Sequence Models

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RNNs

Slides adapted from Richard Socher and Phillip Koehn

Language models

- **Language models** answer the question: How likely is a string of English words good English?
- Autocomplete on phones and websearch
- Creating English-looking documents
- Very common in machine translation systems
  - Help with reordering / style

$$p_{\text{lm}}(\text{the house is small}) > p_{\text{lm}}(\text{small the is house})$$

  - Help with word choice

$$p_{\text{lm}}(\text{I am going home}) > p_{\text{lm}}(\text{I am going house})$$

Fill in the blank

I have a sad story to tell you
It may hurt your feelings a bit
Last night when I walked into my bathroom
I stepped in a big pile of . . .

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Language Modeling: The Good Old Days

n-gram models

- Have a big corpus
- Count n-gram sequences
- Estimate
  $p(w_n \mid w_{n-1} \dots w_{n-k}) =$

$$\frac{\text{Count}(w_{n-k} \dots w_{n-1} w_n)}{\text{Count}(w_{n-k} \dots w_{n-1})} \quad (1)$$

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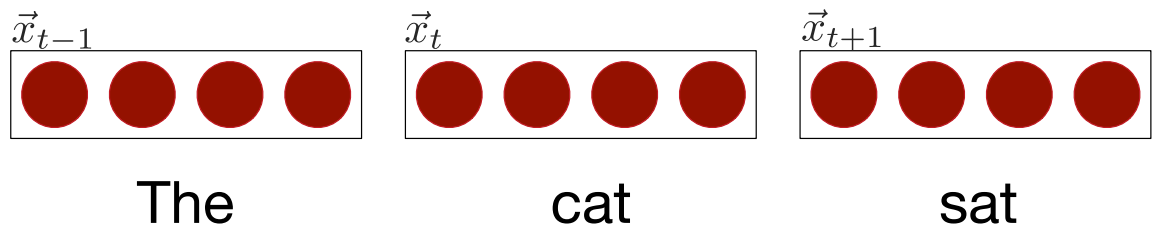
Log-linear models

- Define a feature vector f based on word w and context c
- (Can include n-gram features)
- Learn β from data
- Then $p(w \mid c) =$

