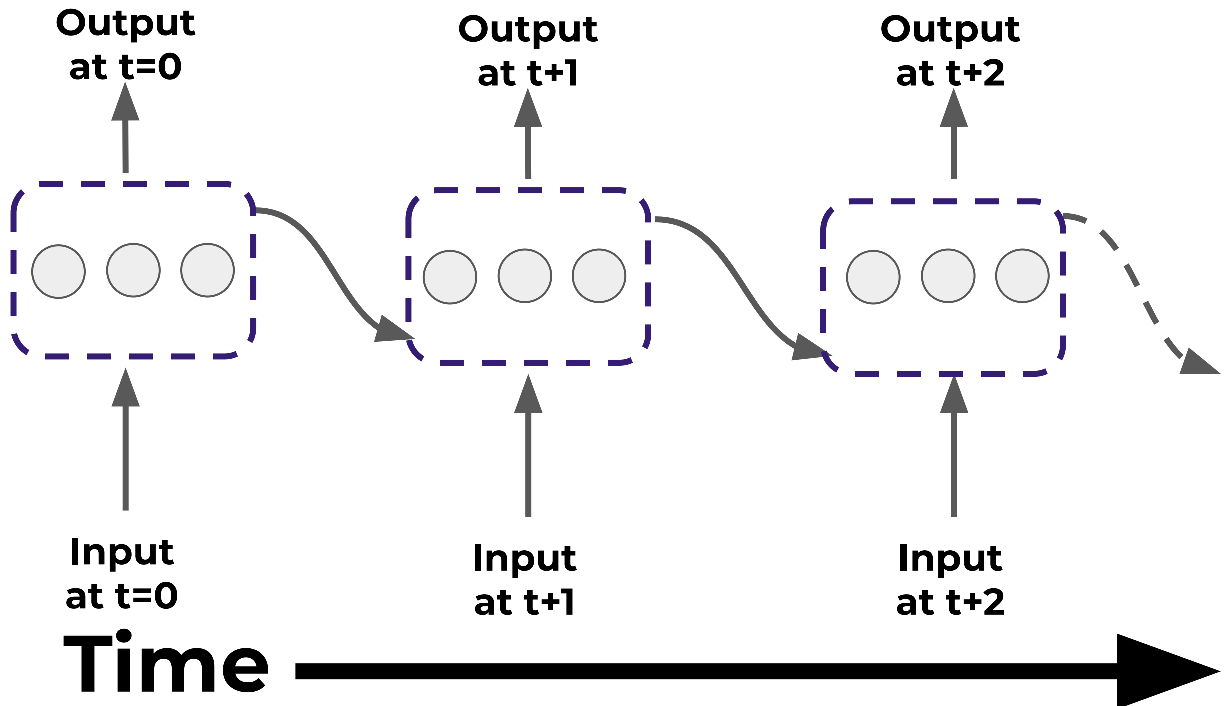
Deep Learning

- RNN Layer with 3 Neurons:



Deep Learning

- "Unrolled" layer.

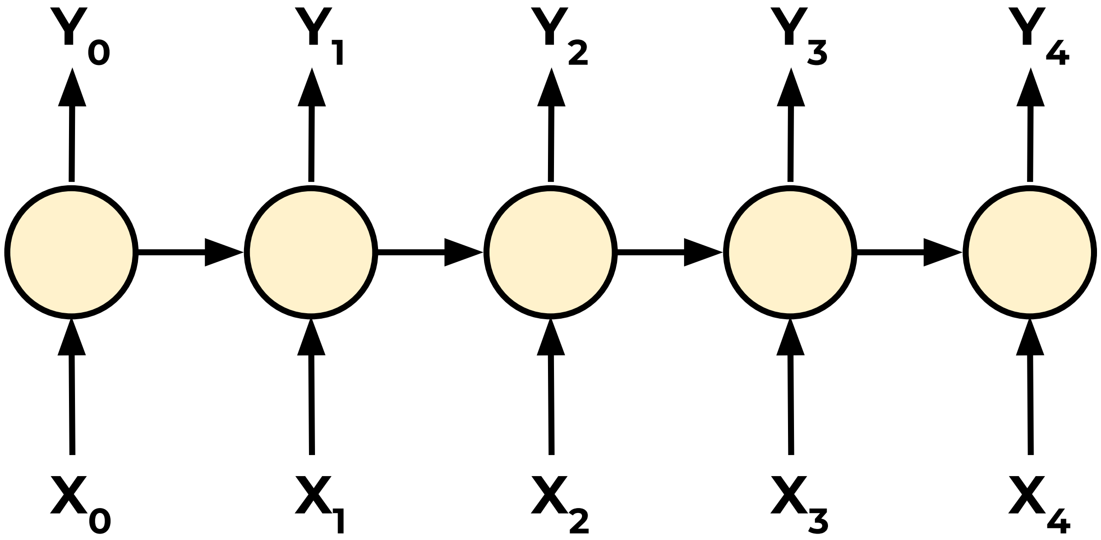


Deep Learning

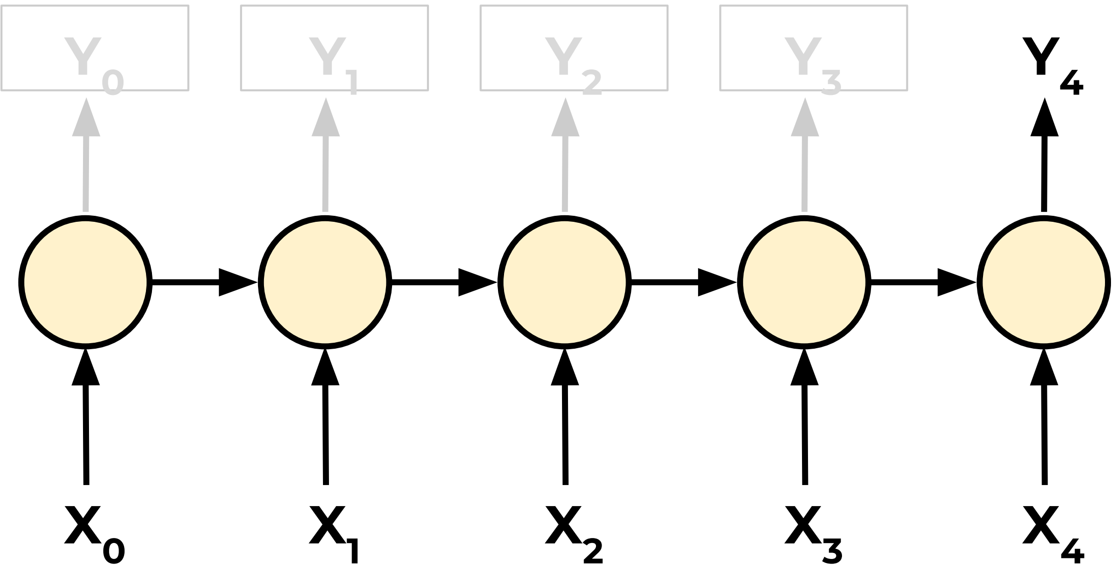
- RNN are also very flexible in their inputs and outputs.
- Let’s see a few examples.

Deep Learning

- Sequence to Sequence

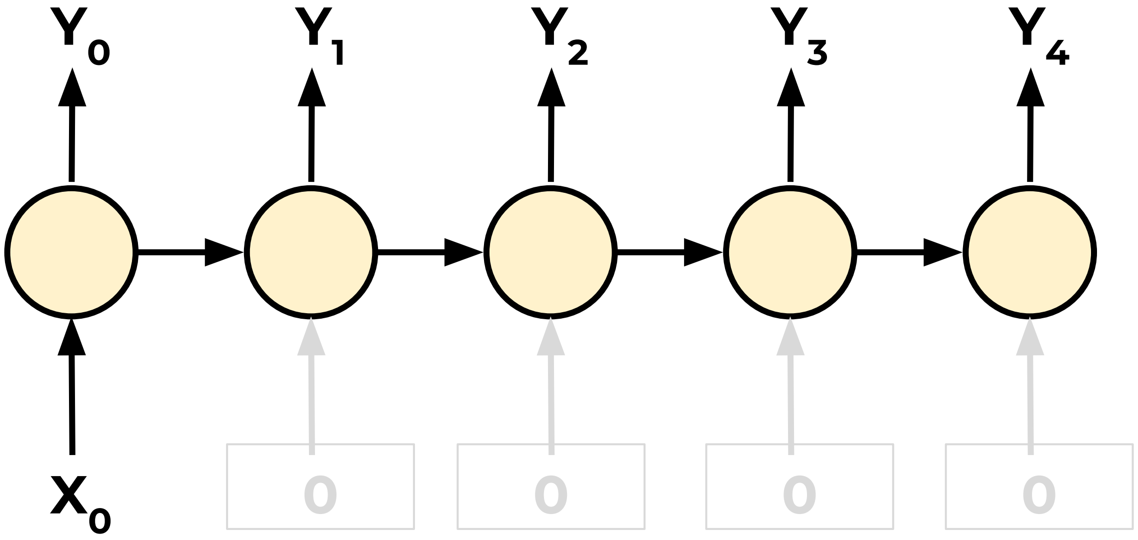


- Sequence to Vector



Deep Learning

- Vector to Sequence



Deep Learning

- Let's explore how we could build a simple RNN model in TensorFlow manually.
- Afterwards we'll see how to use TensorFlow's built in RNN API classes!

