



Sequential Data Processing (RNNs, LSTMs)

Machine Learning Decal

Hosted by Machine Learning at Berkeley



Agenda

Motivation

Recurrent Neural Networks (RNNs)

RNN Demo

Long Short-Term Memory Networks (LSTMs)

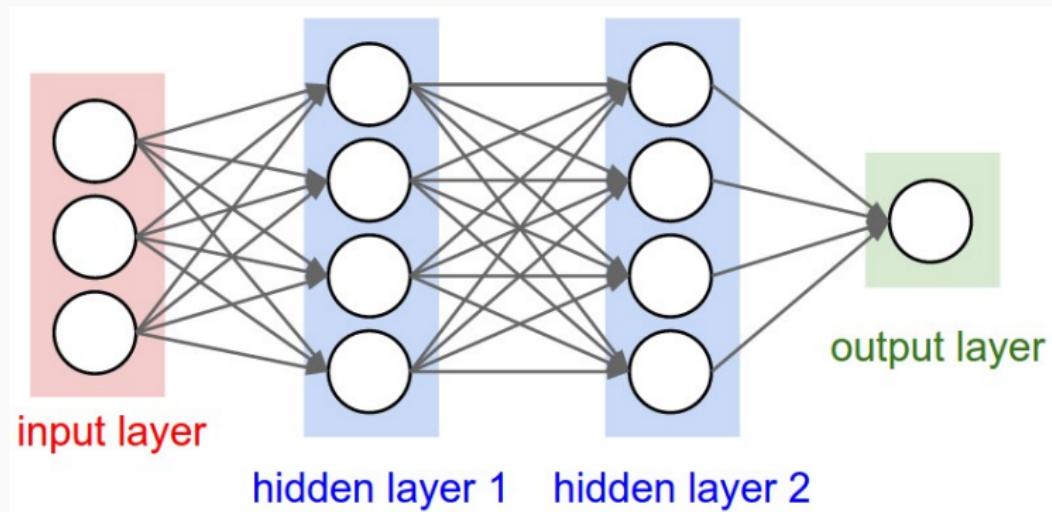
LSTM Demo 1

Momentum

LSTM Demo 2

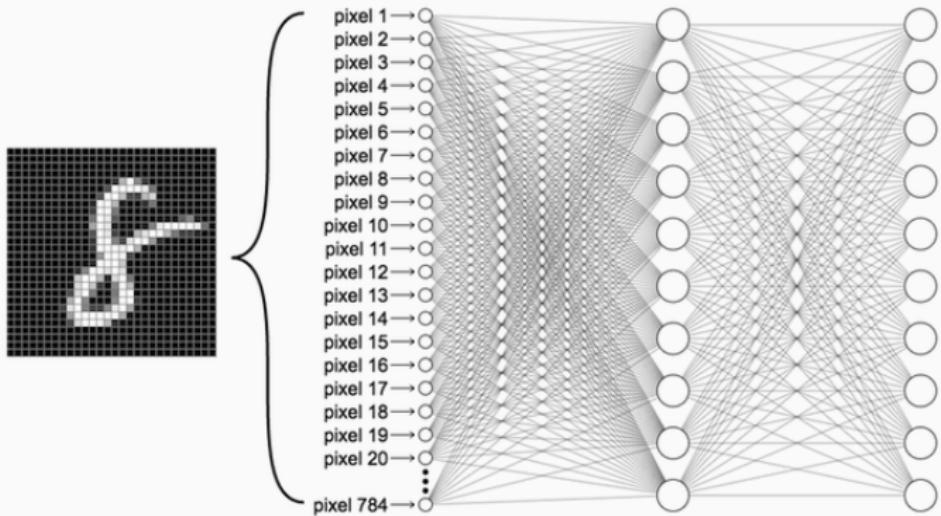
Motivation

Feed Forward Networks



$$a^{(t)} = \sigma \left(W^{(t)} a^{(t-1)} + b^{(t)} \right)$$

Feed Forward Networks



Feed Forward Networks



Feed forward neural networks are *universal function approximators*, meaning that any function from \mathbb{R}^n to \mathbb{R}^m can be represented *arbitrarily well* by some neural network.

A Motivating Example



A Motivating Example



Say we wanted to predict tomorrow's stock prices given daily price readings...

A Motivating Example



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- What will Apple's stock price be tomorrow?

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- Is now a good time to sell Facebook stocks?
- When will Google's stock peak?

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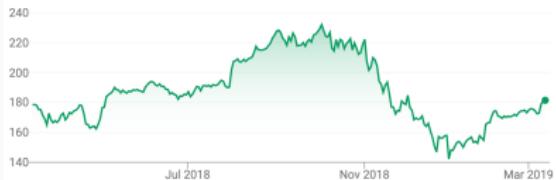
Can we design a feed forward network for this task?

What should our network know?

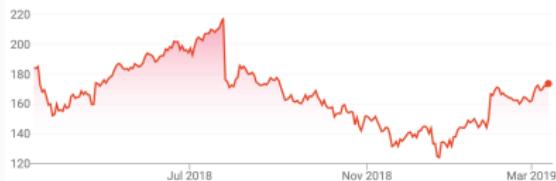


Example Stock Prices Over Time

Apple:



Facebook:



Google:



A Motivating Example



Conclusions:

- Knowing just the price the previous day is not enough.

A Motivating Example



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Conclusions:

- Knowing just the price the previous day is not enough.
- We somehow need context regarding the stock.
- Recent price trends are relevant as well.
- We could leverage the fact that we are given daily readings.

Ideally our model can consider not only the previous day's price but information further in the past.

Shortcomings of Feed Forward Neural Networks



Basic feed forward networks generally struggle with time series problems.