$$\frac{\exp\{\beta f(w, c)\}}{\sum_v \exp\{\beta f(v, c)\}} \quad (2)$$

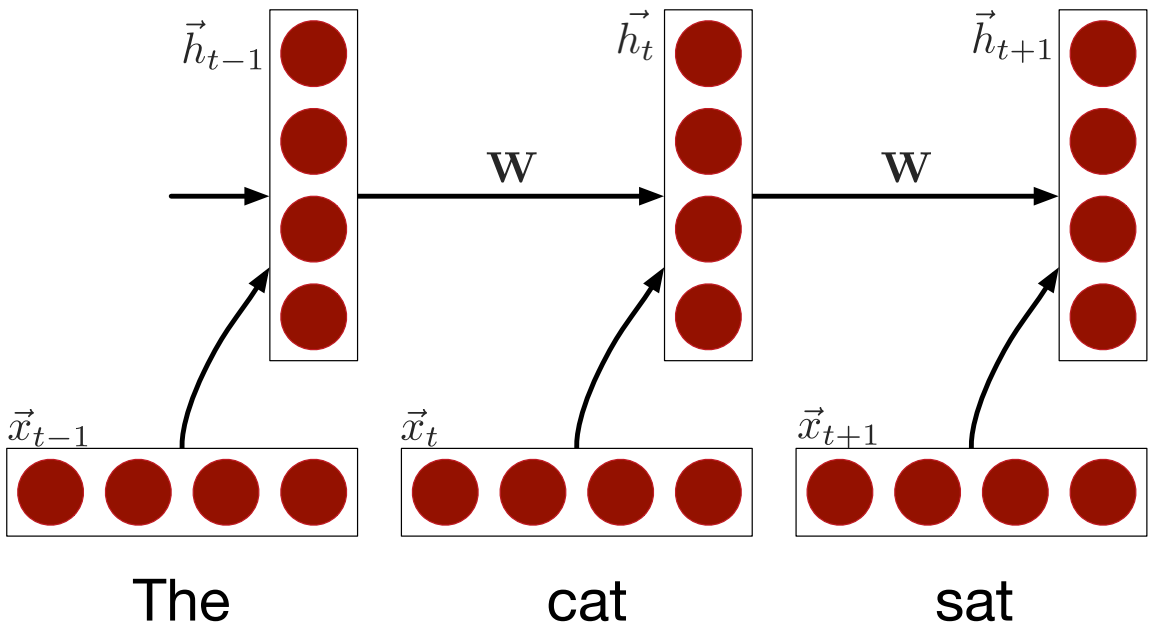
Reccurent Neural Networks

Use Word2Vec or learn representations from scratch



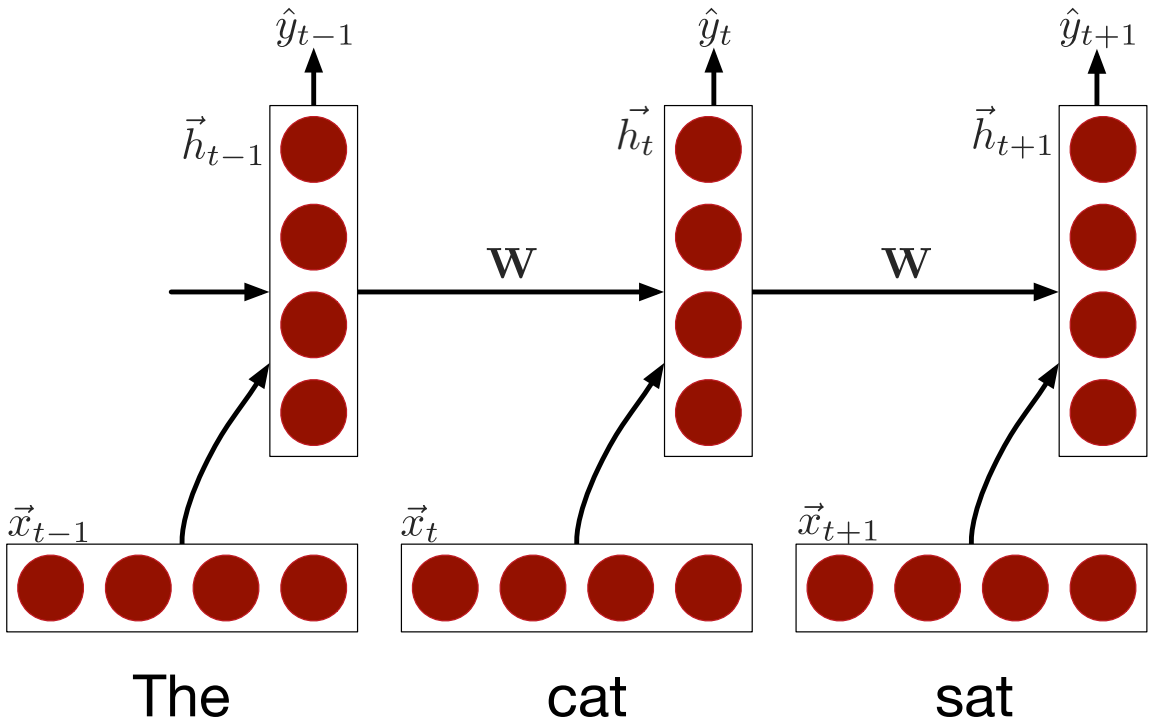
Reccurent Neural Networks

Each hidden state has $D = 500$ or so