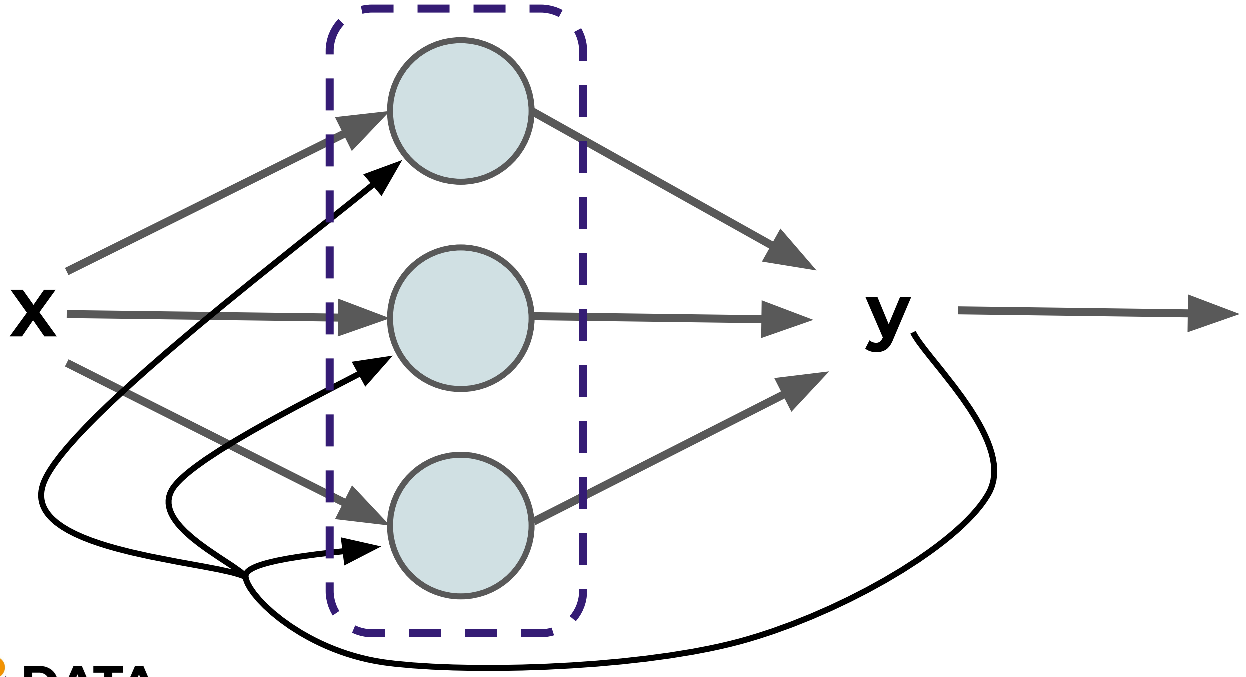
Manual RNN with TF

Deep Learning

- In this lecture we'll manually create a 3 neuron RNN layer with TensorFlow.
- The main idea to focus on here is the input format of the data.
- Let's quickly review what we will create.

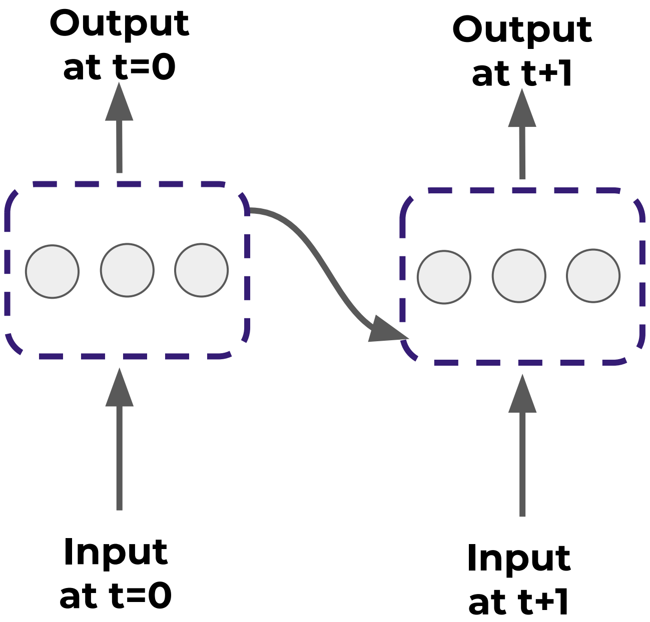
Deep Learning

- We'll construct the following RNN Layer:



Deep Learning

- “Unrolled” layer.



Deep Learning

- We’ll start by running the RNN for 2 batches of data, t=0 and t=1
- Each Recurrent Neuron has 2 sets of weights:
    - Wx for input weights on X
    - Wy for weights on output of original X

Example of RNN Data

t=0	t=1	t=2	t=3	t=4
[The,	brown,	fox,	is,	quick]
[The,	red,	fox,	jumped,	high]

words_in_dataset[0] = [The, The]
words_in_dataset[1] = [brown, red]
words_in_dataset[2] = [fox,fox]
words_in_dataset[3] = [is, jumped]
words_in_dataset[4] = [quick, high]

num_batches = 5, batch_size = 2, time_steps = 5

Vanishing Gradients

- Backpropagation goes backwards from the output to the input layer, propagating the error gradient.
- For deeper networks issues can arise from backpropagation, vanishing and exploding gradients!

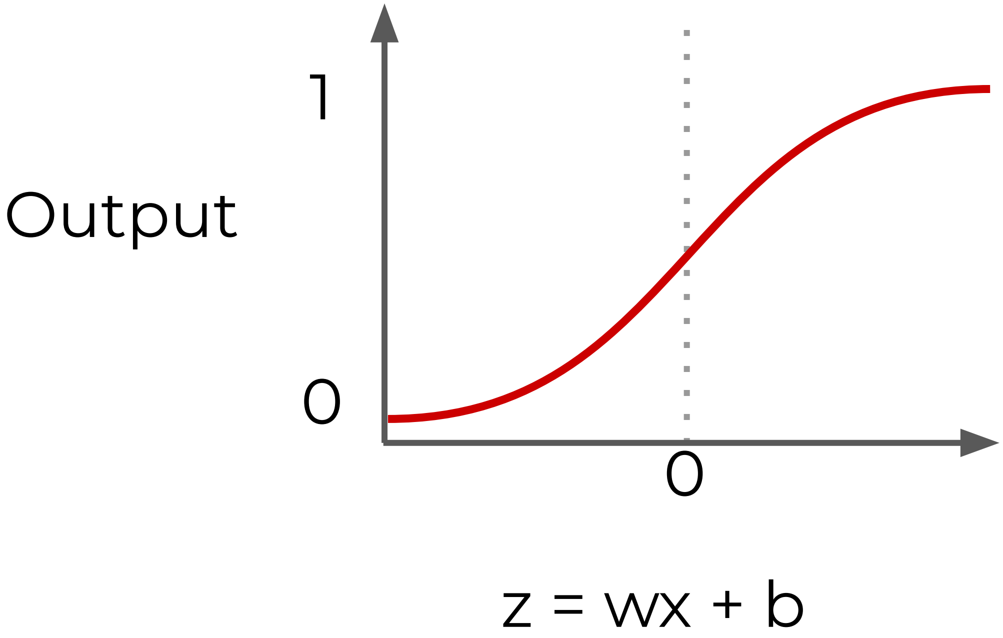
Deep Learning

- As you go back to the “lower” layers, gradients often get smaller, eventually causing weights to never change at lower levels.
- The opposite can also occur, gradients explode on the way back, causing issues.

- Let's discuss why this might occur and how we can fix it.
- Then in the next lecture we'll discuss how these issues specifically affect RNN and how to use LSTM and GRU to fix them.

Deep Learning

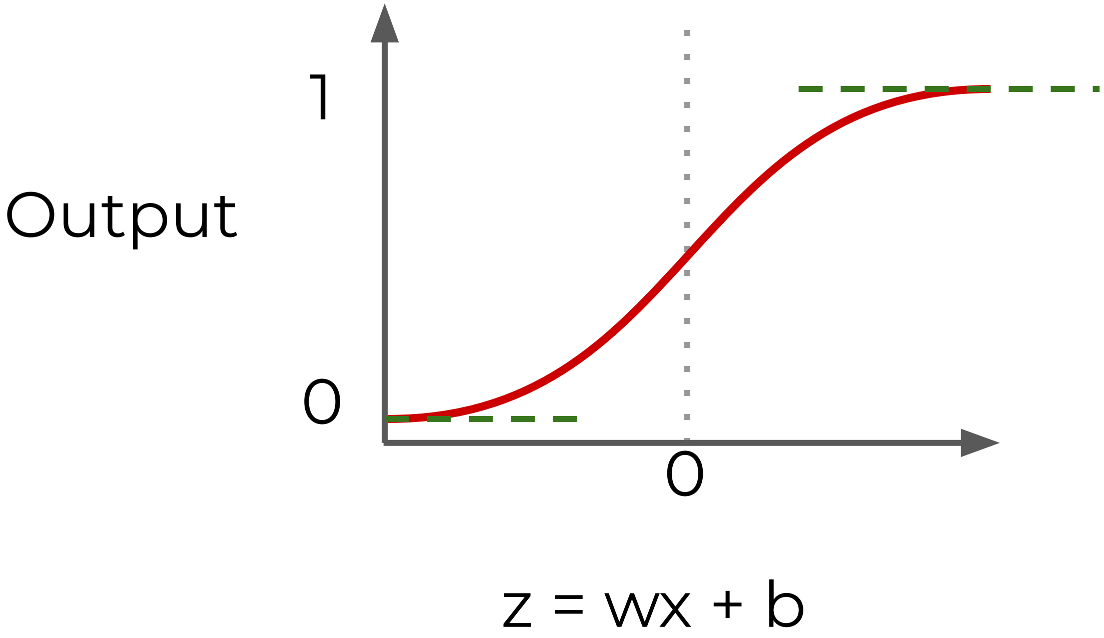
- Why does this happen?



