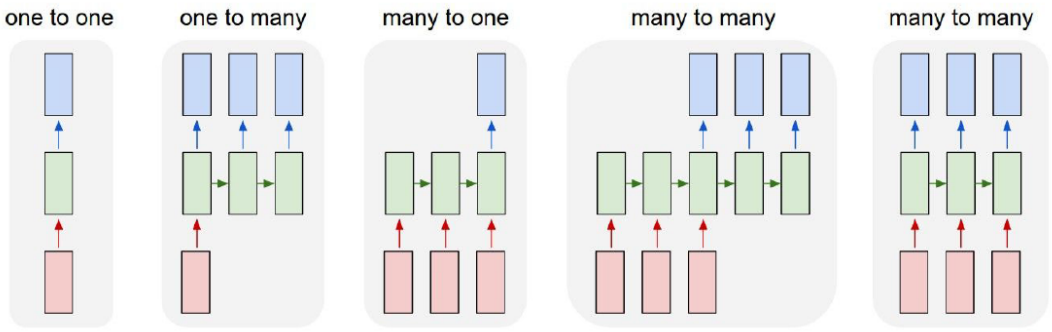
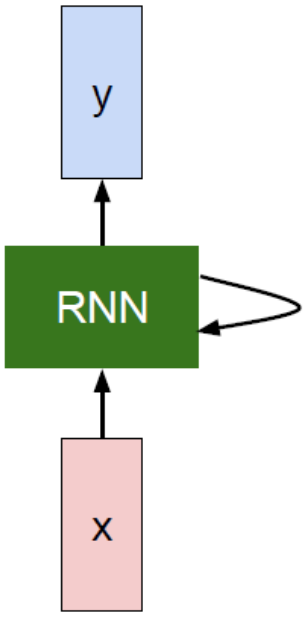
10.md

10. Recurrent Neural networks

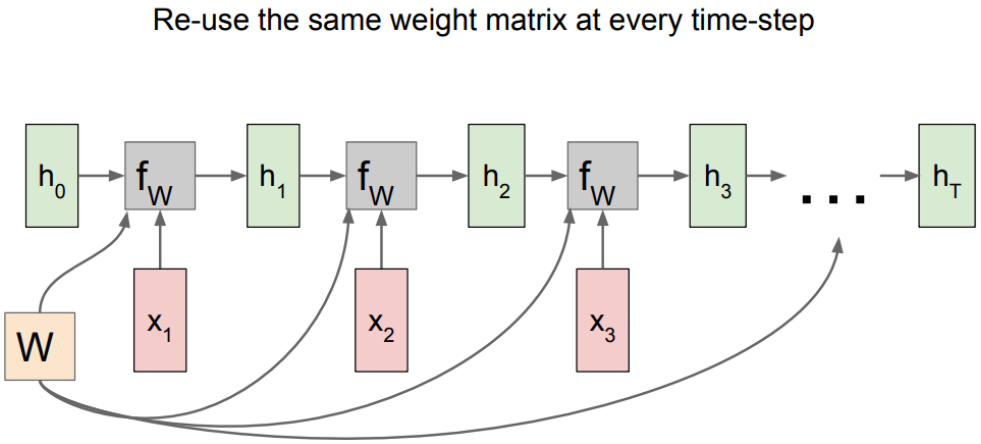
- Vanilla Neural Networks "Feed neural networks", input of fixed size goes through some hidden units and then go to output. We call it a one to one network.
- Recurrent Neural Networks RNN Models:
  - 

  - One to many
    - Example: Image Captioning
      - image ==> sequence of words
  - Many to One
    - Example: Sentiment Classification
      - sequence of words ==> sentiment
  - Many to many
    - Example: Machine Translation
      - seq of words in one language ==> seq of words in another language
    - Example: Video classification on frame level
- RNNs can also work for Non-Sequence Data (One to One problems)
  - It worked in Digit classification through taking a series of “glimpses”
    - “Multiple Object Recognition with Visual Attention”, ICLR 2015.
  - It worked on generating images one piece at a time
    - i.e generating a captcha
- So what is a recurrent neural network?
  - Recurrent core cell that take an input x and that cell has an internal state that are updated each time it reads an input.