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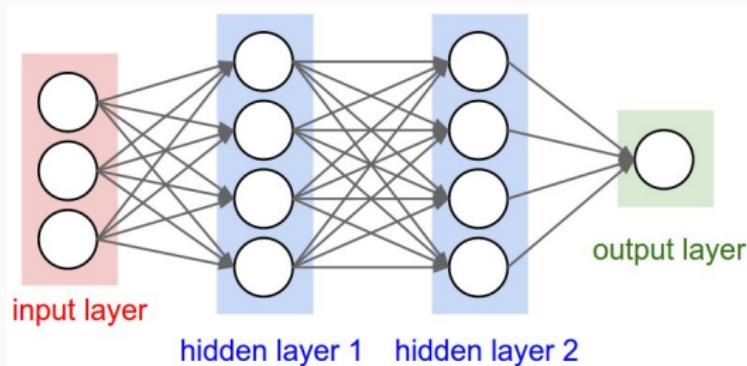
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Example: Language



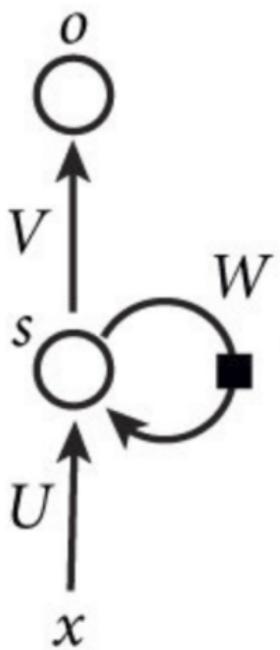
Example: Videos



<https://www.youtube.com/watch?v=pW6nZXeWIGM>

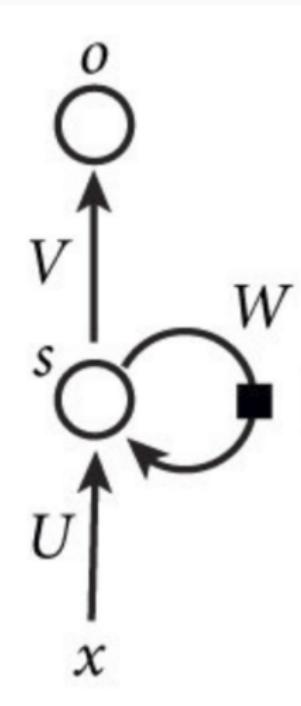
Recurrent Neural Networks (RNNs)

Internal States





Update Equations



$$h^{(t)} = \tanh(b + Wh^{(t-1)} + Ux^{(t)})$$

$$o^{(t)} = c + Vh^{(t)}$$

Backprop?



Remember that backpropagation requires no cycles in the computation graph.



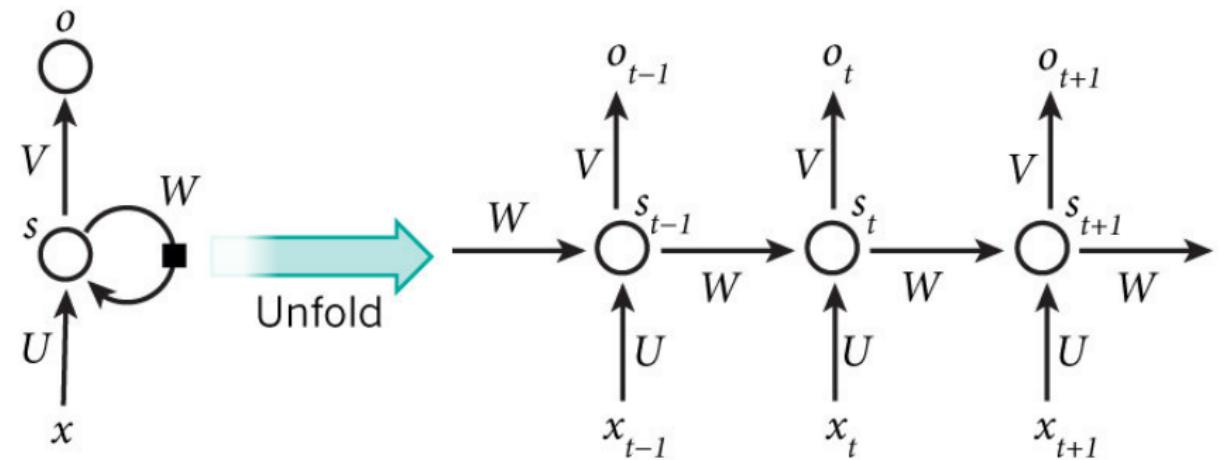
Backprop?

Remember that backpropagation requires no cycles in the computation graph.

Does backprop work for networks with recurrence?



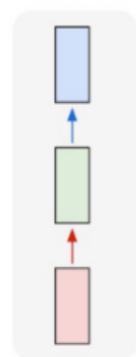
Unrolling the Graph



Uses



one to one



Standard Network

one to many

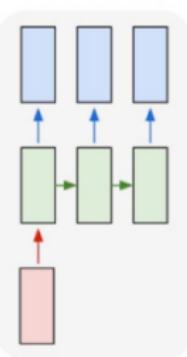
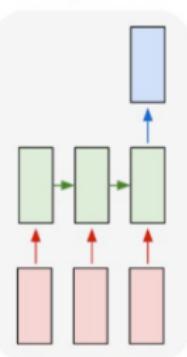