$$f(x) = \frac{1}{1+e^{-(x)}}$$

Deep Learning

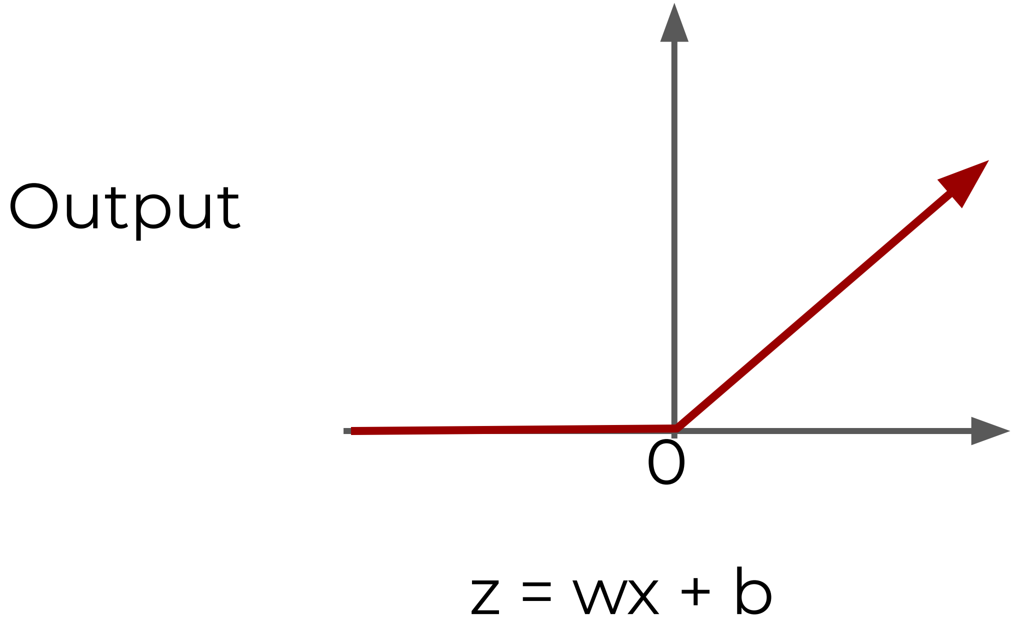
- Why does this happen?



$$f(x) = \frac{1}{1+e^{-(x)}}$$

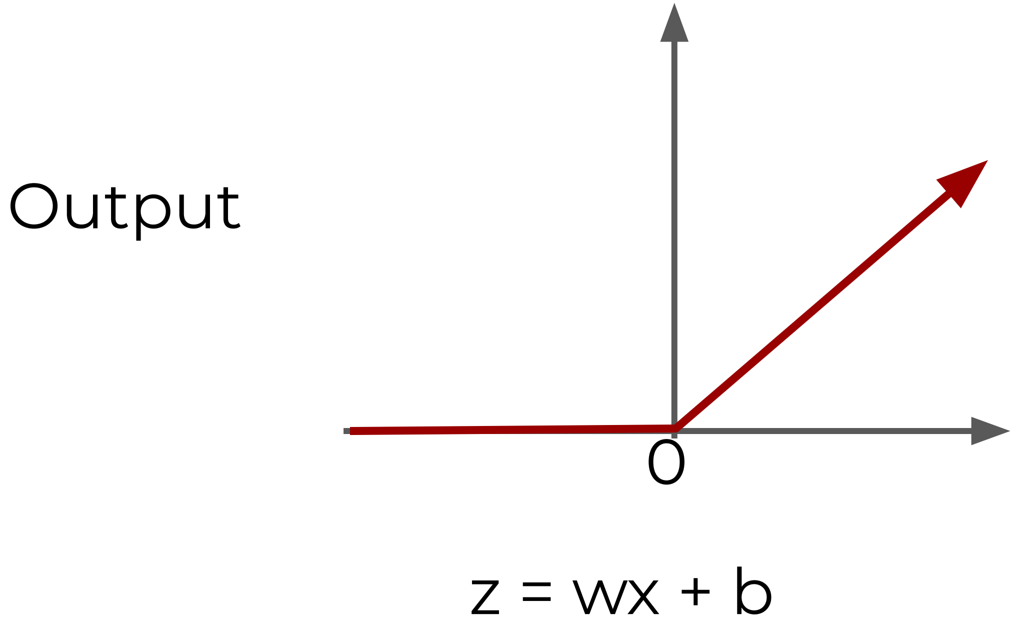
Deep Learning

- Using Different Activation Functions



Deep Learning

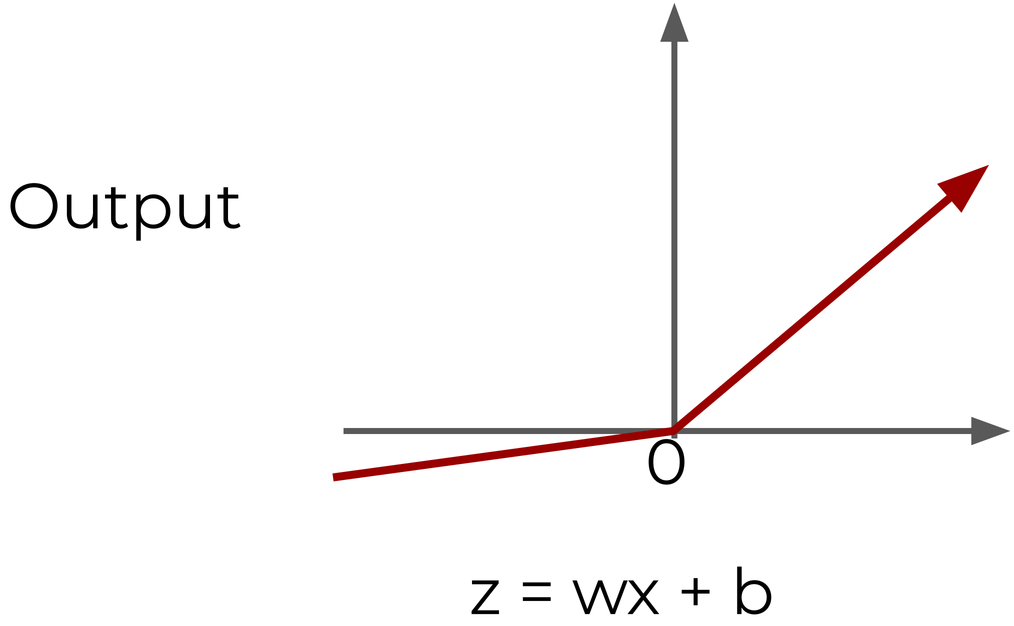
- The ReLu doesn't saturate positive values.



PIERIAN DATA

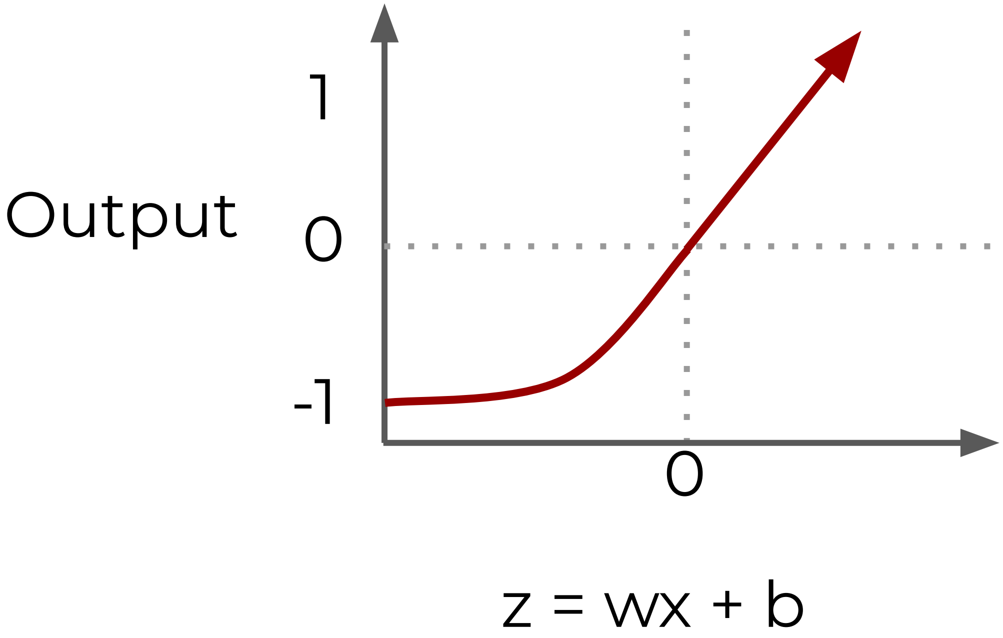
Deep Learning

- “Leaky” ReLU



Deep Learning

- Exponential Linear Unit (ELU)



Deep Learning

- Another solution is to perform batch normalization, where your model will normalize each batch using the batch mean and standard deviation.

Deep Learning

- Apart from batch normalization, researchers have also used “gradient clipping”, where gradients are cut off before reaching a predetermined limit (e.g. cut off gradients to be between -1 and 1)

Deep Learning

- RNN for Time Series present their own gradient challenges, let’s explore special neuron units that help fix these issues!

LSTM and GRU

Deep Learning

- Many of the solutions previously presented for vanishing gradients can also apply to RNN: different activation functions, batch normalizations, etc...
- However because of the length of time series input, these could slow down training

Deep Learning

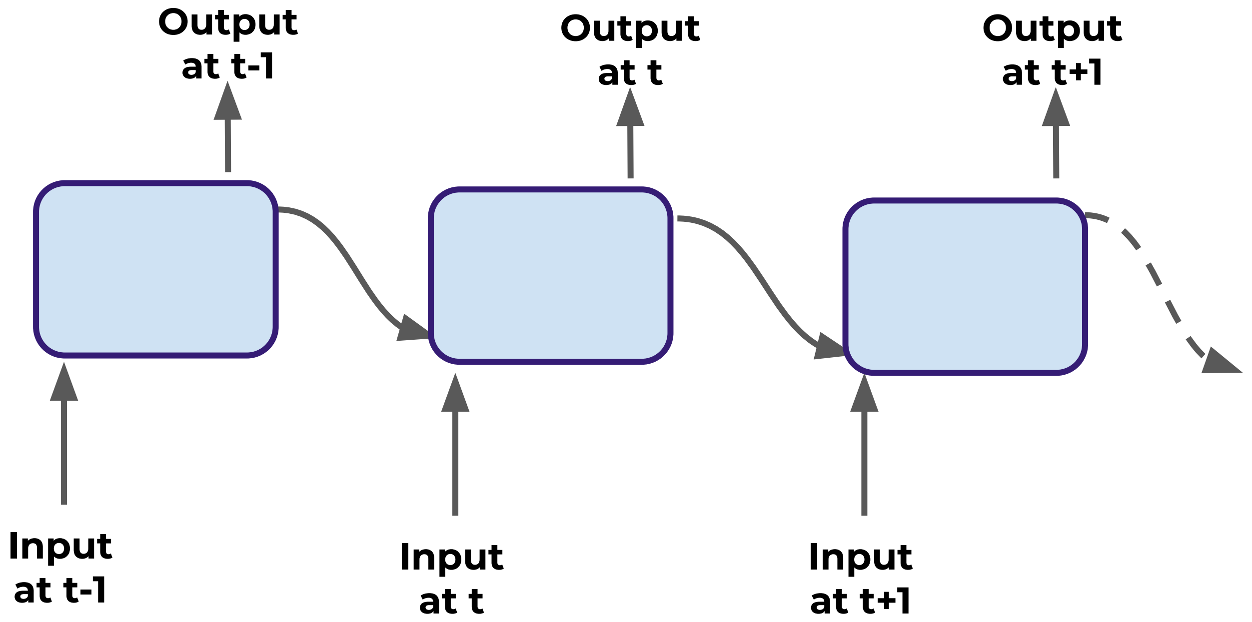
* A possible solution would be to just shorten the time steps used for prediction, but this makes the model worse at predicting longer trends.