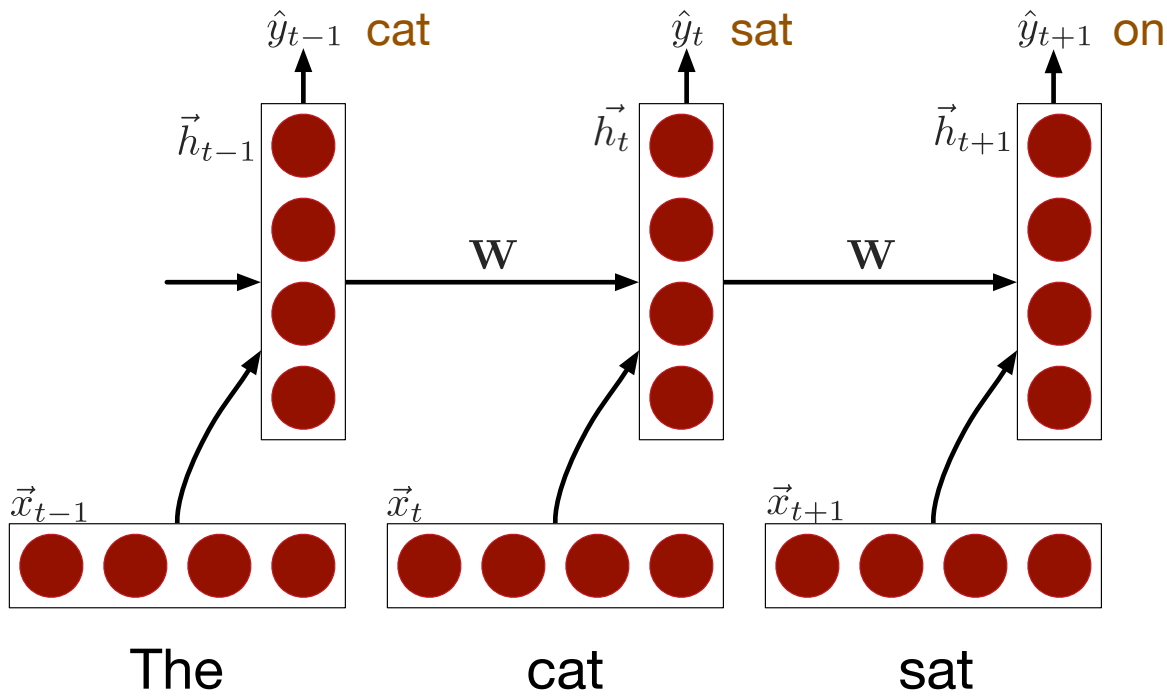
Reccurent Neural Networks

Transform hidden state to V (vocab) matrix $\mathbf{W}^{(s)}\vec{h}_t$



Reccurent Neural Networks

Take softmax to get real distribution



RNN parameters

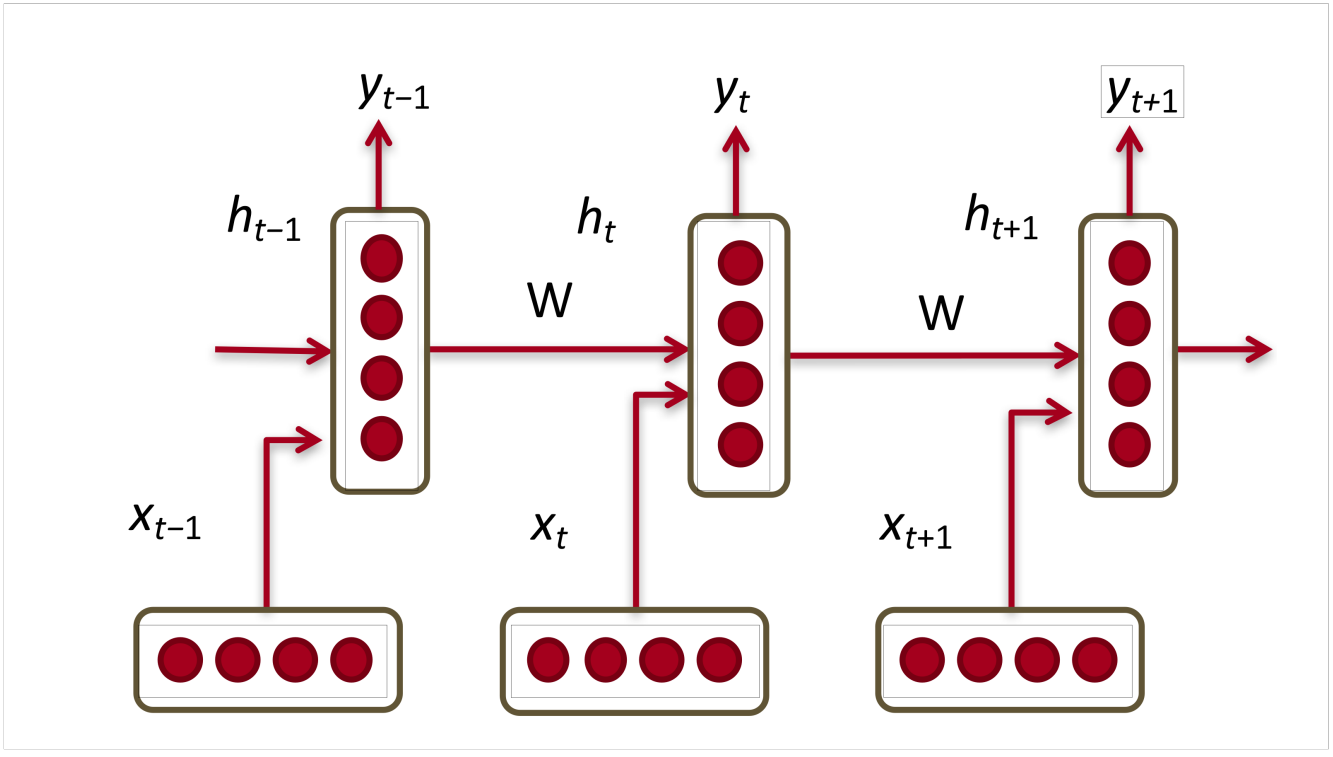
$$h_t = f(W^{(hh)} h_{t-1} + W^{(hx)} x_t) \tag{3}$$