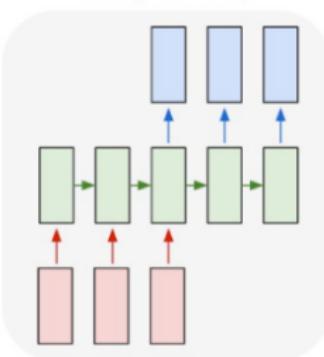
Image Captioning

many to one



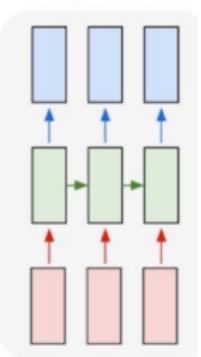
Sentiment Analysis

many to many



Machine Translation

many to many



Language Modeling

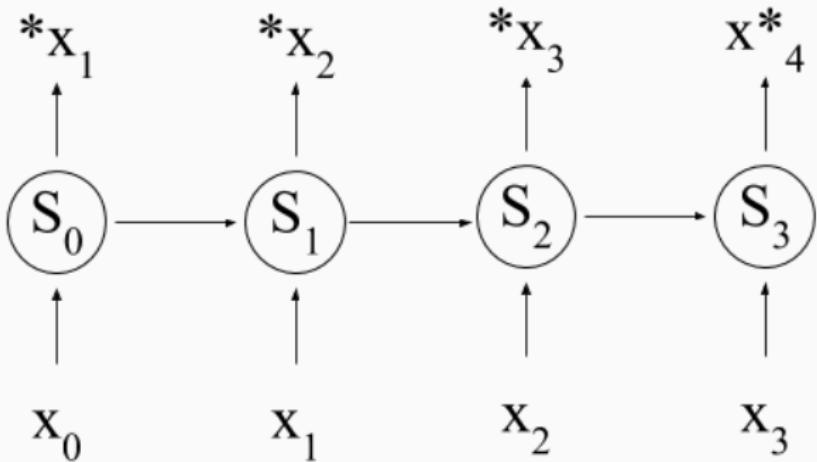
Sequence Modeling



Sequence modeling is the task of predicting the “next item” given current and previous tokens.

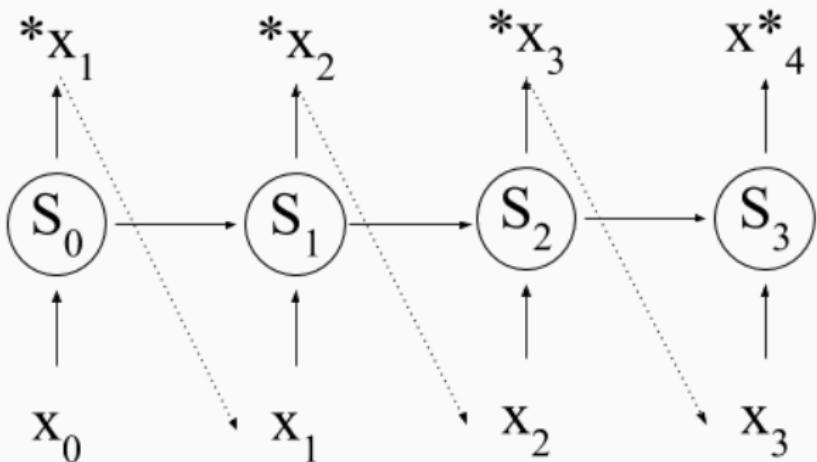
(e.g., Bitcoin price prediction, language modeling).

Sequence Modeling





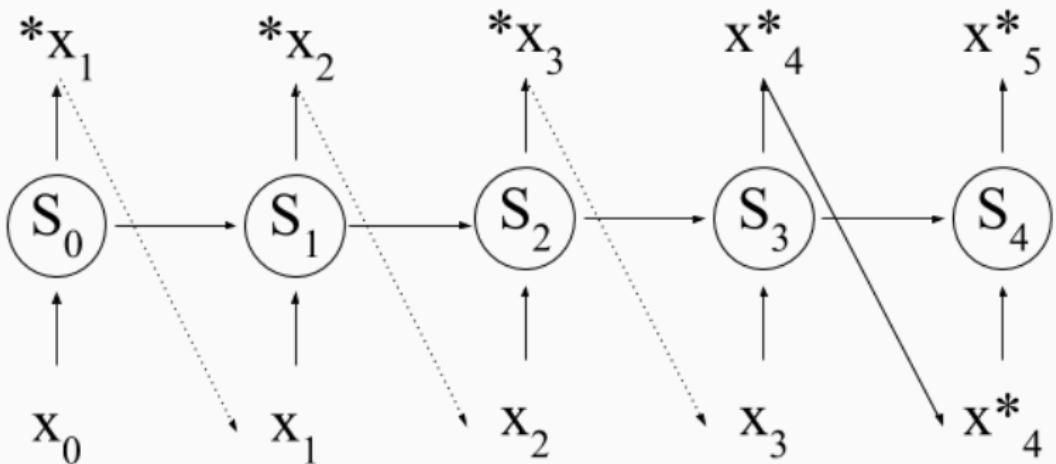
Teacher Forcing



Do we use the previously predicted value or the ground truth value as input?



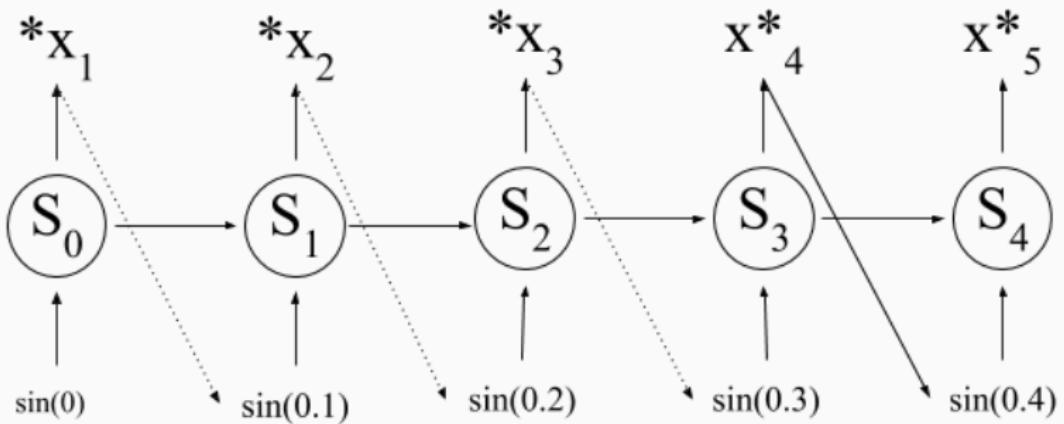
Extrapolation!



Continuously feed the output of the model back in to generate future points.