- Another issue RNN face is that after awhile the network will begin to “forget” the first inputs, as information is lost at each step going through the RNN.
- We need some sort of “long-term memory” for our networks.

- The LSTM (Long Short-Term Memory) cell was created to help address these RNN issues.
- Let’s go through how an LSTM cell works!

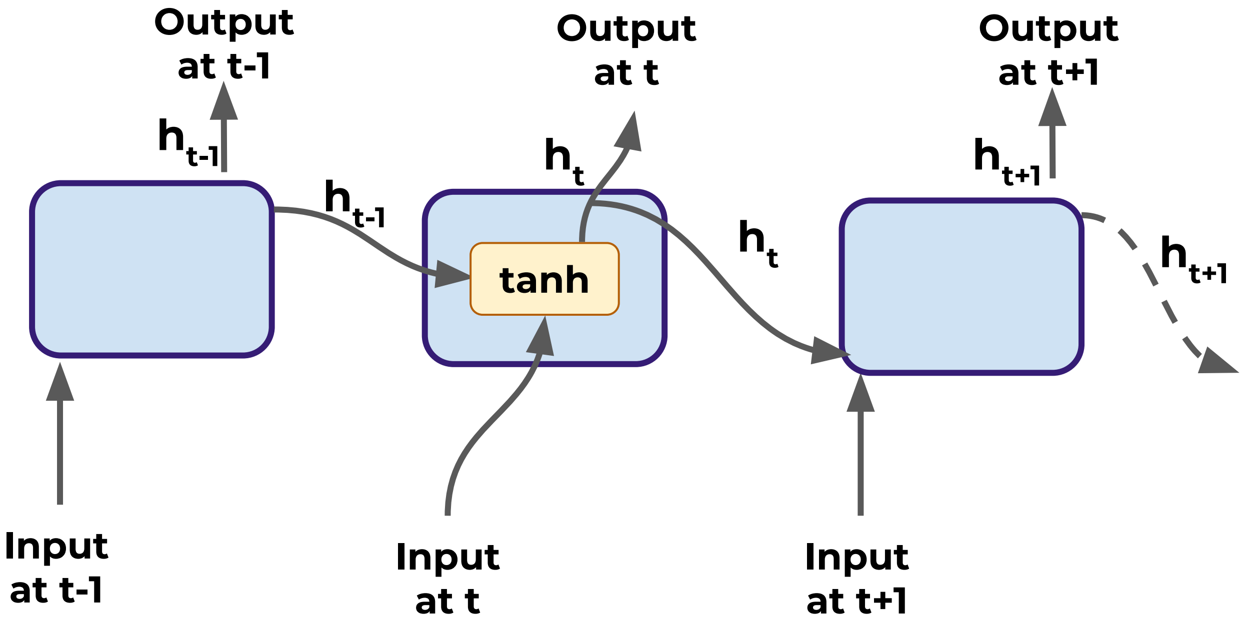
Deep Learning

- A typical RNN

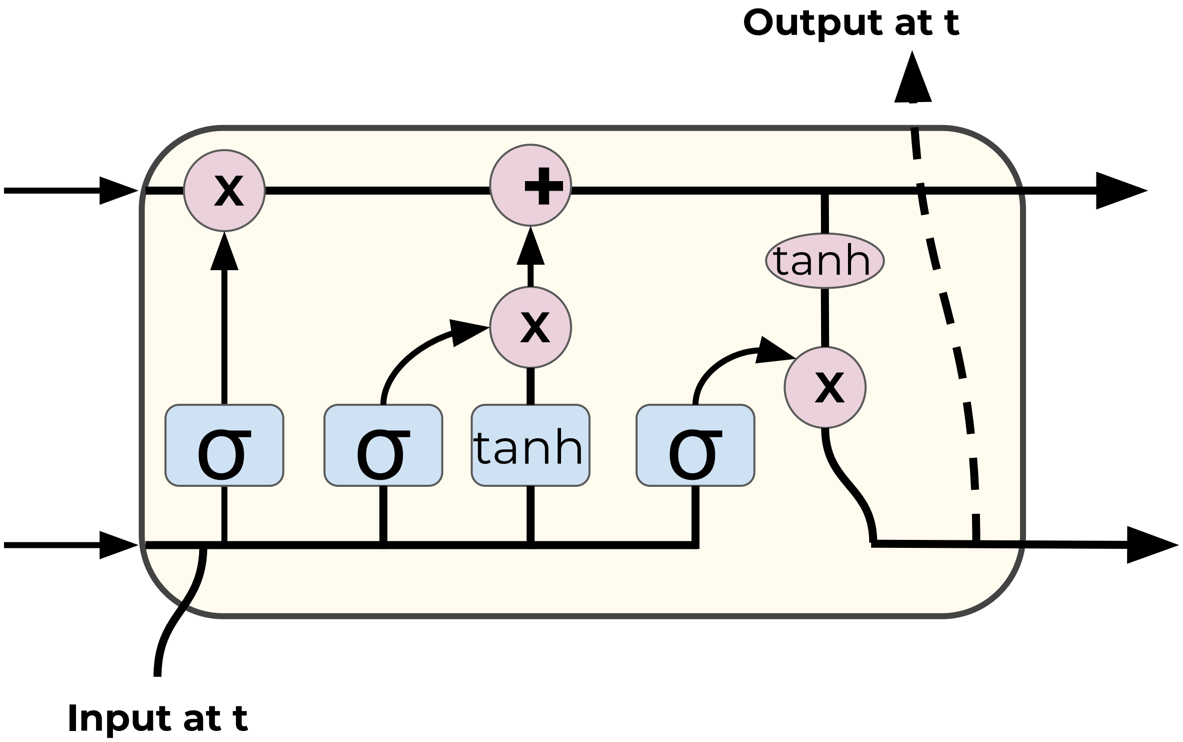


Deep Learning

- A typical RNN cell



An LSTM Cell

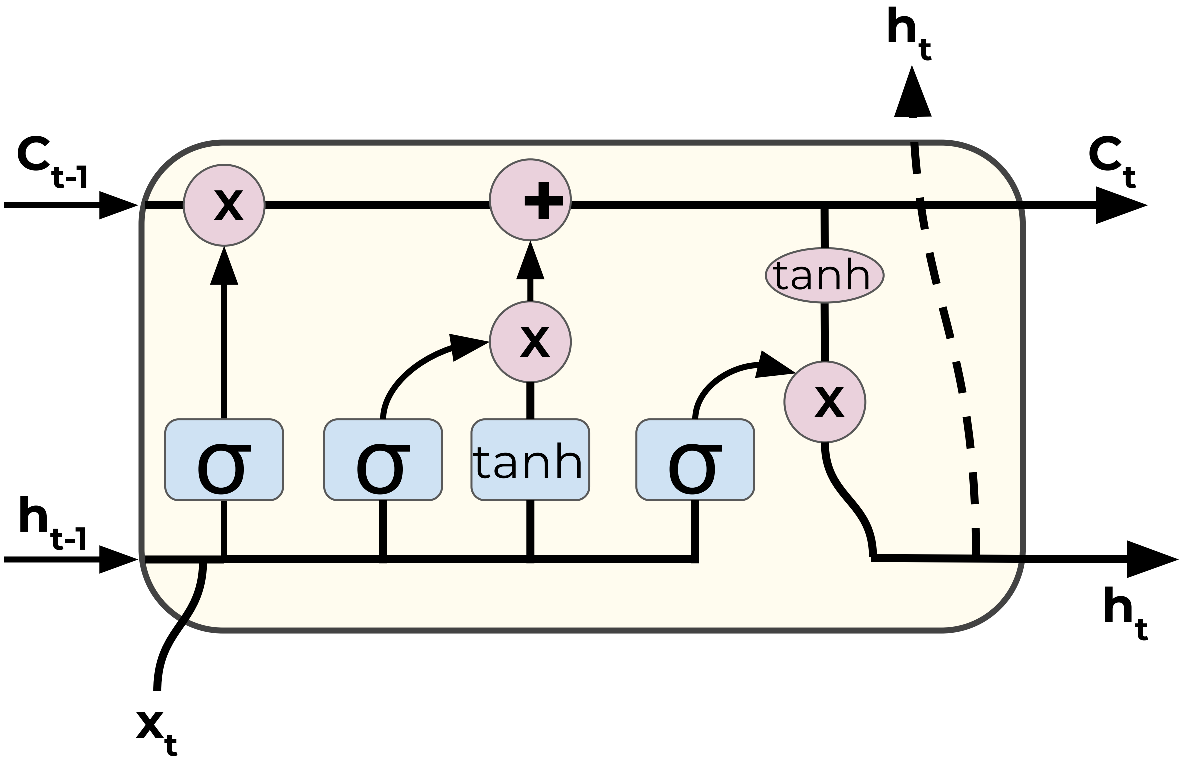


Here we can see the entire LSTM cell.