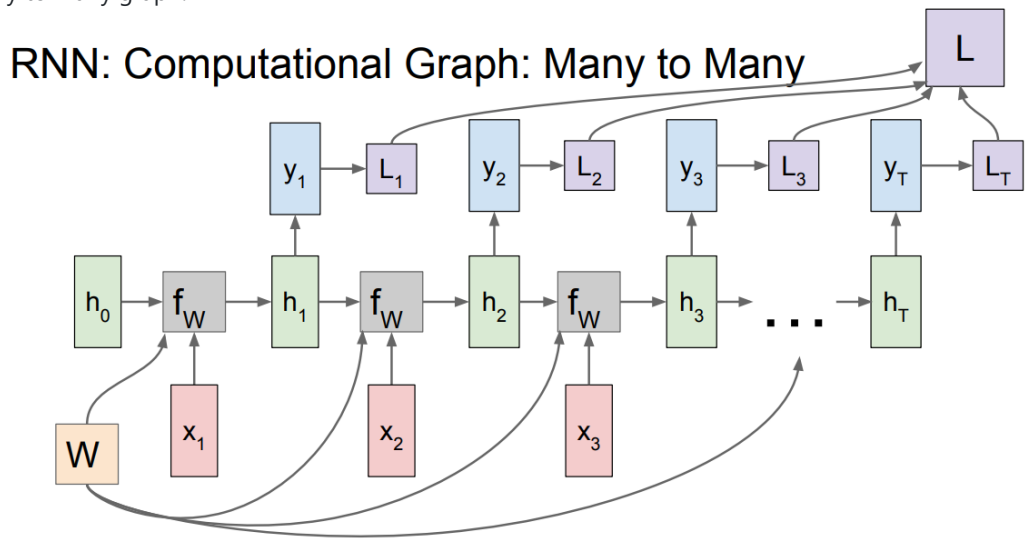
- The RNN block should return a vector.
- We can process a sequence of vectors x by applying a recurrence formula at every time step:
  - ```
    h[t] = fw (h[t-1], x[t])                    # Where fw is some function with parameters W
    ```
  - The same function and the same set of parameters are used at every time step.
- (Vanilla) Recurrent Neural Network:
  - ```
    h[t] = tanh (W[h,h]*h[t-1] + W[x,h]*x[t])    # Then we save h[t]
    y[t] = W[h,y]*h[t]
    ```
  - This is the simplest example of a RNN.
- RNN works on a sequence of related data.

- Recurrent NN Computational graph:

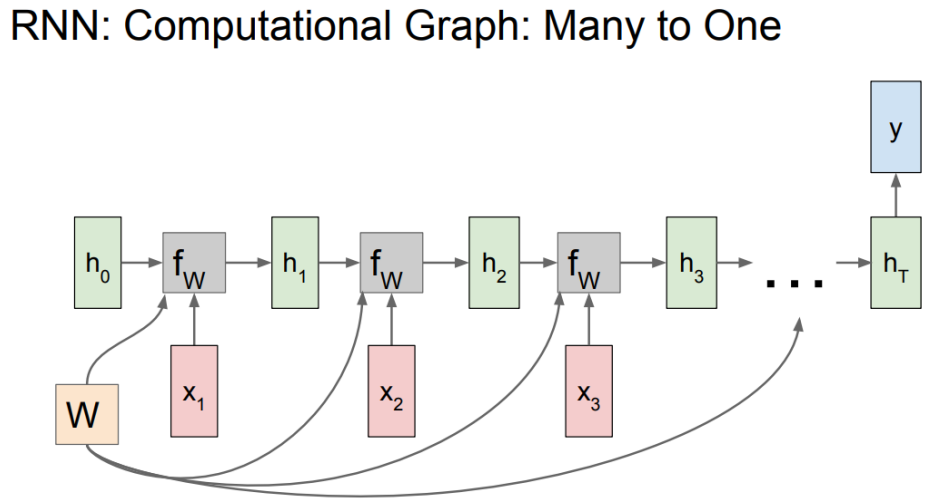


- `h0` are initialized to zero.
- Gradient of `W` is the sum of all the `W` gradients that has been calculated!