RNN Demo

Modeling a Sine Wave



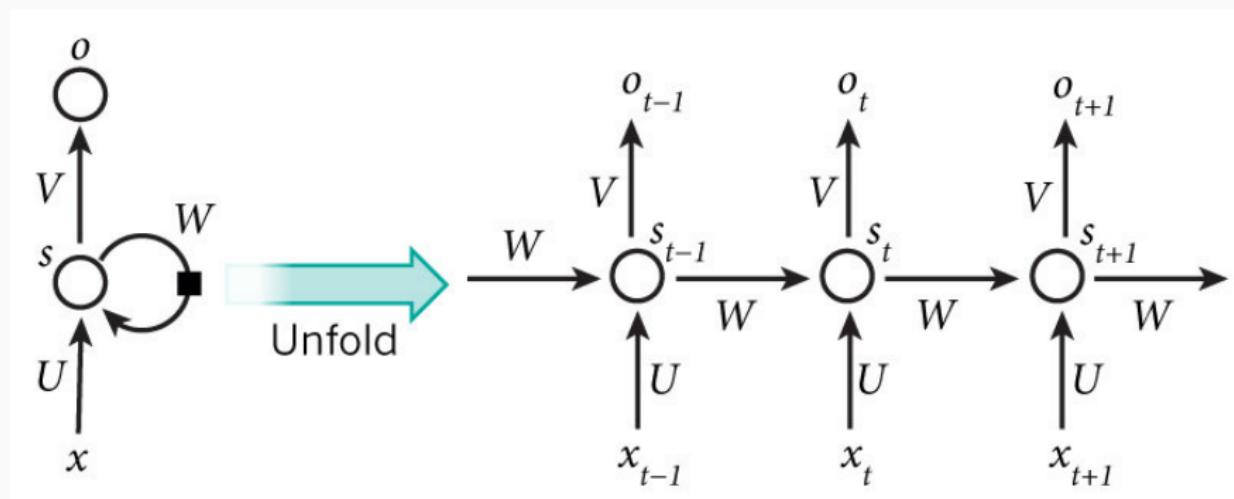
Input and Output of Model



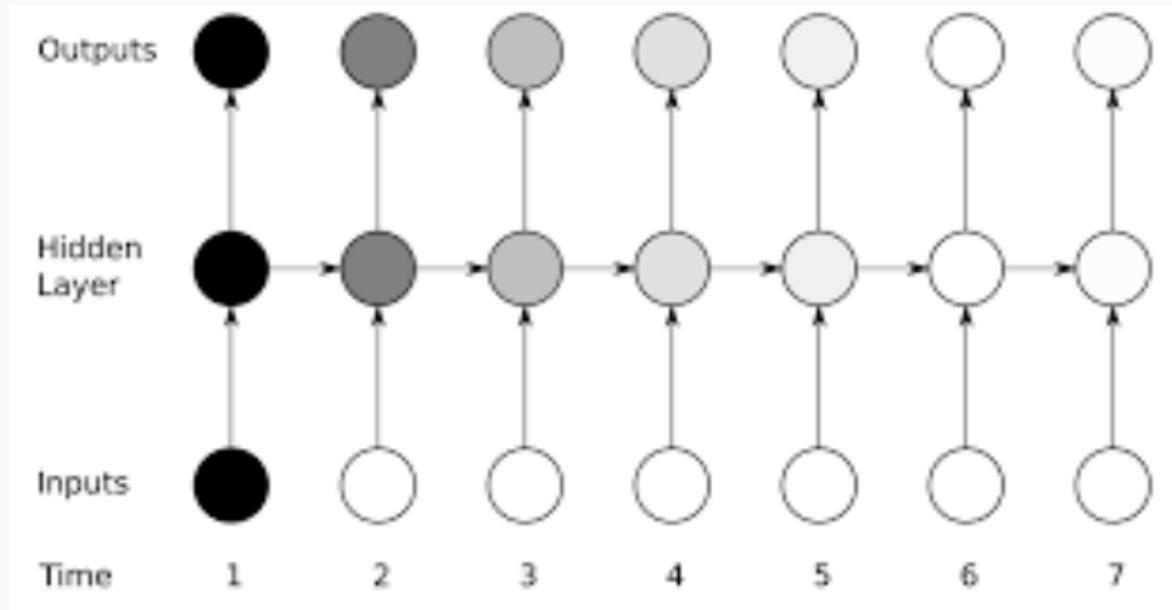
Input	y_0	y_1	...	y_{n-1}
Output	$*y_1$	$*y_2$...	$*y_n$
Target	y_1	y_2	...	y_n

Long Short-Term Memory Networks (LSTMs)

RNN Review

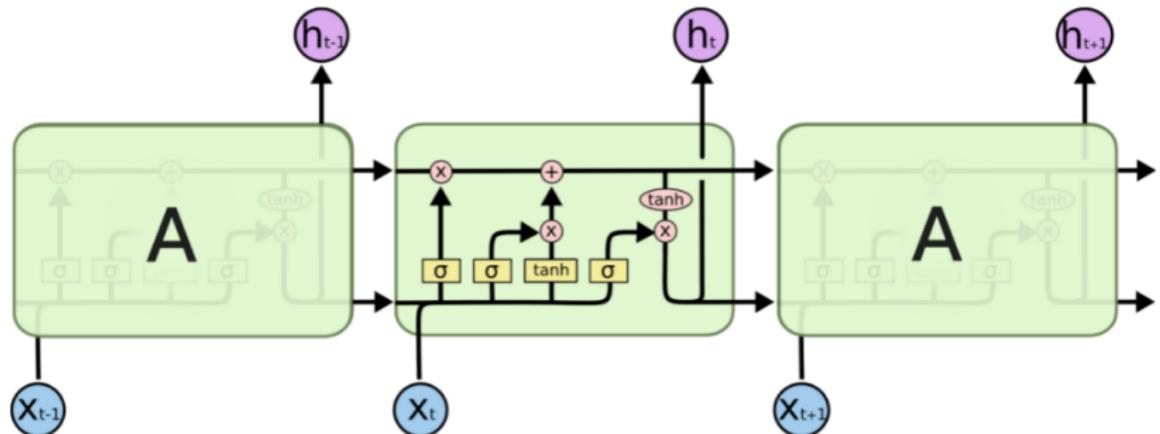


Vanishing Gradient Problem



As we change the input weight matrix U , signal from earlier timesteps exponentially decays through time.

