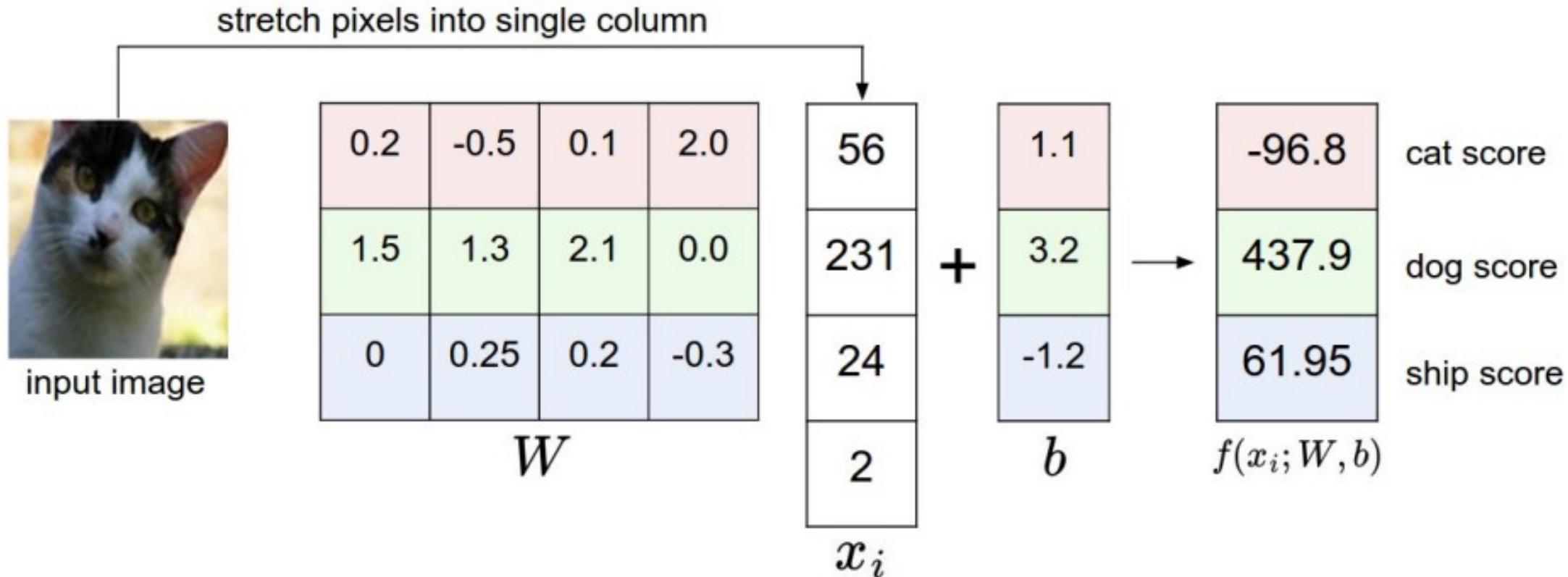


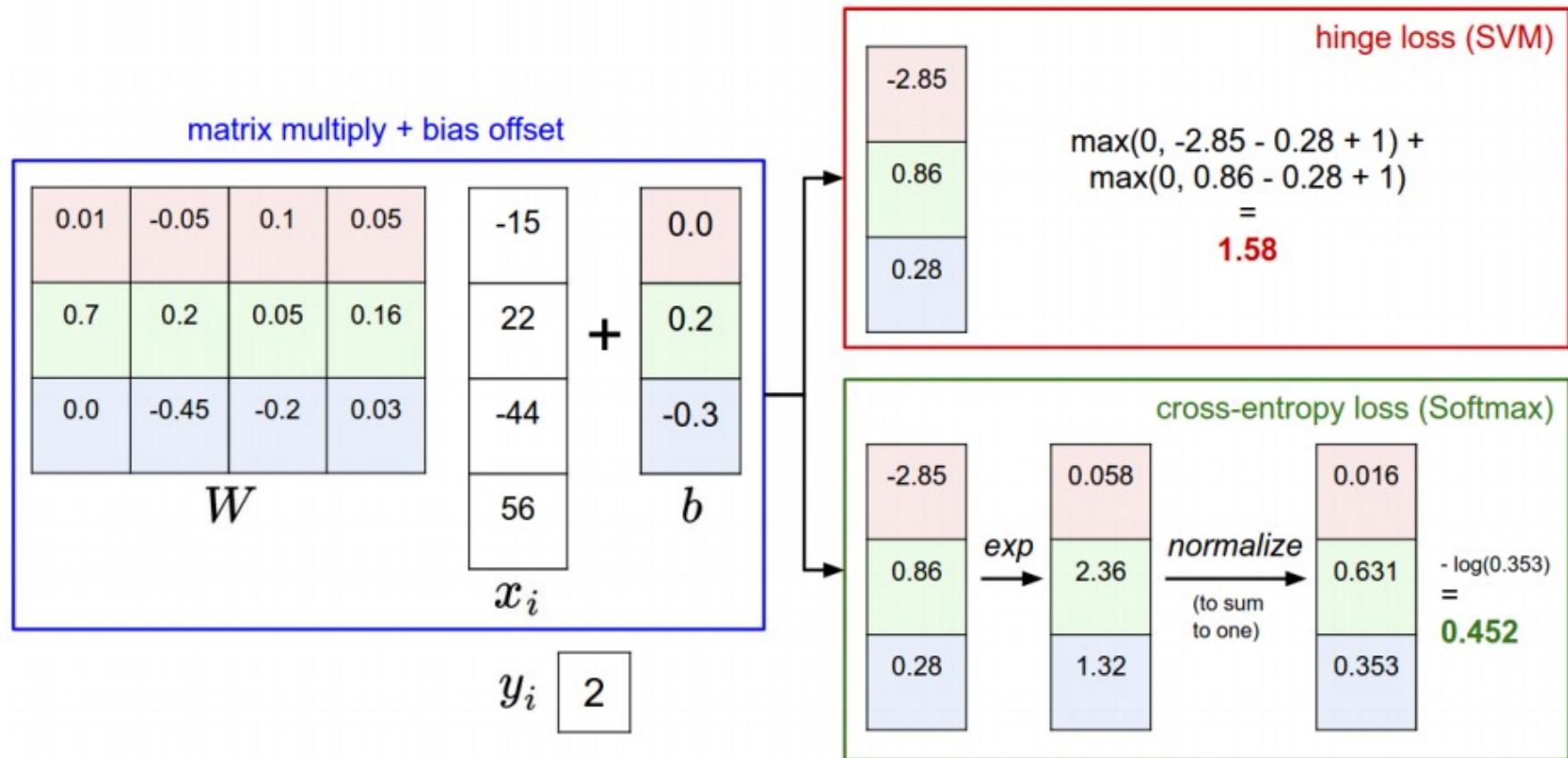
# Administrative

- **Poster Session** on Wednesday!
  - <http://cs231n.stanford.edu/postersession.html>
  - Facebook group: <https://www.facebook.com/events/1024309900974098/>
- **If using AWS, use EBS**
  - Instructions on Piazza
- **A3 Grades** out soon

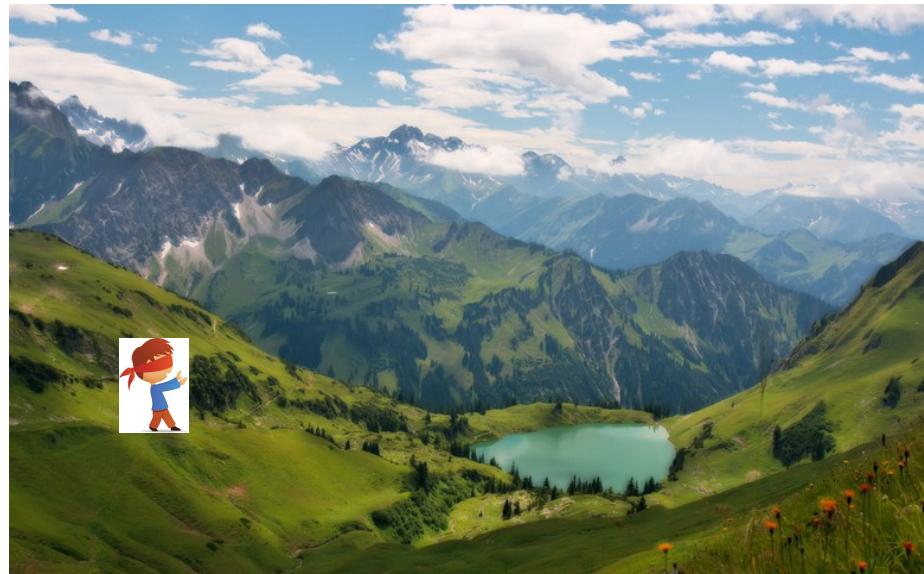
# Together, we've defined Score Functions...