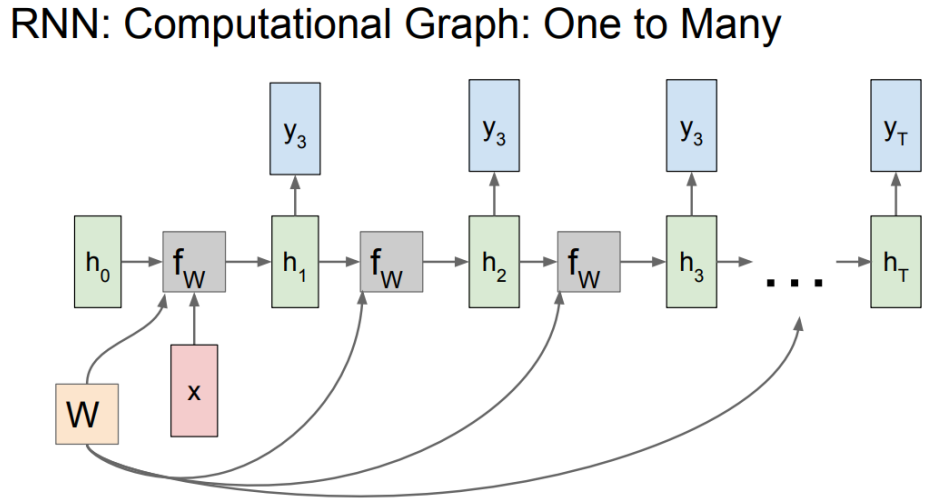
- A many to many graph:



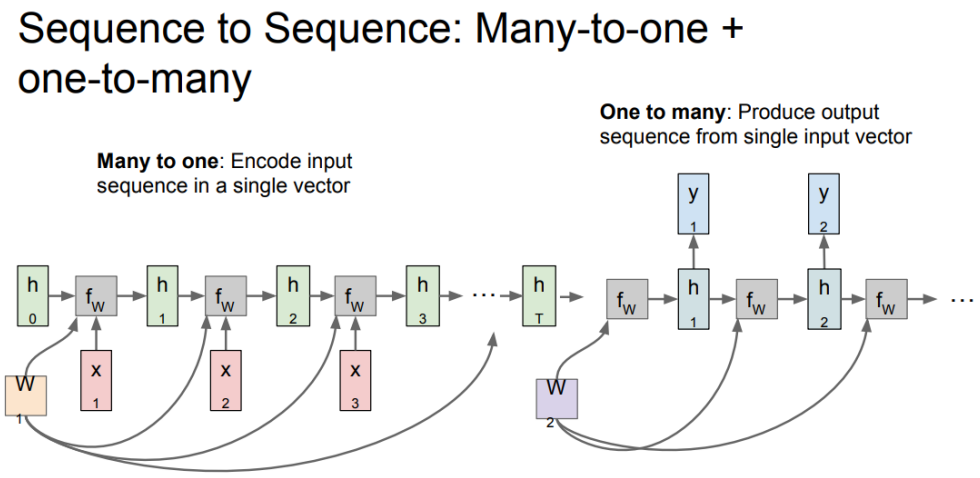
  - Also the last is the sum of all losses and the weights of Y is one and is updated through summing all the gradients!
- A many to one graph:



- A one to many graph:



- sequence to sequence graph:



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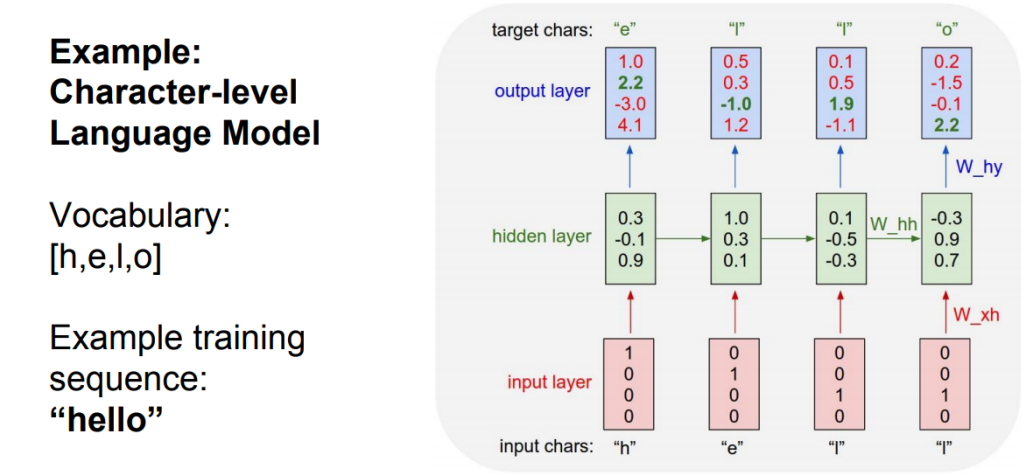
- Encoder and decoder philosophy.