Let's go through the process!

http://colah.github.io/posts/2015-08-Understanding-LSTMs/

An LSTM Cell



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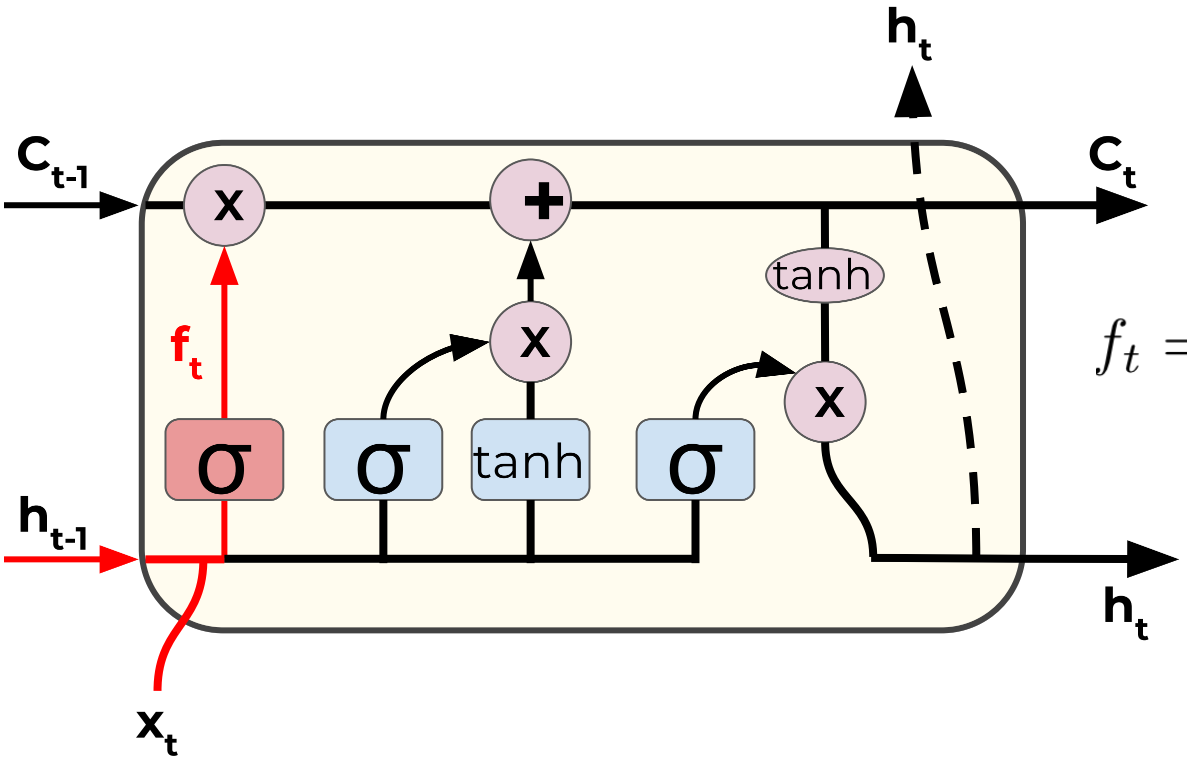
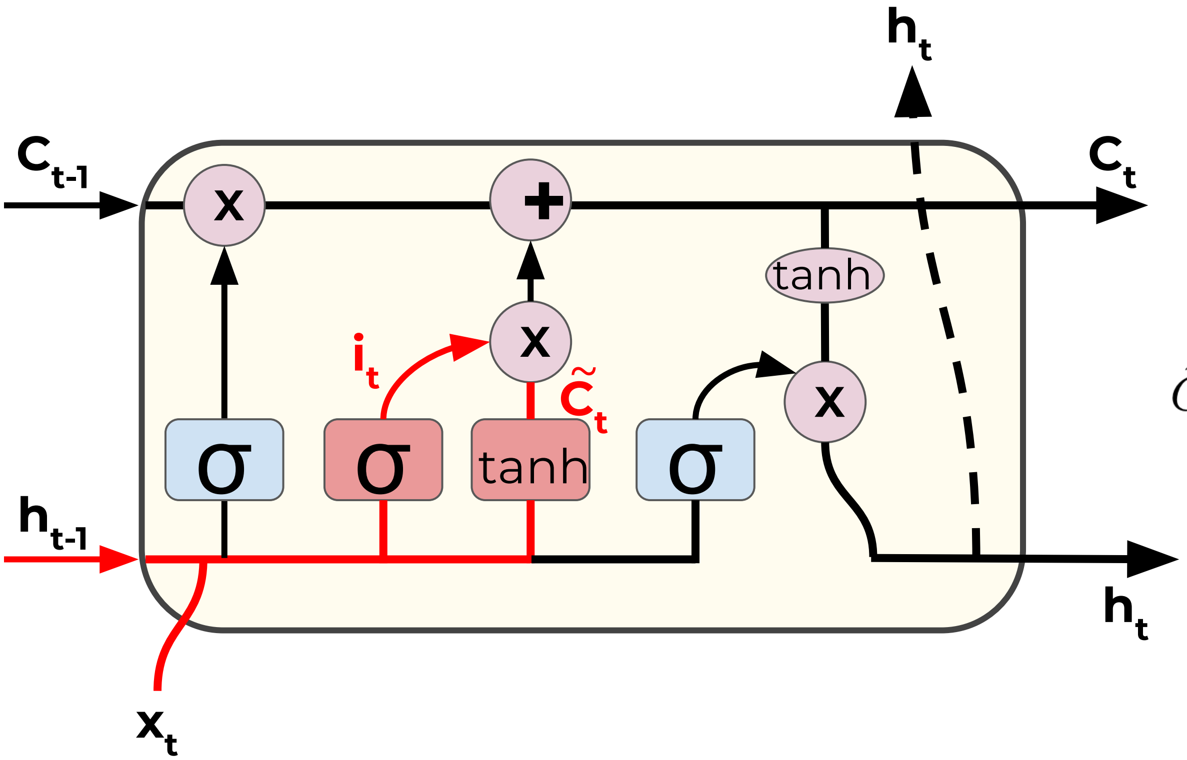
Let's go through the process!