# And Loss Functions...

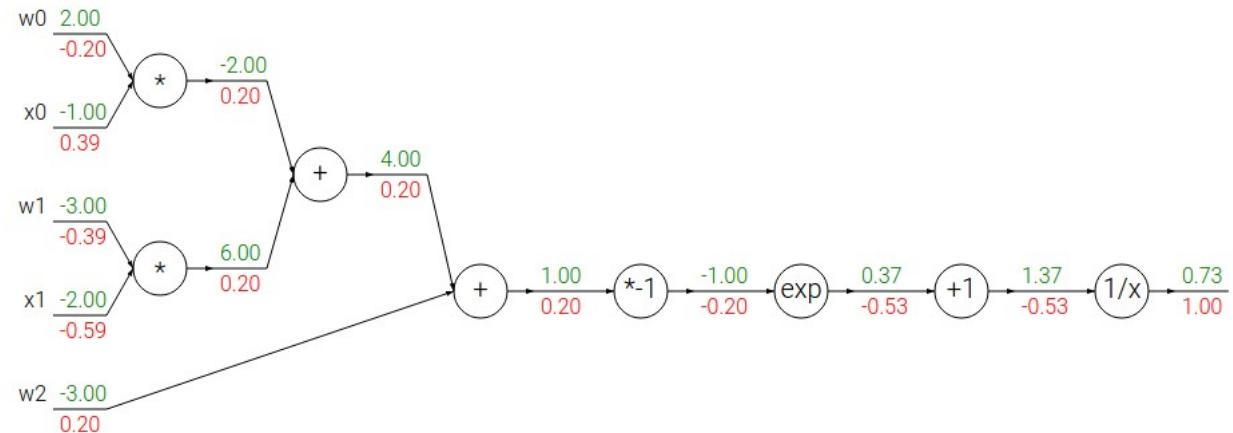


# We've learned how to optimize them...

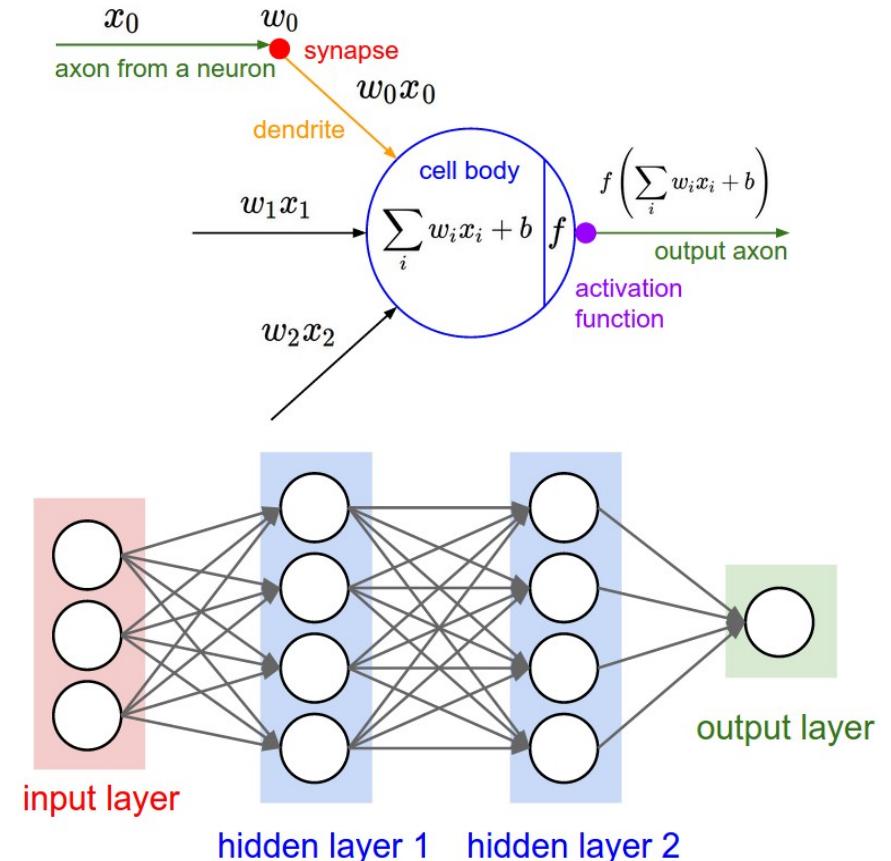
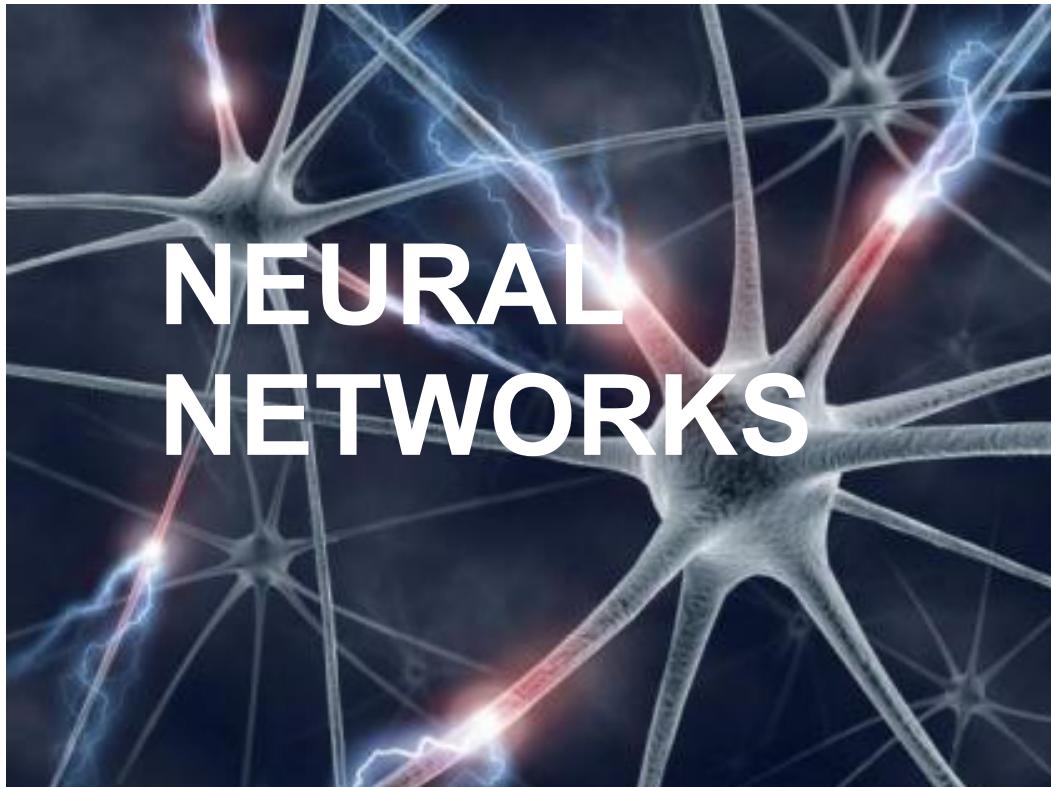


Chain rule:

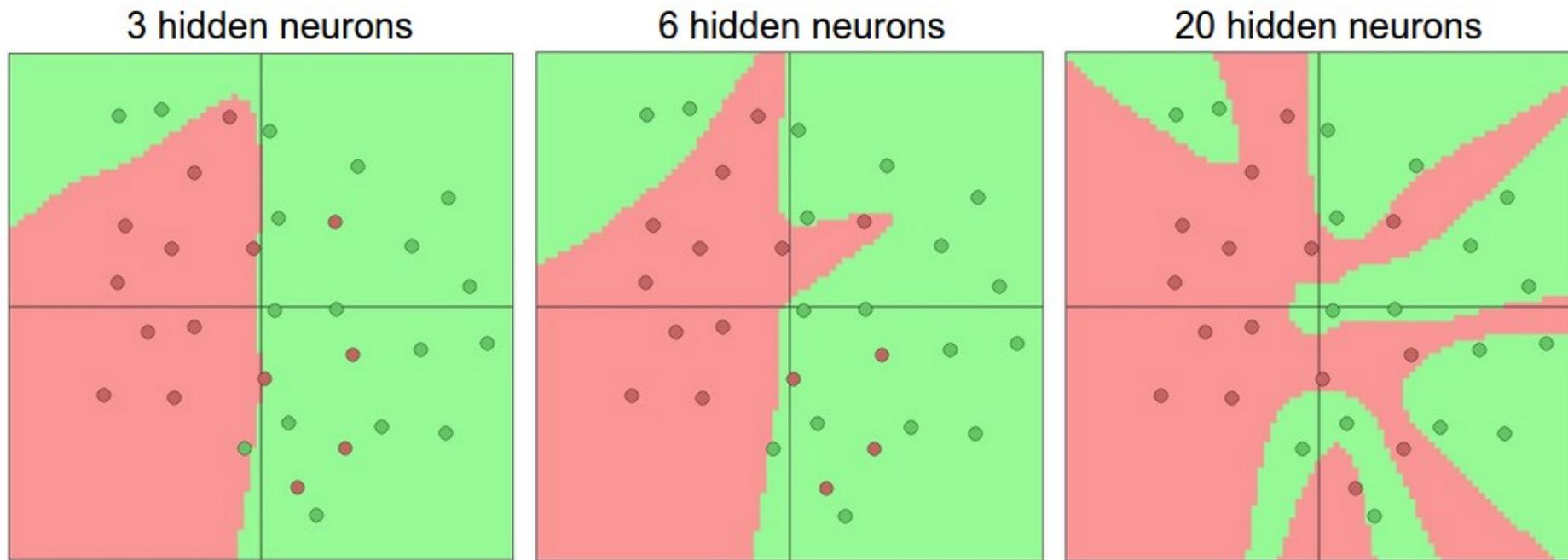
$$\frac{\partial f}{\partial x} = \frac{\partial f}{\partial q} \frac{\partial q}{\partial x}$$



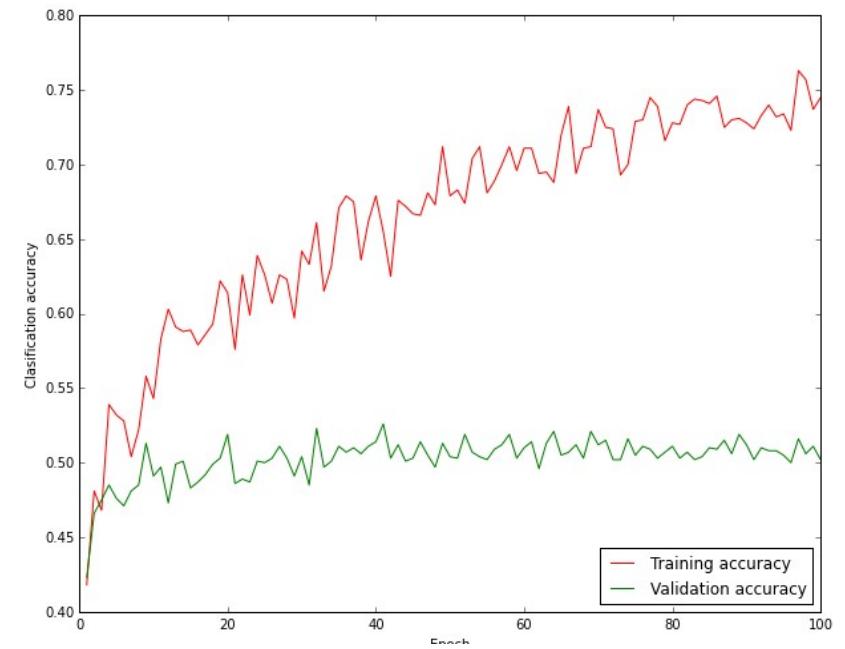
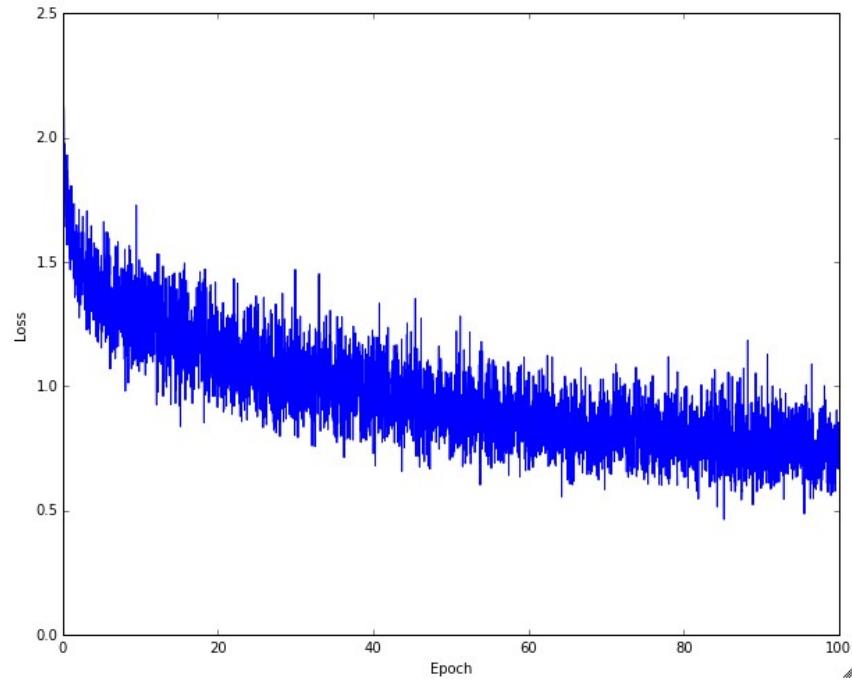
# We learned to express more powerful Score Functions...