$$\hat{y}_t = \text{softmax}(W^{(S)} h_t) \tag{4}$$

$$P(x_{t+1} = v_j \mid x_t, \ldots x_1) = \hat{y}_{t,j} \tag{5}$$

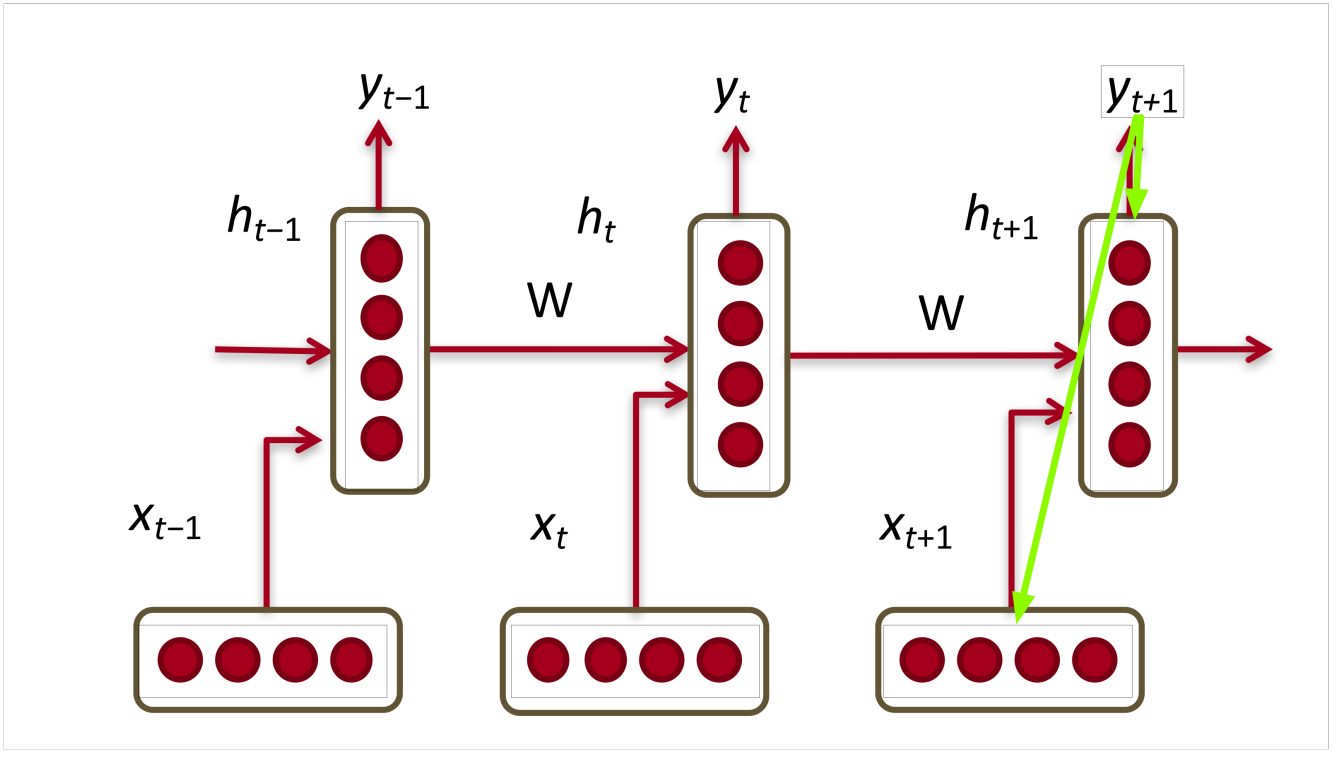
- Learn parameter h_0 to initialize hidden layer
- x_t is representation of input (e.g., word embedding)
- $\hat{y}$ is probability distribution over vocabulary