LSTMs: A Solution to Vanishing Gradient



Neural Network Layer

Pointwise Operation

Vector Transfer

Concatenate

Copy

Fundamental Idea

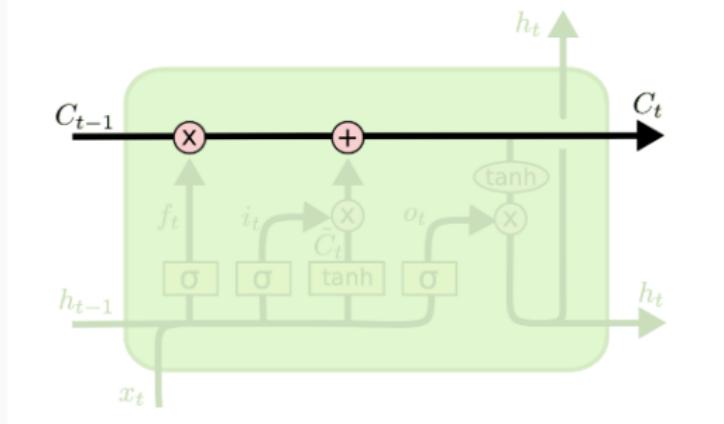


Why does the LSTM avoid the vanishing gradient issue?



Fundamental Idea

Why does the LSTM avoid the vanishing gradient issue?



The cell state is a single, continuous 'information highway' across the entire calculation that does not have any matrix multiplications!

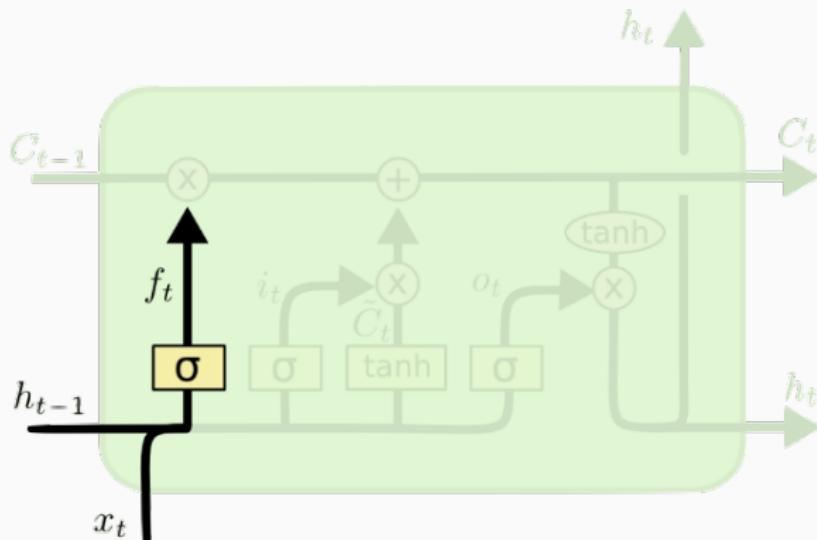


LSTMs contain five parts:

- A cell state.
- A forget gate.
- An input gate.
- An update gate.
- An output gate.