An LSTM Cell



$$f_t = \sigma\left(W_f \cdot [h_{t-1}, x_t] \; + \; b_f\right)$$

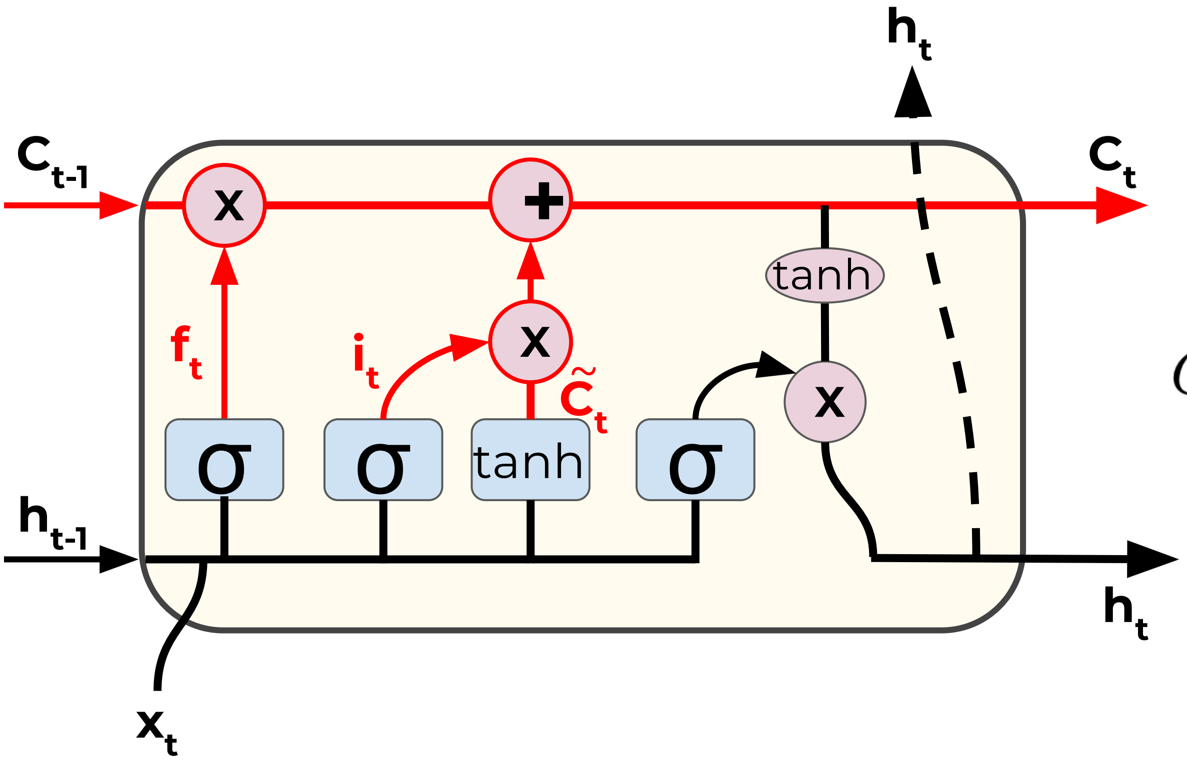
An LSTM Cell



$$i_t = \sigma\left(W_i \cdot [h_{t-1}, x_t] \ + \ b_i\right)$$

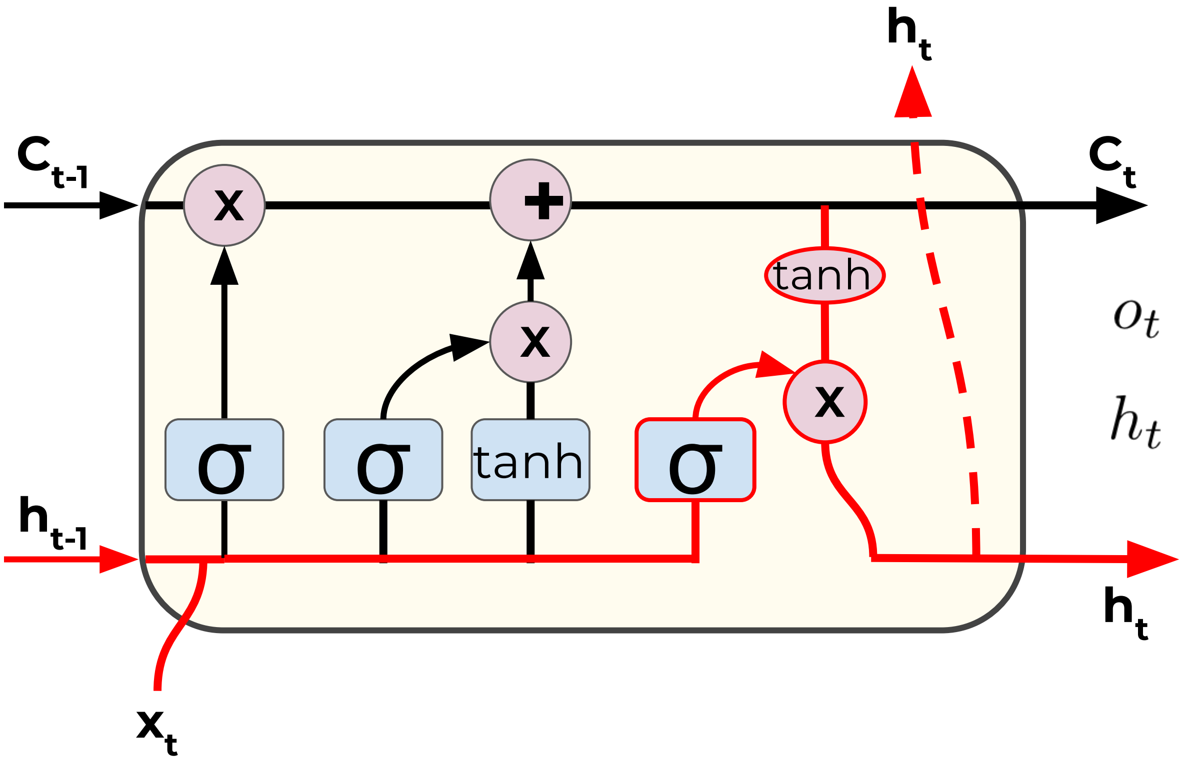
$$\tilde{C}_t = \tanh(W_C \cdot [h_{t-1}, x_t] \ + \ b_C)$$

An LSTM Cell



$$C_t = f_t * C_{t-1} + i_t * \tilde{C}_t$$

An LSTM Cell

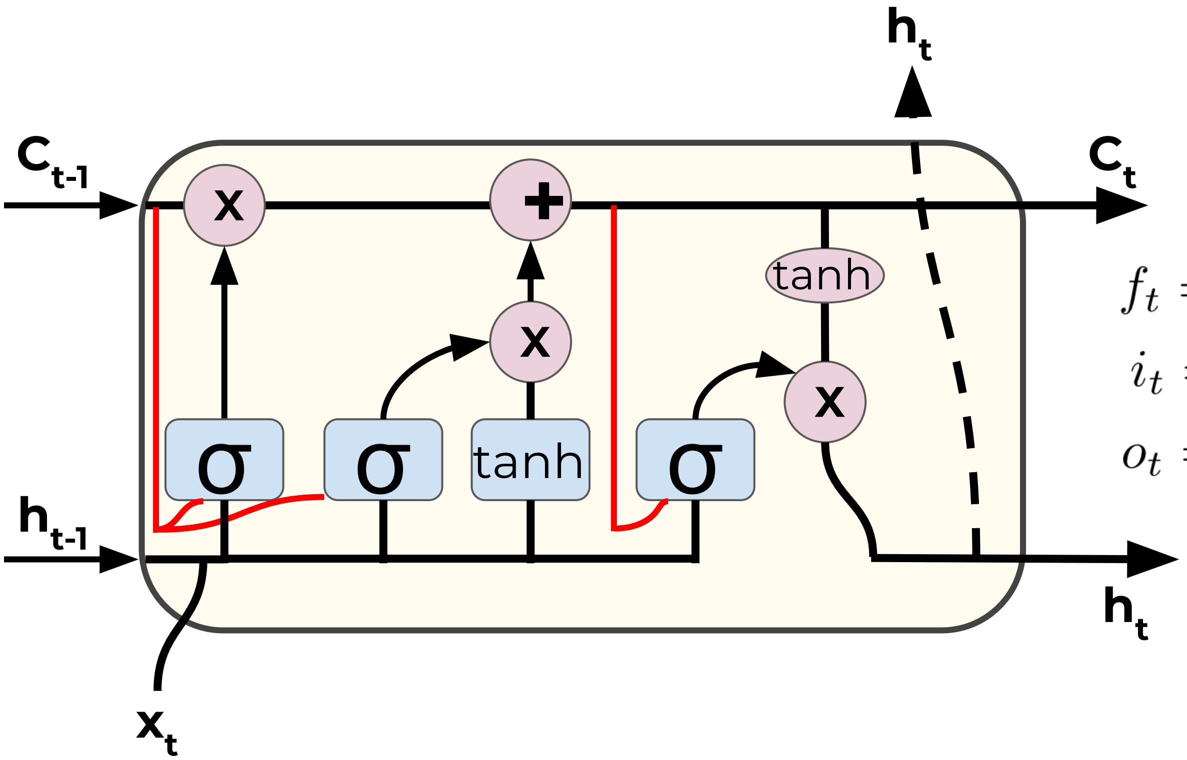


$$o_t = \sigma\left(W_o \left[h_{t-1}, x_t\right] + b_o\right)$$

$$h_t = o_t * \tanh\left(C_t\right)$$

PIERIAN DATA

An LSTM Cell with "peepholes"



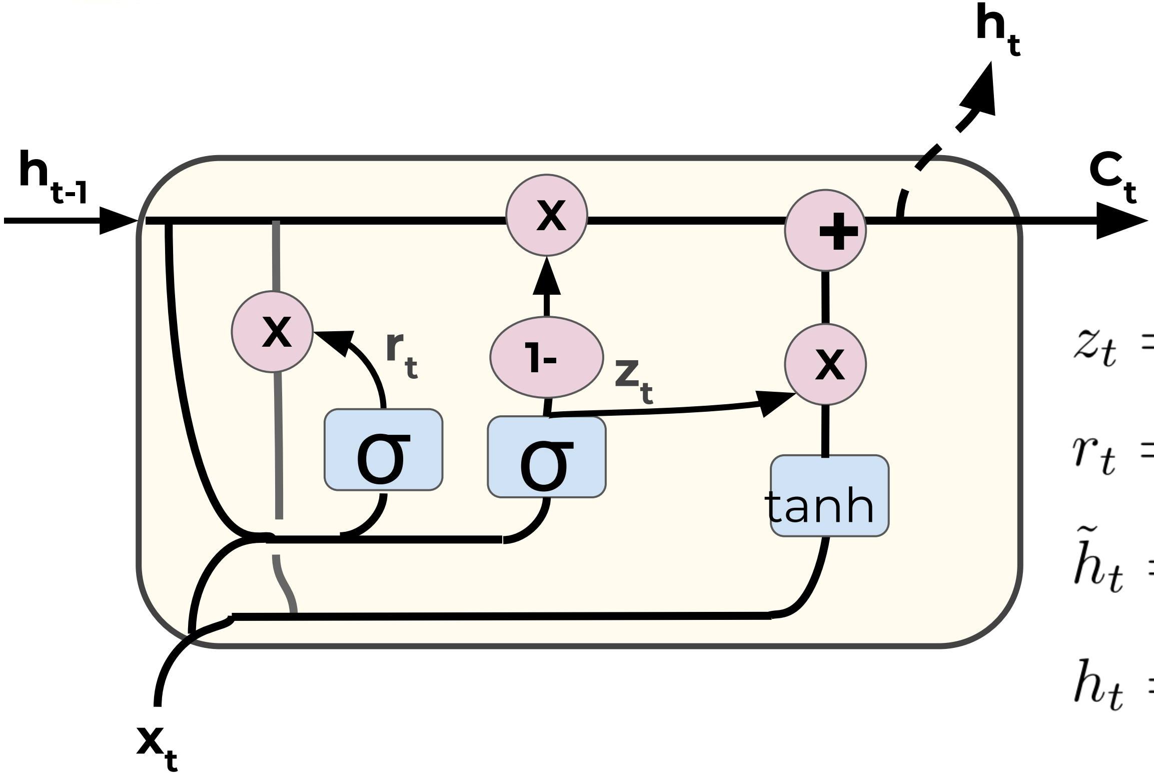
$$f_t = \sigma\left(W_f \cdot [\boldsymbol{C_{t-1}}, h_{t-1}, x_t] \ + \ b_f\right)$$

$$i_t = \sigma\left(W_i \cdot [\boldsymbol{C_{t-1}}, h_{t-1}, x_t] \ + \ b_i\right)$$

$$o_t = \sigma\left(W_o \cdot [\boldsymbol{C_t}, h_{t-1}, x_t] \ + \ b_o\right)$$

PIERIAN DATA

Gated Recurrent Unit (GRU)



$$z_t = \sigma\left(W_z \cdot [h_{t-1}, x_t]\right)$$

$$r_t = \sigma\left(W_r \cdot [h_{t-1}, x_t]\right)$$

$$\tilde{h}_t = \tanh\left(W \cdot [r_t * h_{t-1}, x_t]\right)$$

$$h_t = (1 - z_t) * h_{t-1} + z_t * \tilde{h}_t$$

Deep Learning

- Fortunately TensorFlow comes with these neuron models built into a nice API, making it easy to swap them in and out.
- Up next we'll explore using this TensorFlow RNN API for Time Series prediction and generation!

RNN with TF API

Deep Learning

- Now that we understand various possible improvements for RNN, let's use TensorFlow built-in tf.nn function API to solve sequence problems!