Training Woes



Multiplying same matrix over and over

Training Woes



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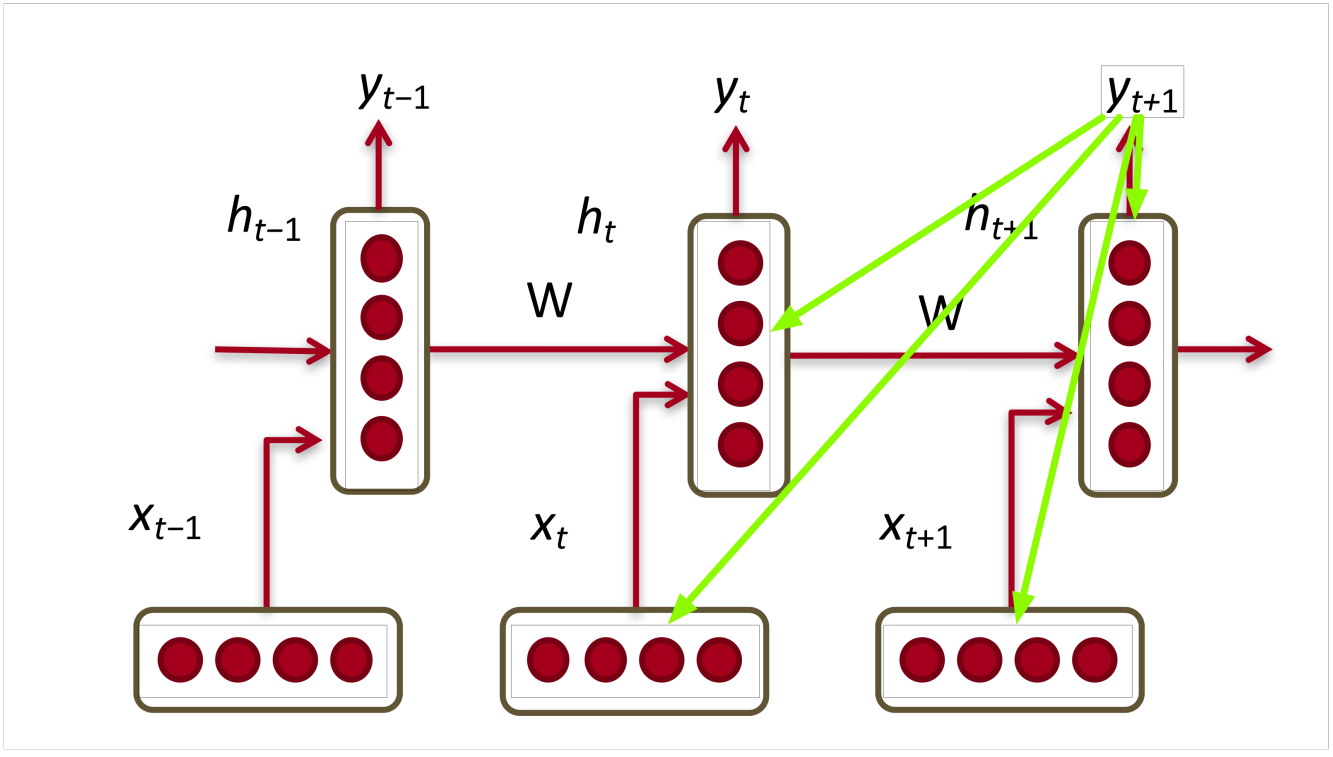