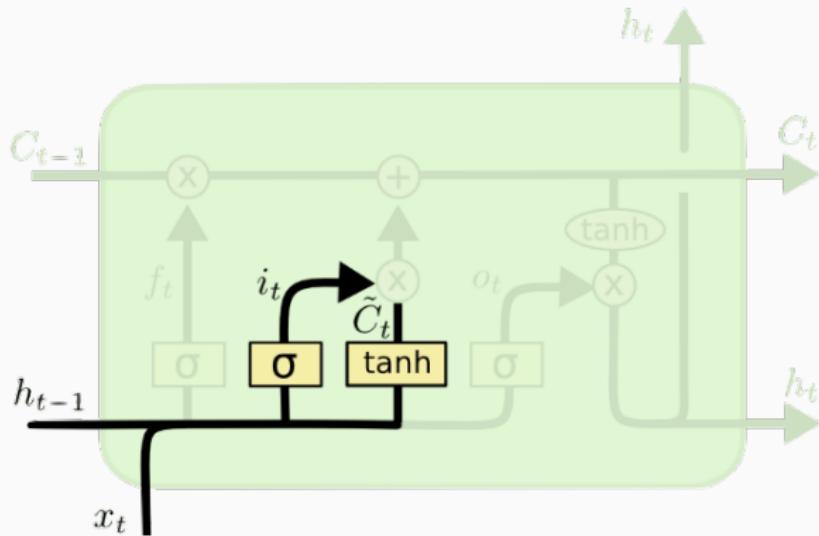
The Forget Gate Layer



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



The Input Gate Layer

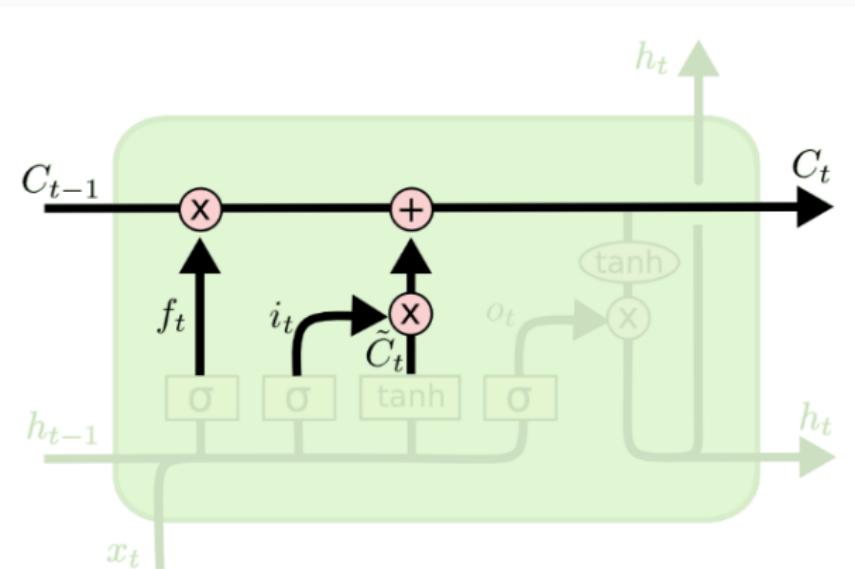


$$i_t = \sigma(W_i \cdot [h_{t-1}, x_t] + b_i)$$

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



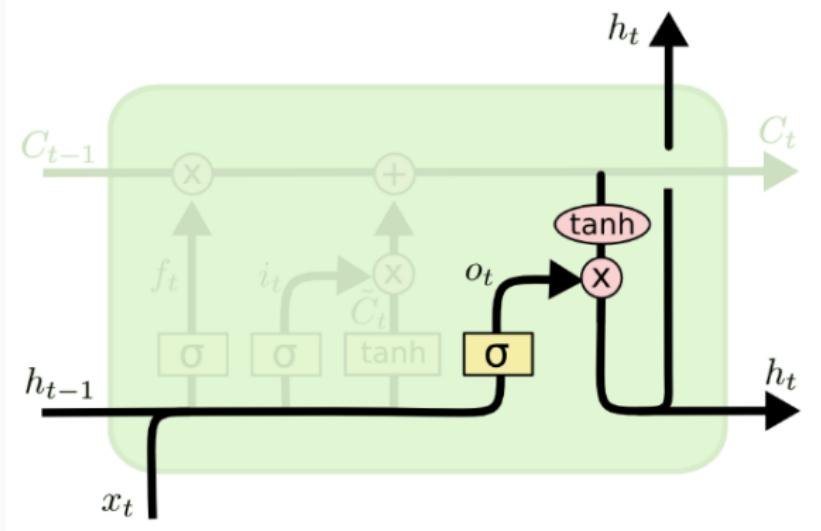
The Update Gate Layer



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



The Output Gate Layer



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

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

LSTM Recap



LSTM Recap



- Determine which parts of the cell state should be forgotten ('forget mask').

LSTM Recap



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- Determine how ('cell state candidate') and to what extent ('update mask') you want to add to the cell state.

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- Determine which parts of the cell state you want to be present in the hidden state ('hidden mask').
- Set the hidden state to the tanh activated cell state multiplied by the 'hidden mask'. Output the hidden state.

LSTM Demo 1

Revisiting the Sine Wave



When we used an RNN we fixed the starting position for all sine waves to $x = 0$.

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What do we do now?

Revisiting the Sine Wave



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Revisiting the Sine Wave



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Perhaps if we gave our model the capability of learning this phase from part of the wave, we could then use a similar RNN to model the rest of the sine wave!

Revisiting the Sine Wave

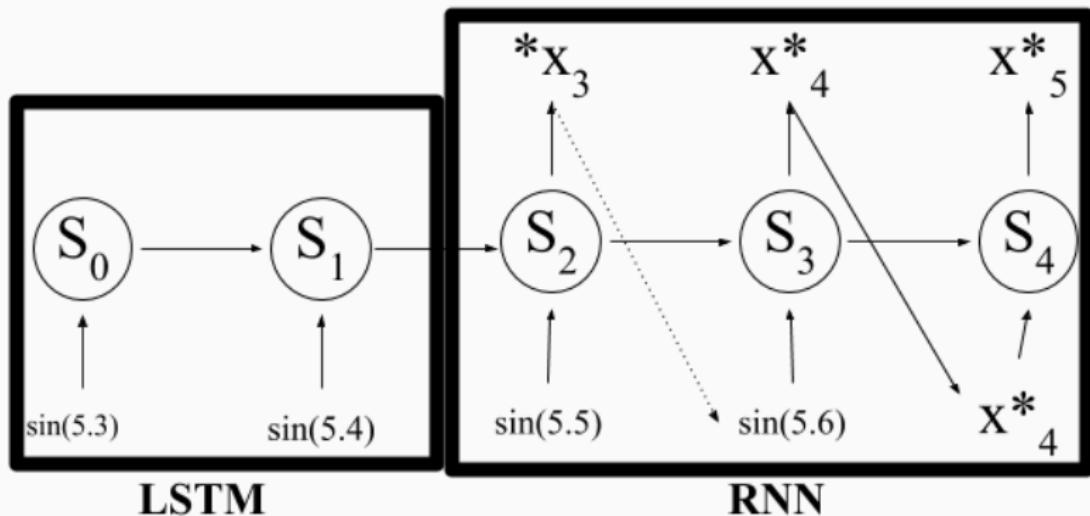


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Idea: Pass the first half of the wave through an LSTM to encode the phase, or whatever information it thinks might be relevant. Then use the earlier process on the rest of the wave with a RNN.