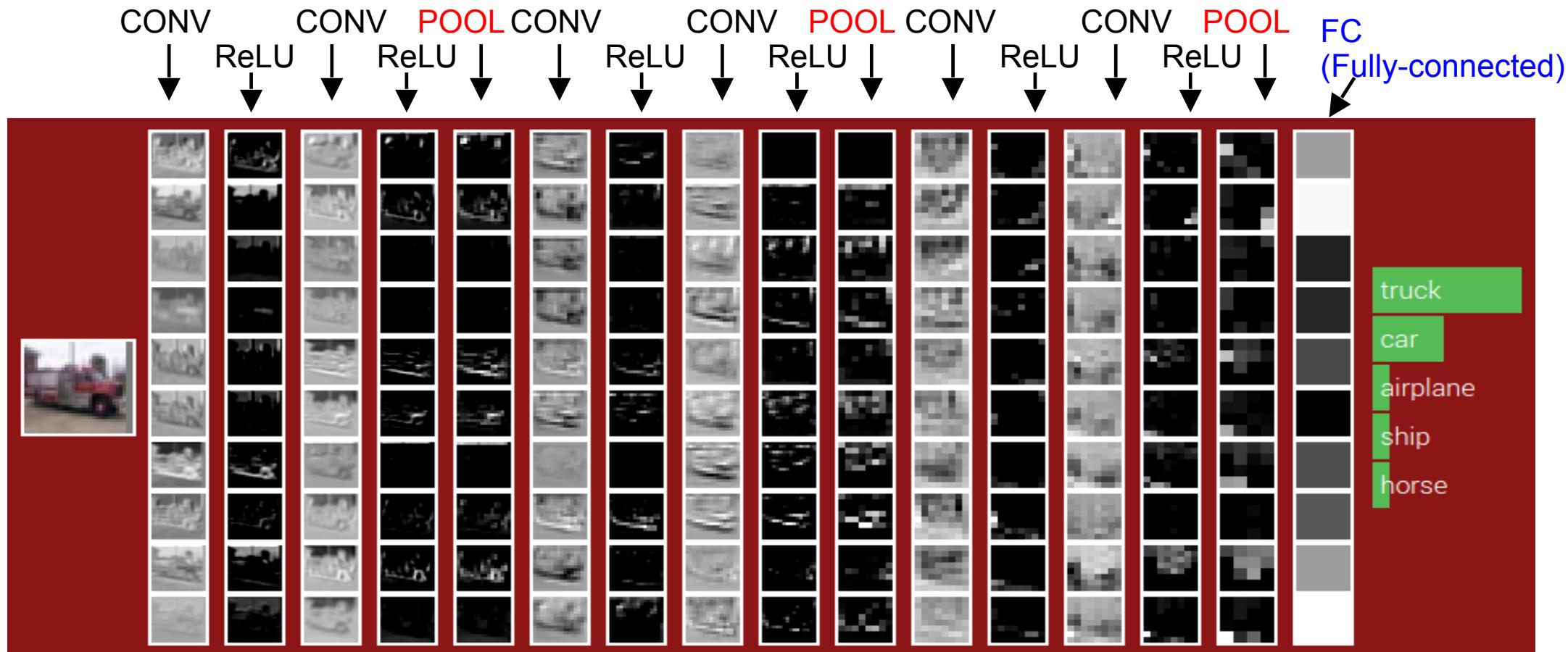
# For an extra wiggle...



# Together we tamed the learning process...



# Together we explored image-specific Neural Nets...



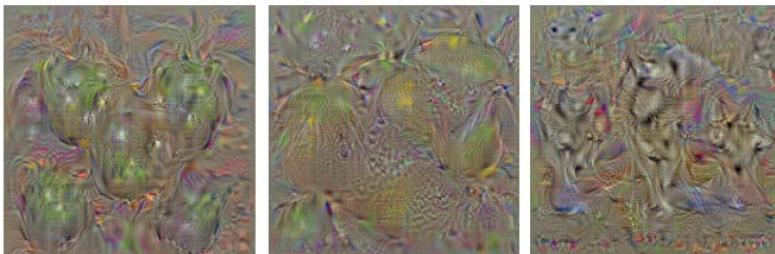
# We explored how they work...