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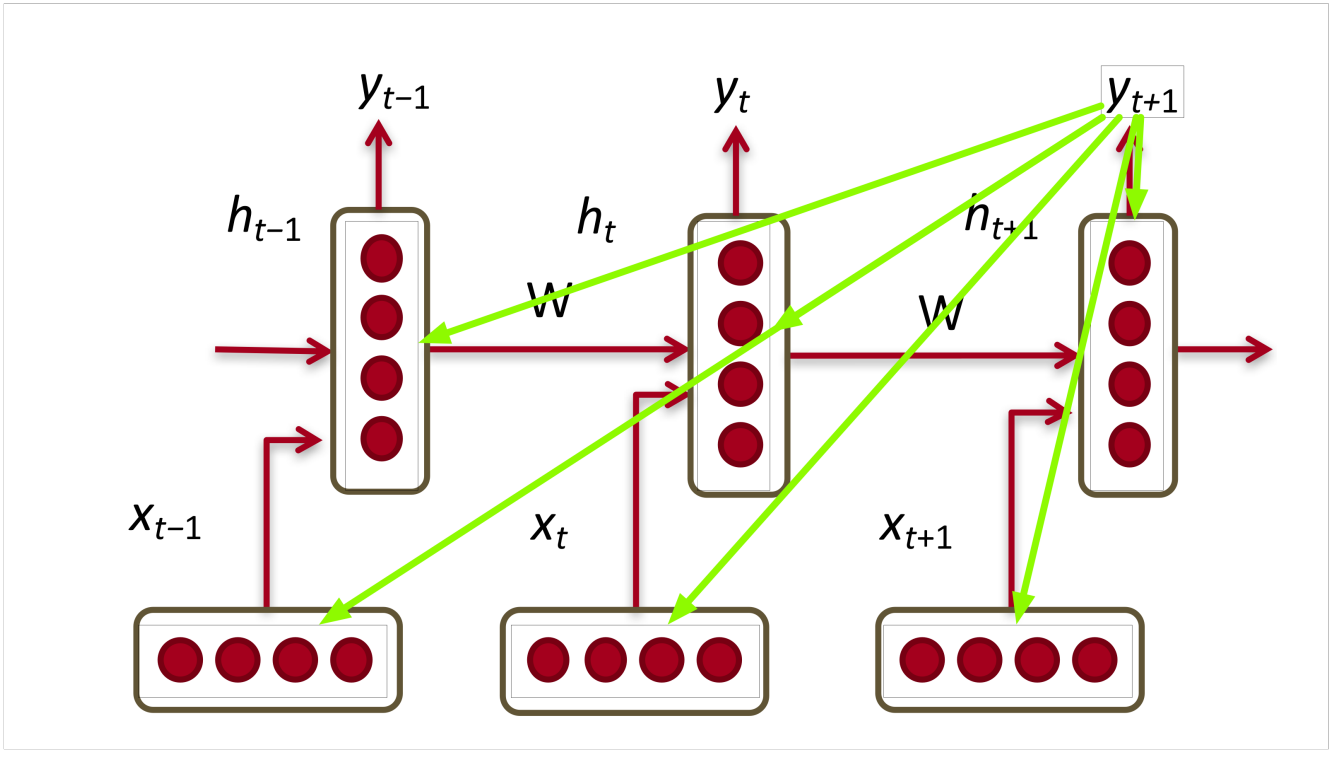