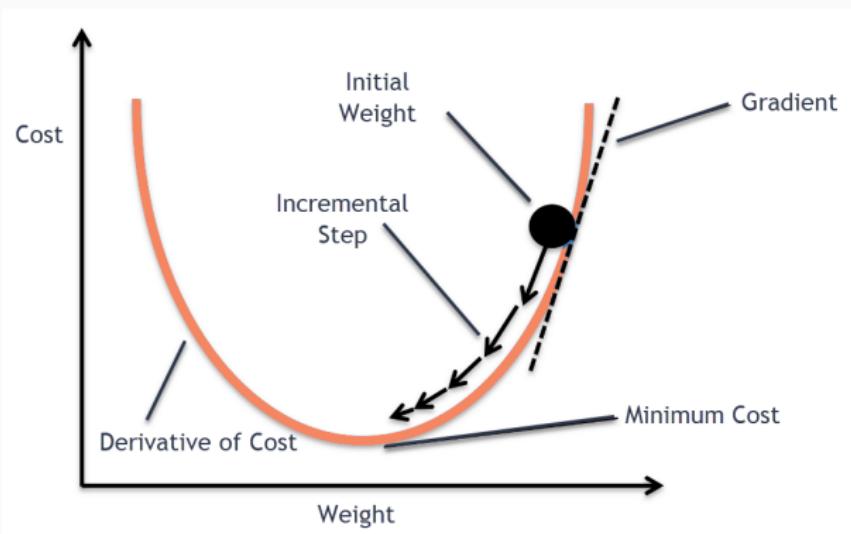
LSTM Encoder + RNN



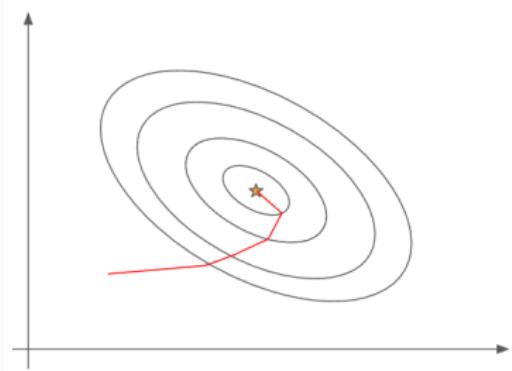
Momentum



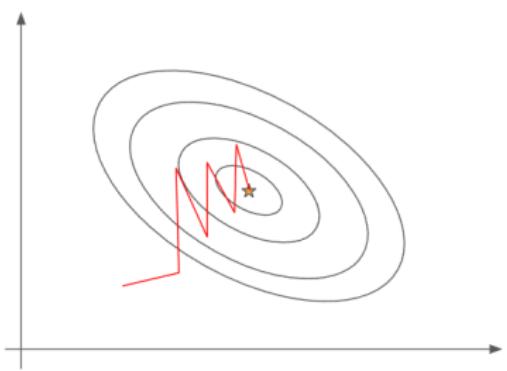
Ideal Gradient Descent



Stochastic Gradient Descent



Gradient Descent



Stochastic Gradient Descent

Enhancing Gradient Descent



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Enhancing Gradient Descent



- LSTMs can be difficult to train because the weights must be applicable to any input at any possible time step.
- Basic gradient descent only considers the current location, and is thus sensitive to specific data points.
- A good model should aggregate feedback as opposed to reacting to all feedback independently.

An Idea



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In typical mini batch learning, this direction entirely changes as each batch.

We still want to update weights frequently, ruling out massive batch sizes.

What if instead of exclusively considering the previous batch we consider previous data as well?

Momentum

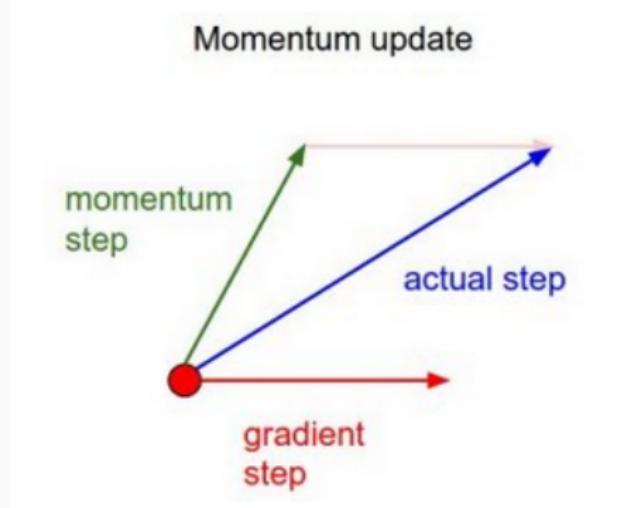


Use batch gradient to update *how we update* weights.

Momentum



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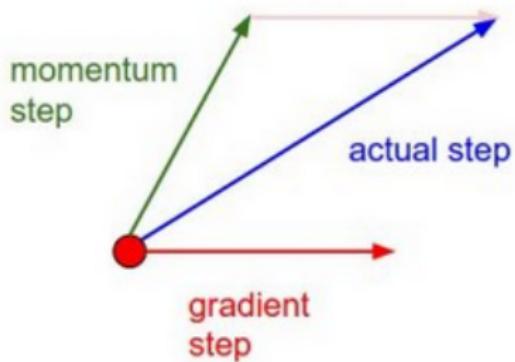




Momentum

Use batch gradient to update *how we update* weights.

Momentum update



$$z^{(t)} = \beta z^{(t-1)} + (1-\beta) \nabla_{\theta} C(\theta; X, y)$$

$$w^{(t)} = w^{(t-1)} - \alpha z^{(t)}$$

Key Benefits



- Allows for aggregation without having to use large batch sizes.

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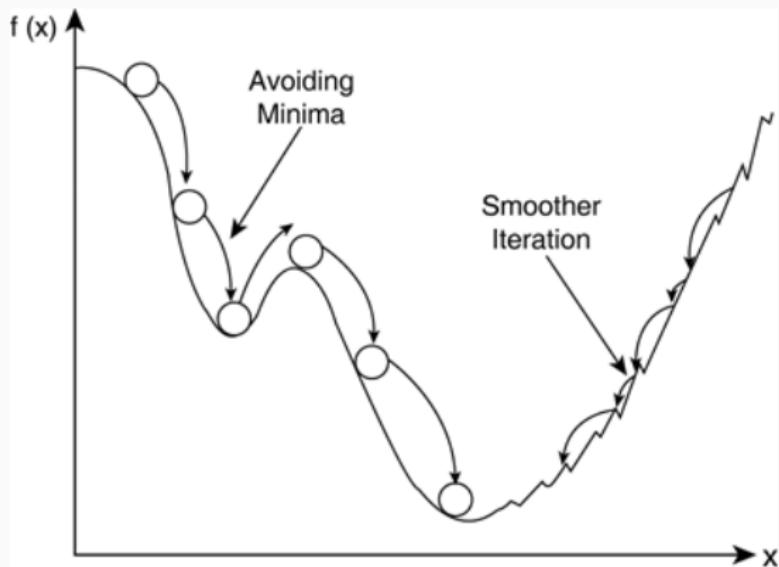
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Key Benefits



- Allows for aggregation without having to use large batch sizes.
- Smoother iteration to reduce sensitivity to variable loss surfaces.
- Escape poor local minimums.

Optimization Methods



Other Enhanced Gradient Descent Algorithms



Most all neural networks benefit from some form of enhanced Gradient Descent, not only LSTM's.

Other Enhanced Gradient Descent Algorithms



Most all neural networks benefit from some form of enhanced Gradient Descent, not only LSTM's.

Some popular optimization algorithms used:

- Adam
- RMSProp
- Adagrad
- Adadelta
- Nesterov Momentum

All are fundamentally based in Gradient Descent!