Deep Learning

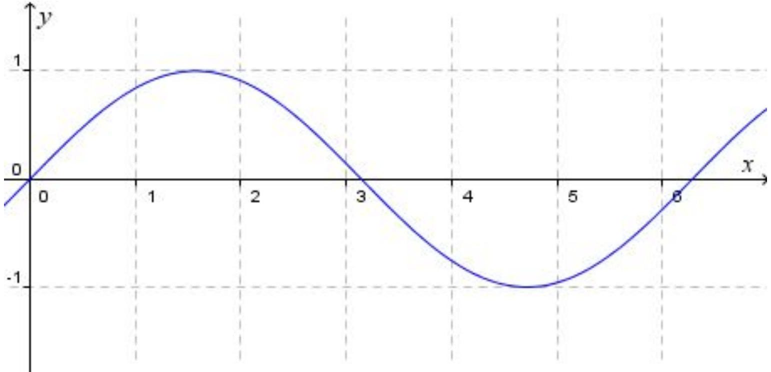
- Recall our original sequence thought exercise:
  - [1,2,3,4,5,6]
- Can we predict the sequence shifted one time step forward?
  - [2,3,4,5,6,7]

Deep Learning

- What about this time series?
  - [0,0.84,0.91,0.14,-0.75,-0.96,-0.28]

Deep Learning

- What about this time series?
  - [0,0.84,0.91,0.14,-0.75,-0.96,-0.28]
- It’s actually just sin(x):
  - [0.84,0.91,0.14,-0.75,-0.96,-0.28,0.65]



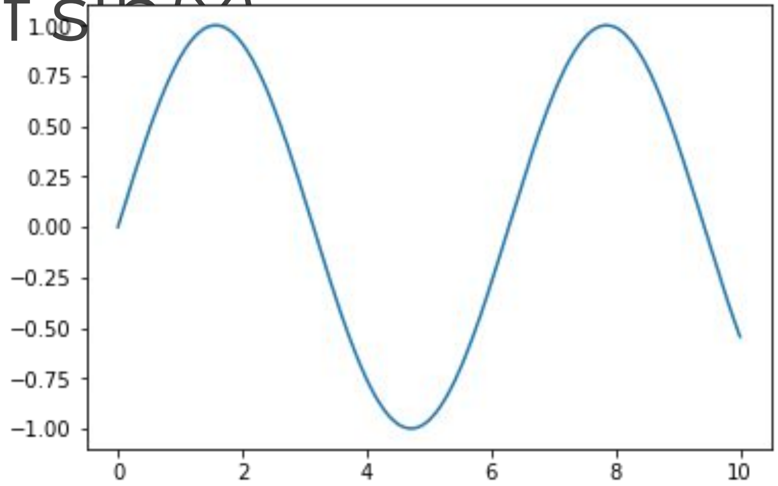
PIERIAN DATA

Deep Learning

- We'll start by creating a RNN that attempts to predict a time series shifted over 1 unit into the future.
- Then we'll attempt to generate new sequences with a seed series.

Deep Learning

- We'll first create a simple class to generate sin(x) and also grab random batches of sin(x).



Deep Learning

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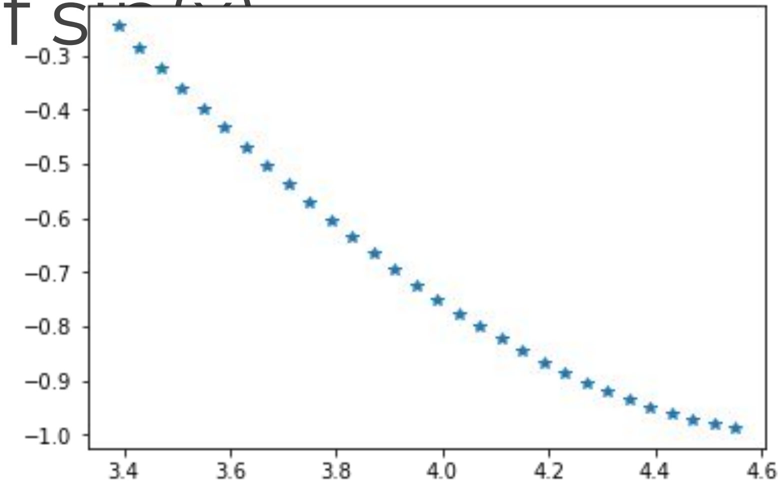

Deep Learning

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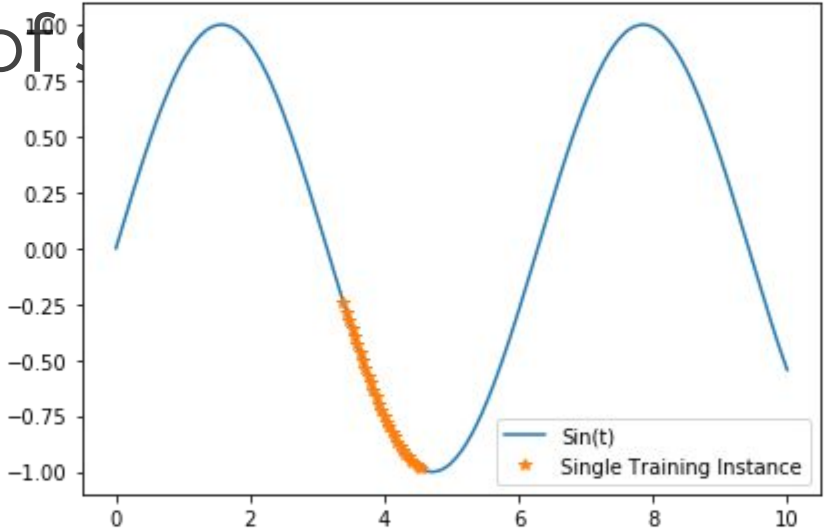
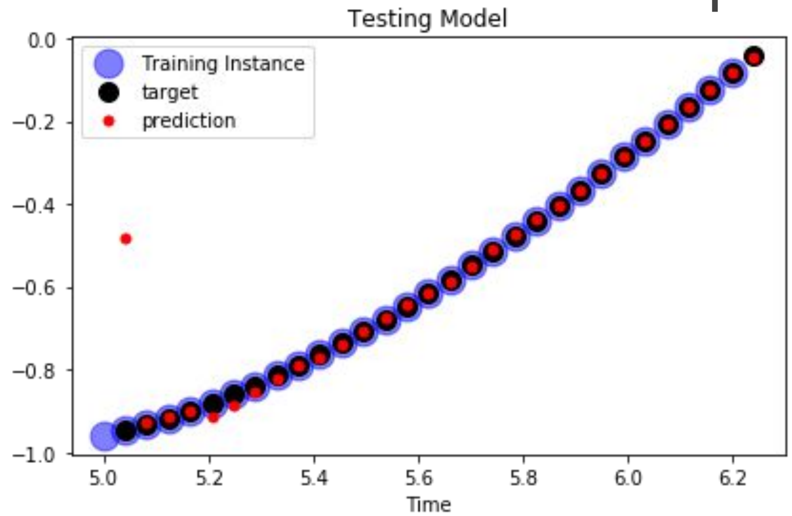


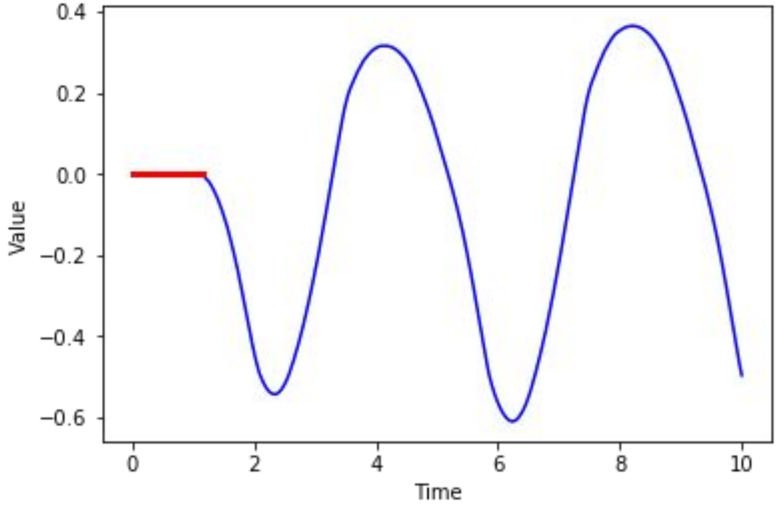
Deep Learning

- Then the trained model will be given a time series and attempt to predict a time series shifted one time step ahead



Deep Learning

● Afterwards we'll use the same model to generate much longer time series given a seed series.



Deep Learning

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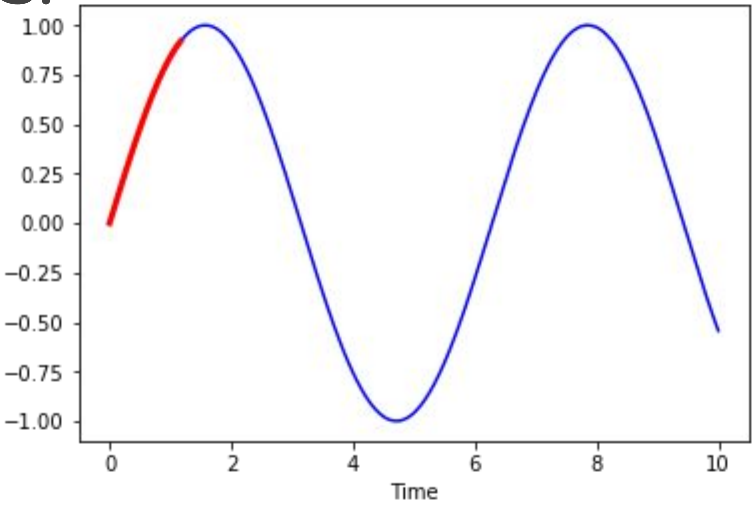


Time Series Exercise

Time Series Exercise Solutions

Quick Note on Word2Vec

Deep Learning

- Optional series of lectures describing Word2Vec with TensorFlow.
- Recommend you check out gensim library if you are further interested in Word2Vec.

Word2Vec

Deep Learning

- Now that we understand how to work with time series of data, let’s take a look at another common series data source, words.
- For example a sentence can be:
    - [“Hi”,”how”,”are”,”you”]

Deep Learning

- In “classic” NLP , words are typically replaced by numbers indicating some frequency relationship to their documents.
- In doing this, we lose information about the relationship between the words themselves.

Deep Learning

- Count-Based
    - Frequency of words in corpus
- Predictive Based
    - Neighboring words are predicted based on a vector space

Deep Learning

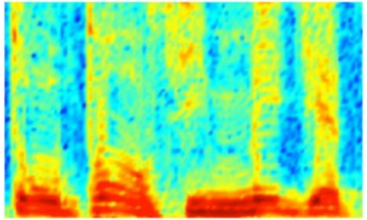
- Let's explore one of Neural Network's most famous use cases in natural language processing:
  - The Word2Vec model created by Mikolov et al.

* The goal of the Word2Vec model is to learn word embeddings by modeling each word as a vector in n-dimensional space.
* But why use word-embeddings?