Multiplying same matrix over and over

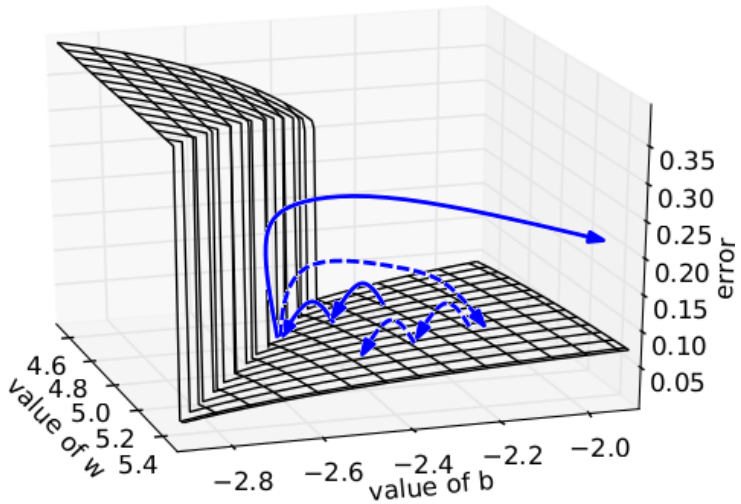
Vanishing / Exploding Gradient

- Work out the math:
  - Define β_W / β_h as upper bound of norms of W, h
  - Bengio et al 1994: Partial derivative is $(\beta_W \beta_h)^{t-k}$
  - This can be very small or very big
- If it's big, SGD jumps too far
- If it's small, we don't learn what we need: "Jane walked into the room with John, who wasn't paying attention to what was going on. After poking him to get his attention, John said hi to _____"

Gradient Clipping

Algorithm 1 Pseudo-code for norm clipping the gradients whenever they explode

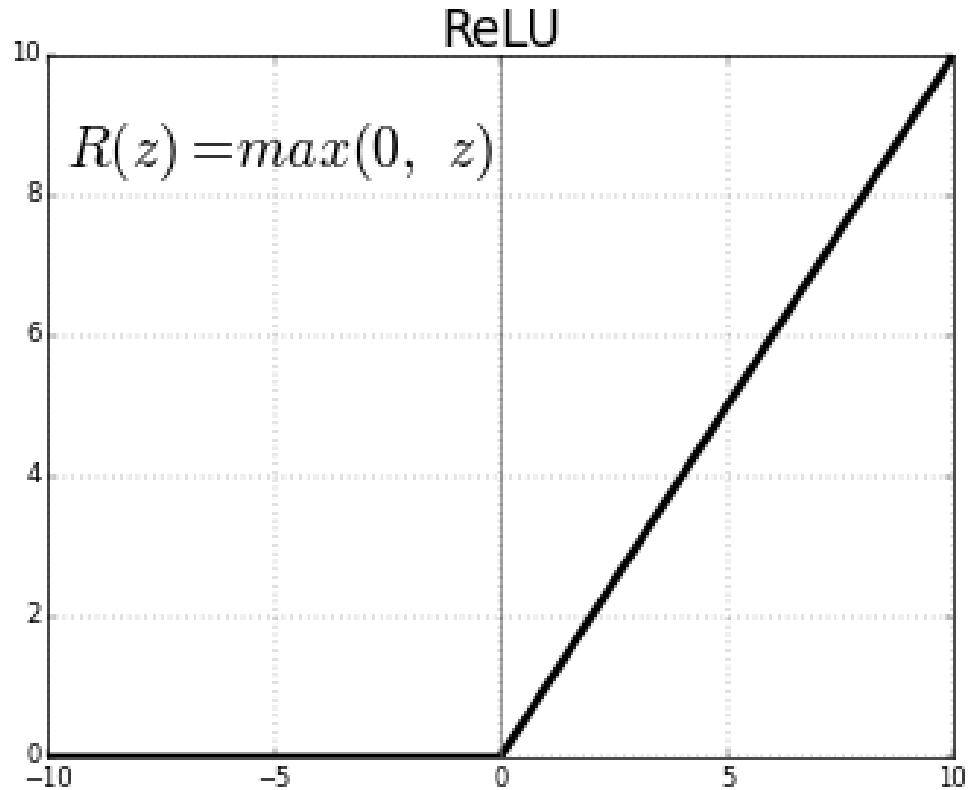
$\hat{\mathbf{g}} \leftarrow \frac{\partial \mathcal{E}}{\partial \theta}$
if $\|\hat{\mathbf{g}}\| \geq threshold$ **then**
  $\hat{\mathbf{g}} \leftarrow \frac{threshold}{\|\hat{\mathbf{g}}\|}\hat{\mathbf{g}}$
end if