- Examples:
  - Suppose we are building words using characters. We want a model to predict the next character of a sequence. Lets say that the characters are only `[h, e, l, o]` and the words are [hello]
    - Training:



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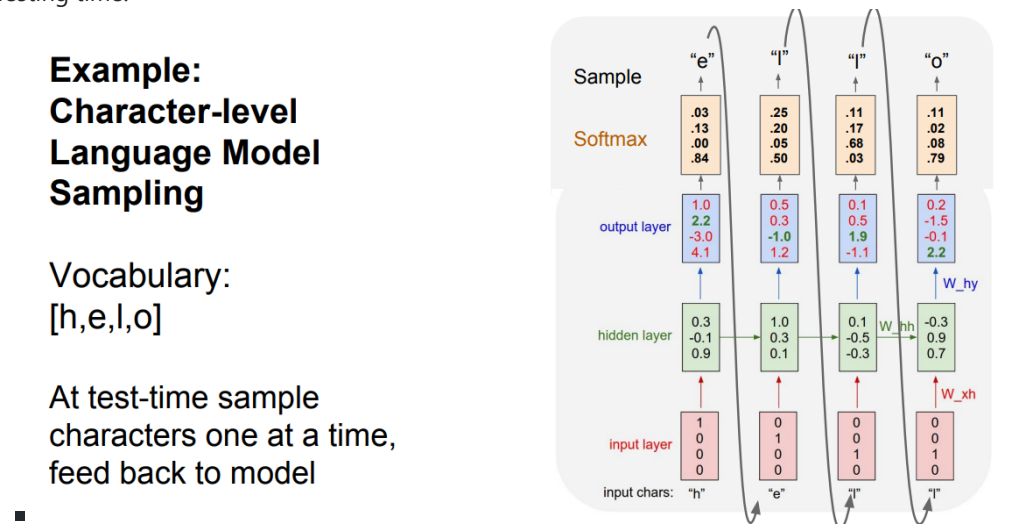
- Only the third prediction here is true. The loss needs to be optimized.
- We can train the network by feeding the whole word(s).

- Testing time:



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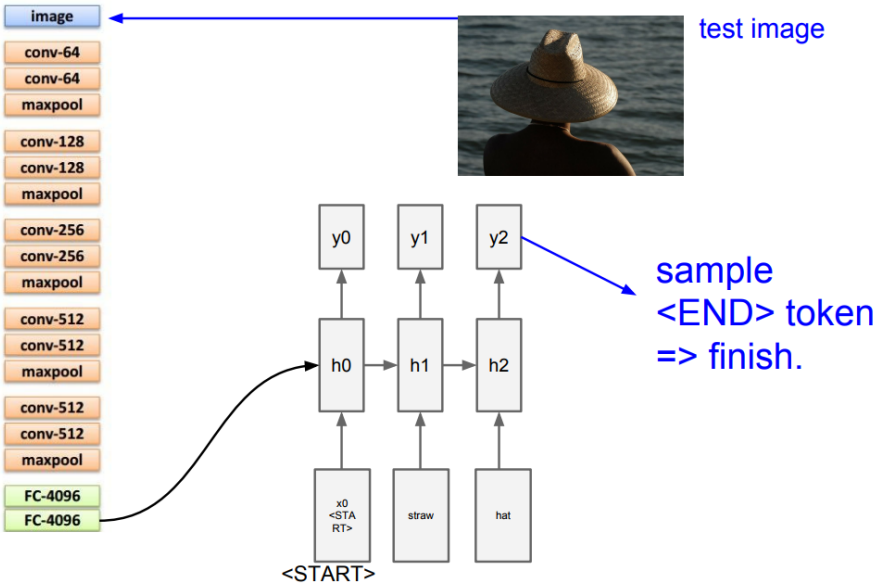
        - At test time we work with a character by character. The output character will be the next input with the other saved hidden activations.
        - This link contains all the code but uses Truncated Backpropagation through time as we will discuss.