dumbbell

cup

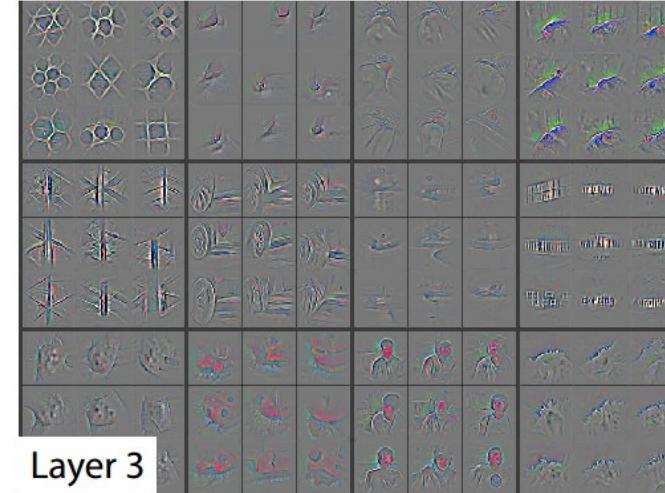
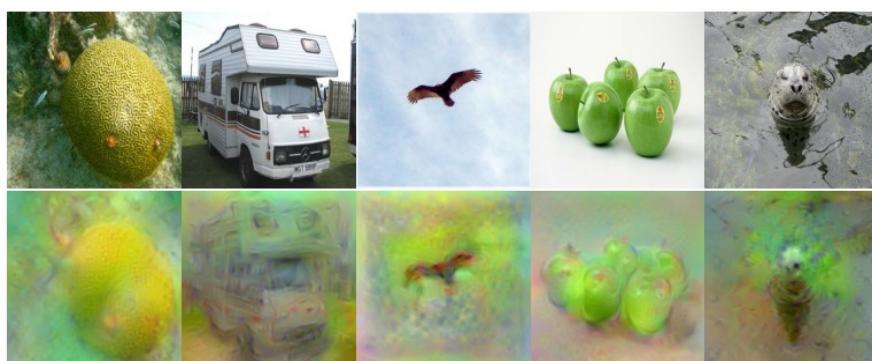
dalmatian