From Pascanu et al. 2013

- If they get too big, stop at boundary
- Prevents (dashed) values from jumping around (solid)

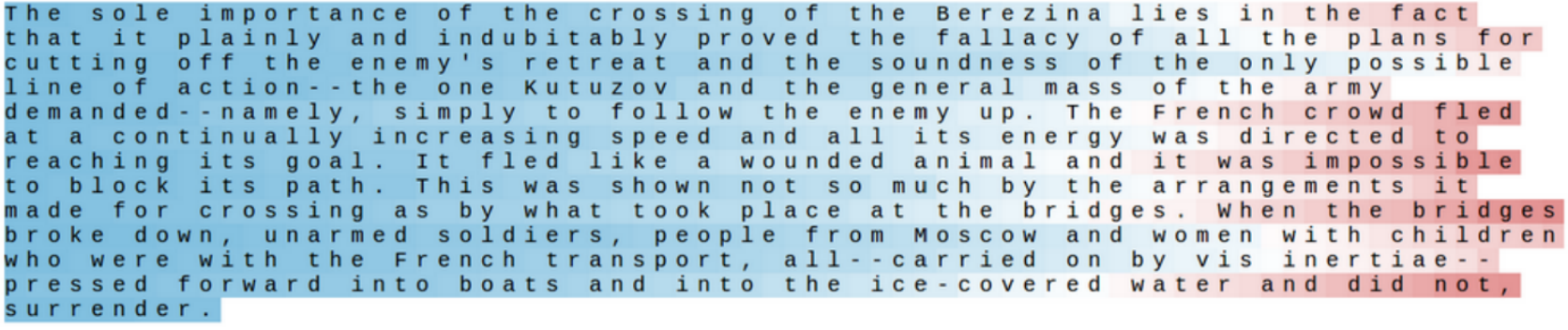
Fixing Vanishing Gradients



- ReLU activation
- Initialize W to identity matrix

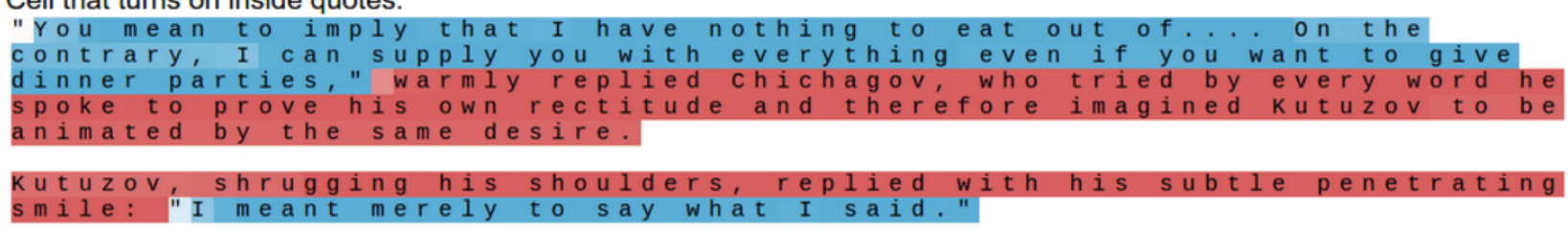
Vizualization from Karpathy et al

Cell sensitive to position in line:



Vizualization from Karpathy et al

Cell that turns on inside quotes:



Vizualization from Karpathy et al

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;
}
```

RNN Recap

- Simple model
- Complicated training (but good toolkits available)
- Do we need to remember everything?