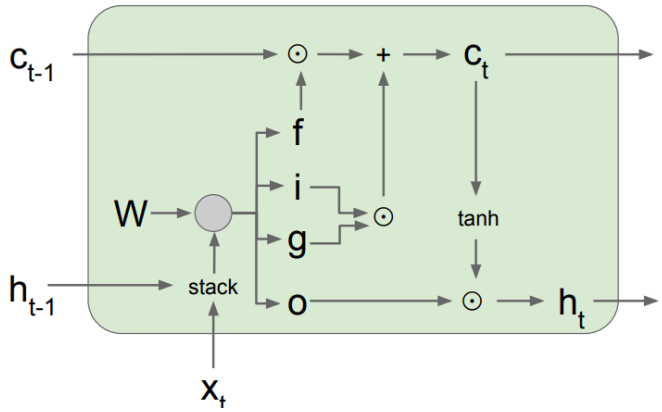
- Backpropagation through time Forward through entire sequence to compute loss, then backward through entire sequence to compute gradient.
    - But if we choose the whole sequence it will be so slow and take so much memory and will never converge!
- So in practice people are doing "Truncated Backpropagation through time" as we go on we Run forward and backward through chunks of the sequence instead of whole sequence
    - Then Carry hidden states forward in time forever, but only backpropagate for some smaller number of steps.
- Example on image captioning:



    - They use token to finish running.
    - The biggest dataset for image captioning is Microsoft COCO.
- Image Captioning with Attention is a project in which when the RNN is generating captions, it looks at a specific part of the image not the whole image.
    - Image Captioning with Attention technique is also used in "Visual Question Answering" problem
- Multilayer RNNs is generally using some layers as the hidden layer that are feed into again. **LSTM** is a multilayer RNNs.
- Backward flow of gradients in RNN can explode or vanish. Exploding is controlled with gradient clipping. Vanishing is controlled with additive interactions (LSTM)
- LSTM stands for Long Short Term Memory. It was designed to help the vanishing gradient problem on RNNs.
    - It consists of:
        - f: Forget gate, Whether to erase cell
        - i: Input gate, whether to write to cell
        - g: Gate gate (?), How much to write to cell
        - o: Output gate, How much to reveal cell

Long Short Term Memory (LSTM)

[Hochreiter et al., 1997]



$$\begin{pmatrix} i \\ f \\ o \\ g \end{pmatrix} = \begin{pmatrix} \sigma \\ \sigma \\ \sigma \\ \tanh \end{pmatrix} W \begin{pmatrix} h_{t-1} \\ x_t \end{pmatrix}$$

$$c_t = f \odot c_{t-1} + i \odot g$$

$$h_t = o \odot \tanh(c_t)$$

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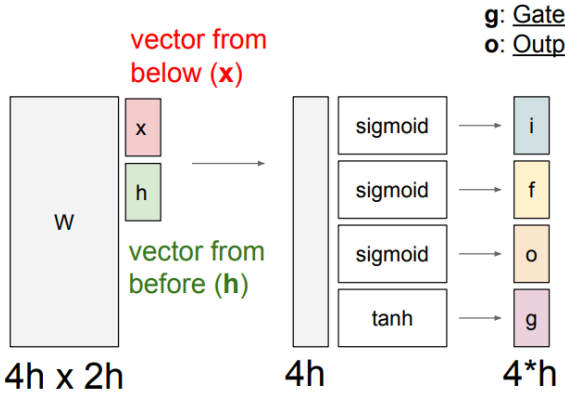

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  - The LSTM gradients are easily computed like ResNet
  - The LSTM is keeping data on the long or short memory as it trains means it can remember not just the things from last layer but layers.

- Highway networks is something between ResNet and LSTM that is still in research.
- Better/simpler architectures are a hot topic of current research
- Better understanding (both theoretical and empirical) is needed.
- RNN is used for problems that uses sequences of related inputs more. Like NLP and Speech recognition.