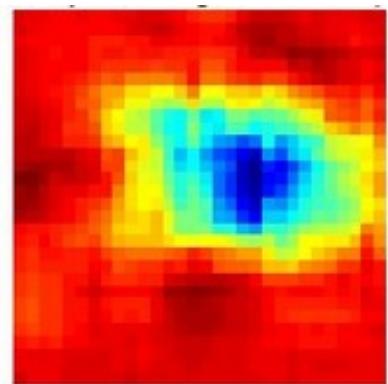
bell pepper

lemon

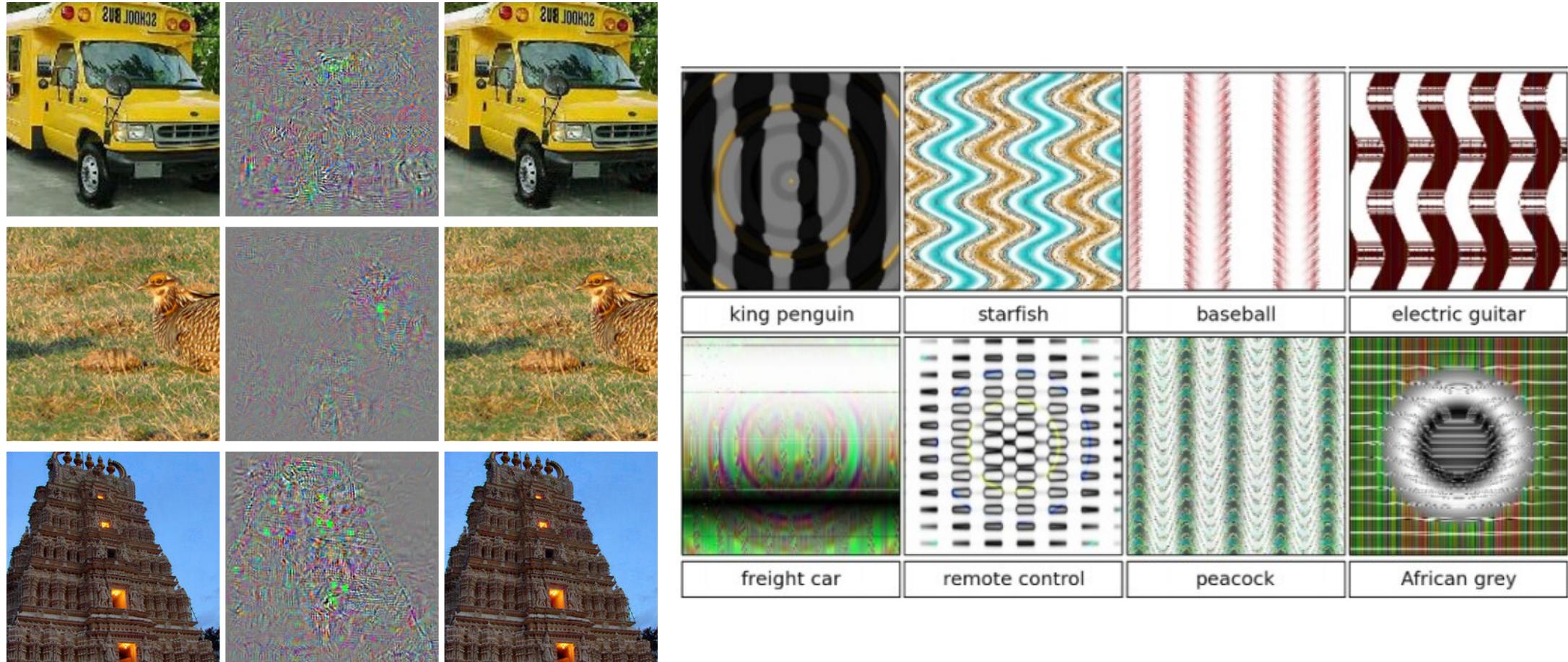
husky



True Label: Pomeranian



# And how they don't... (but really they still do)



# And how to make art



# We looked at what makes ConvNets “tick”...

| ConvNet Configuration       |                        |                               |  |  |  |
|-----------------------------|------------------------|-------------------------------|--|--|--|
| A                           | A-LRN                  | B                             | C  | D  | E  |
| 11 weight layers            | 11 weight layers       | 13 weight layers              | 16 weight layers                           | 16 weight layers                           | 19 weight layers                           |
| input (224 × 224 RGB image) |                        |                               |  |  |  |
| conv3-64                    | conv3-64<br>LRN        | conv3-64<br><b>conv3-64</b>   | conv3-64<br>conv3-64                       | conv3-64<br>conv3-64                       | conv3-64<br>conv3-64                       |
| maxpool                     |                        |                               |  |  |  |
| conv3-128                   | conv3-128              | conv3-128<br><b>conv3-128</b> | conv3-128<br>conv3-128                     | conv3-128<br>conv3-128                     | conv3-128<br>conv3-128                     |
| maxpool                     |                        |                               |  |  |  |
| conv3-256<br>conv3-256      | conv3-256<br>conv3-256 | conv3-256<br>conv3-256        | conv3-256<br>conv3-256<br><b>conv1-256</b> | conv3-256<br>conv3-256<br><b>conv3-256</b> | conv3-256<br>conv3-256<br><b>conv3-256</b> |
| maxpool                     |                        |                               |  |  |  |
| conv3-512<br>conv3-512      | conv3-512<br>conv3-512 | conv3-512<br>conv3-512        | conv3-512<br>conv3-512<br><b>conv1-512</b> | conv3-512<br>conv3-512<br><b>conv3-512</b> | conv3-512<br>conv3-512<br><b>conv3-512</b> |
| maxpool                     |                        |                               |  |  |  |