Deep Learning

Representation of Data

AUDIO



Audio Spectrogram

DENSE

IMAGES

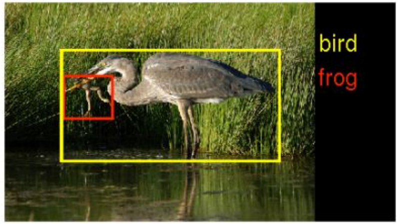


Image pixels

DENSE

TEXT

0	0	0	0.2	0	0.7	0	0	0	...	...

Word, context, or
document vectors

SPARSE

Deep Learning

- Word2Vec creates vector spaced models that represent (embed) words in a continuous vector space.
- With words represented as vectors we can perform vector mathematics on words (e.g. check similarity, add/subtract vectors)

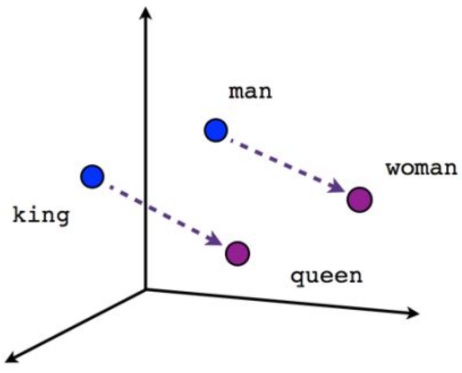
Deep Learning

- At the start of training each embedding is random, but through backpropagation the model will adjust the value of each word vector in the given number of dimensions.
- More dimensions means more training time, but also more “information” per

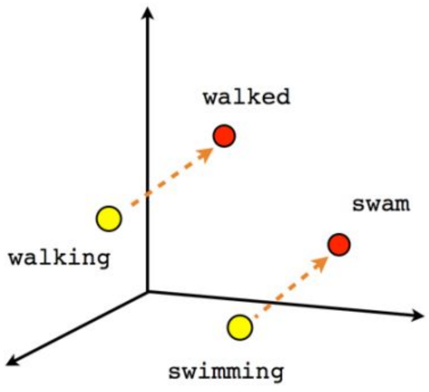
Deep Learning

* Similar words will find their vectors closer together.
* Even more impressive, the model may produce axes that represent concepts, such as gender, verbs, singular vs plural, etc...

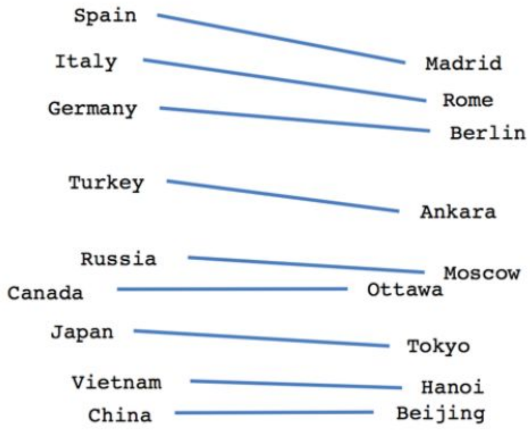
Deep Learning



Male-Female



Verb tense



Country-Capital

Deep Learning

- Similar words will find their vectors closer together.
- Even more impressive, the model may produce axes that represent concepts, such as gender, verbs, singular vs plural, etc...

Deep Learning

- Prediction Target
- Skip-Gram Model
  - The dog chews the bone
  - Typically better for larger data sets
- CBOW (Continuous Bag of Words)
  - The dog chews the bone
  - Typically better for smaller data sets

Deep Learning

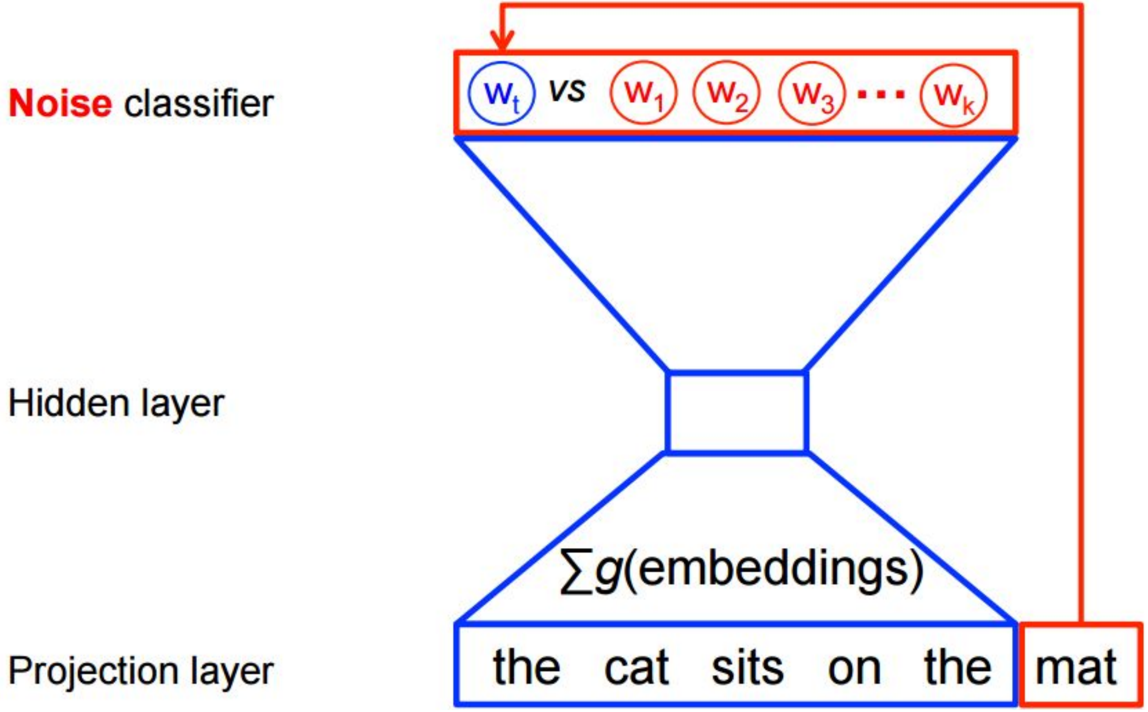
- The dog chews the w_t=?

bone vs [book,car,house,sun,....guitar
]

Target word

Noise words

Deep Learning



Deep Learning

- Noise-Contrastive Training
- Target word is predicted by maximizing
  - $J_{NEG} = \log Q_\theta(D=1|w_t,h) + k_{n\sim Pnoise}\ E\ [\log Q_\theta(D=0|w_n,h)]$
- $Q_\theta(D=1|w_t,h)$ is binary logistic regression is the probability that the word w_t is in the context h in the dataset D parameterized by θ.

Deep Learning

- Noise-Contrastive Training
- Target word is predicted by maximizing
  - $J_{NEG} = \log Q_\theta(D=1|w_t,h) + k_{n\sim Pnoise}\, E\,[\log Q_\theta(D=0|w_n,h)]$
- w_n are k words drawn from noise distribution

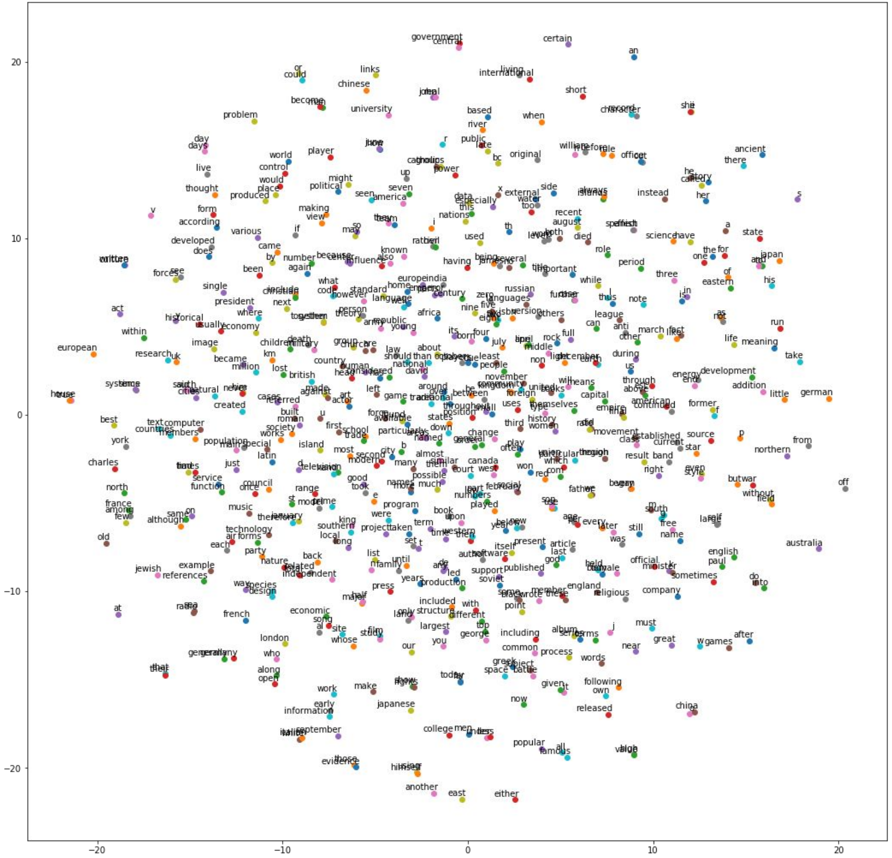
Deep Learning

- Noise-Contrastive Training
- Target word is predicted by maximizing
  - $J_{NEG} = \log Q_\theta(D=1|w_t,h) + k_{n\sim Pnoise}\, E\,[\log Q_\theta(D=0|w_n,h)]$
- The goal is to assign high probability to correct words and low probability to noise words.

Deep Learning

- Once we have vectors for each word we can visualize relationships by reducing the dimensions from 150 to 2 using t-Distributed Stochastic Neighbor Embedding .

Deep Learning



PIERIAN DATA

Let’s get started!

Word2Vec Code Along

Deep Learning

- We will be using the TensorFlow Documentation example implementation of Word2Vec.
- We will be referring to the provided notebook for blocks of code often!

Deep Learning

- If Word2Vec is something that interests you further, check out the gensim library for Python, it has a much simpler to use API for Word2Vec and additional functionality!