LSTM Demo 2

Text Generation



Now we are going to try to generate novel text using an LSTM.

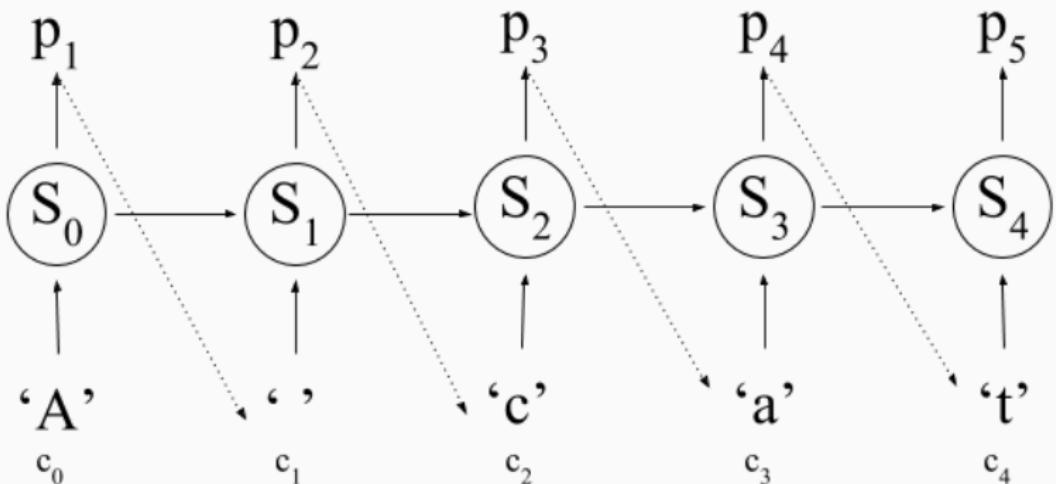
Text Generation



Now we are going to try to generate novel text using an LSTM.

The idea is that we let the model 'read' a lot of existing english text, so that it can learn how to model the language and reproduce similar samples.

Model Architecture



Note: p_i represents a probability distribution spanning all possible characters for character i .

Analyzing LSTMs



Cell that turns on inside quotes:

```
"You mean to imply that I have nothing to eat out of.... On the  
contrary, I can supply you with everything even if you want to give  
dinner parties," warmly replied Chichagov, who tried by every word he  
spoke to prove his own rectitude and therefore imagined Kutuzov to be  
animated by the same desire.  
  
Kutuzov, shrugging his shoulders, replied with his subtle penetrating  
smile: "I meant merely to say what I said."
```

LSTMs keep track of interesting information!

Analyzing LSTMs



Cell that robustly activates inside if statements:

```
static int __dequeue_signal(struct sigpending *pending, sigset_t *mask,
    siginfo_t *info)
{
    int sig = next_signal(pending, mask);
    if (sig) {
        if (current->notifier) {
            if (sigismember(current->notifier_mask, sig)) {
                if (!!(current->notifier)(current->notifier_data)) {
                    clear_thread_flag(TIF_SIGPENDING);
                    return 0;
                }
            }
        }
        collect_signal(sig, pending, info);
    }
    return sig;
}
```

Analyzing LSTMs



Cell sensitive to position in line:

The sole importance of the crossing of the Berezina lies in the fact that it plainly and indubitably proved the fallacy of all the plans for cutting off the enemy's retreat and the soundness of the only possible line of action--the one Kutuzov and the general mass of the army demanded--namely, simply to follow the enemy up. The French crowd fled at a continually increasing speed and all its energy was directed to reaching its goal. It fled like a wounded animal and it was impossible to block its path. This was shown not so much by the arrangements it made for crossing as by what took place at the bridges. When the bridges broke down, unarmed soldiers, people from Moscow and women with children who were with the French transport, all--carried on by vis inertiae--pressed forward into boats and into the ice-covered water and did not, surrender.

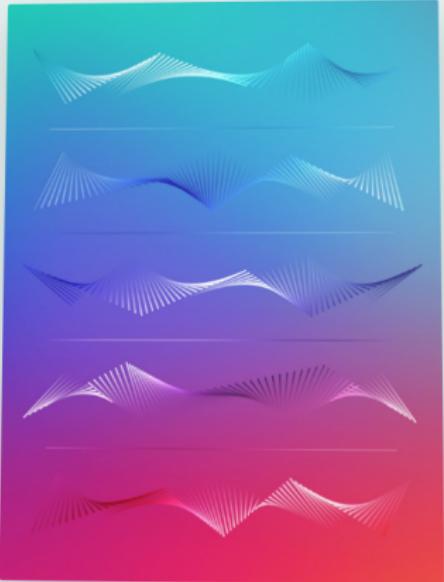
Analyzing LSTMs



Cell that might be helpful in predicting a new line. Note that it only turns on for some "):

```
char *audit_unpack_string(void **bufp, size_t *remain, si
{
    char *str;
    if (!*bufp || (len == 0) || (len > *remain))
        return ERR_PTR(-EINVAL);
    /* of the currently implemented string fields, PATH_MAX
     * defines the longest valid length.
     */
    if (len > PATH_MAX)
        return ERR_PTR(-ENAMETOOLONG);
    str = kmalloc(len + 1, GFP_KERNEL);
    if (unlikely(!str))
        return ERR_PTR(-ENOMEM);
    memcpy(str, *bufp, len);
    str[len] = 0;
    *bufp += len;
    *remain -= len;
    return str;
}
```

Analyzing LSTMs



APRIL 6, 2017

Unsupervised Sentiment Neuron

We've developed an [unsupervised](#) system which learns an excellent representation of sentiment, despite being trained only to predict the next character in the text of Amazon reviews.

A [linear model](#) using this representation achieves state-of-the-art sentiment analysis accuracy on a small but extensively-studied dataset, the Stanford Sentiment Treebank (we get 91.8% accuracy versus the previous best of 90.2%), and can match the performance of previous supervised systems using 30-100x fewer labeled examples. Our representation also contains a distinct "[sentiment neuron](#)" which contains almost all of the sentiment signal.

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