| conv3-512<br>conv3-512      | conv3-512<br>conv3-512 | conv3-512<br>conv3-512        | conv3-512<br>conv3-512<br><b>conv1-512</b> | conv3-512<br>conv3-512<br><b>conv3-512</b> | conv3-512<br>conv3-512<br><b>conv3-512</b> |
| maxpool                     |                        |                               |  |  |  |
| FC-4096                     |                        |                               |  |  |  |
| FC-4096                     |                        |                               |  |  |  |
| FC-1000                     |                        |                               |  |  |  |
| soft-max                    |                        |                               |  |  |  |

Table 2: Number of parameters (in millions).

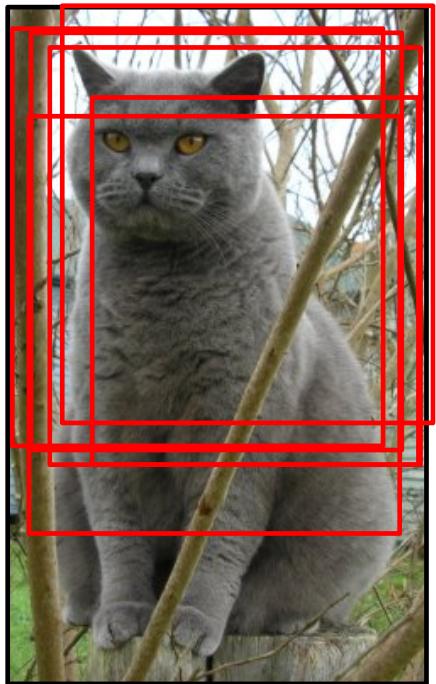
| Network              | A,A-LRN | B   | C   | D   | E   |
|----------------------|---------|-----|-----|-----|-----|
| Number of parameters | 133     | 133 | 134 | 138 | 144 |

| Error %  | Train Top-1 | Val Top-1 | Val Top-5 |
|--|-------------|-----------|-----------|
| Our replication of<br>(Krizhevsky et al., 2012), 1 convnet | 35.1        | 40.5      | 18.1      |
| Removed layers 3,4   | 41.8        | 45.4      | 22.1      |
| Removed layer 7  | 27.4        | 40.0      | 18.4      |
| Removed layers 6,7   | 27.4        | 44.8      | 22.4      |
| Removed layer 3,4,6,7                                      | 71.1        | 71.3      | 50.1      |
| Adjust layers 6,7: 2048 units                              | 40.3        | 41.7      | 18.8      |
| Adjust layers 6,7: 8192 units                              | 26.8        | 40.0      | 18.1      |

|  |             |             |             |
|--|-------------|-------------|-------------|
| Our Model (as per Fig. 3)  | 33.1        | 38.4        | 16.5        |
| Adjust layers 6,7: 2048 units  | 38.2        | 40.2        | 17.6        |
| Adjust layers 6,7: 8192 units  | 22.0        | 38.8        | 17.0        |
| Adjust layers 3,4,5: 512,1024,512 maps                               | 18.8        | <b>37.5</b> | <b>16.0</b> |
| Adjust layers 6,7: 8192 units and<br>Layers 3,4,5: 512,1024,512 maps | <b>10.0</b> | 38.3        | 16.9        |

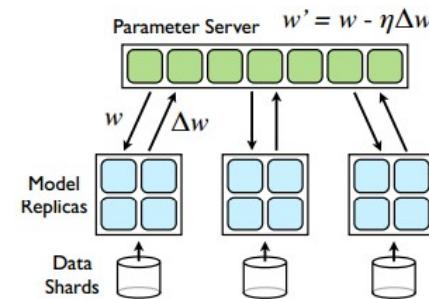
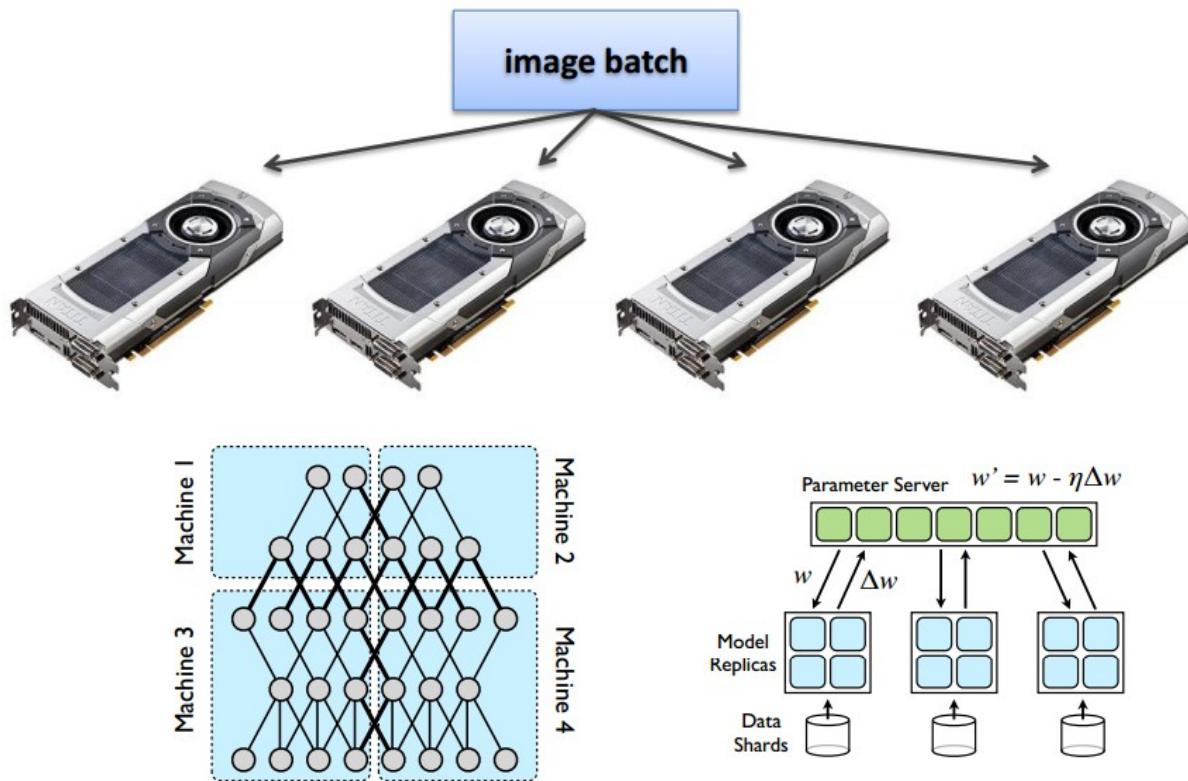
|                |   |     |   |   |     |              |
|----------------|---|-----|---|---|-----|--------------|
| (p) CNN M      | - | (C) | f | s | 4K  | <b>79.89</b> |
| (x) CNN M 2048 | - | (C) | f | s | 2K  | <b>80.10</b> |
| (y) CNN M 1024 | - | (C) | f | s | 1K  | <b>79.91</b> |
| (z) CNN M 128  | - | (C) | f | s | 128 | <b>78.60</b> |

We learned tips/tricks for  
making ConvNets work well in practice

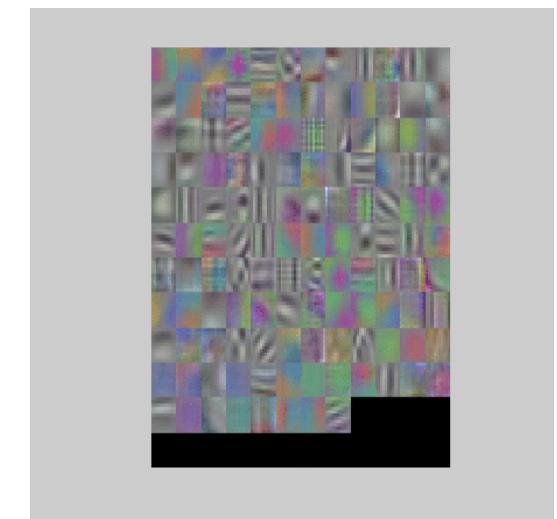
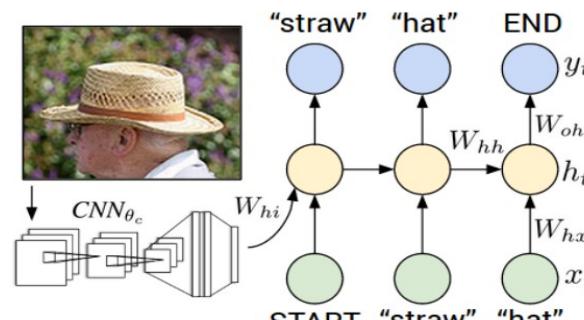
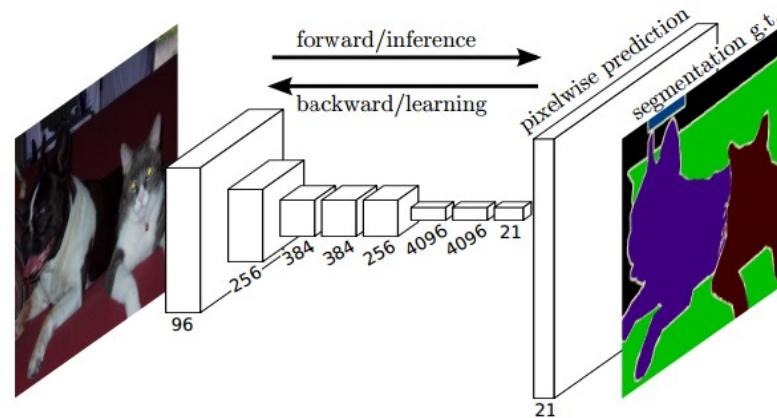
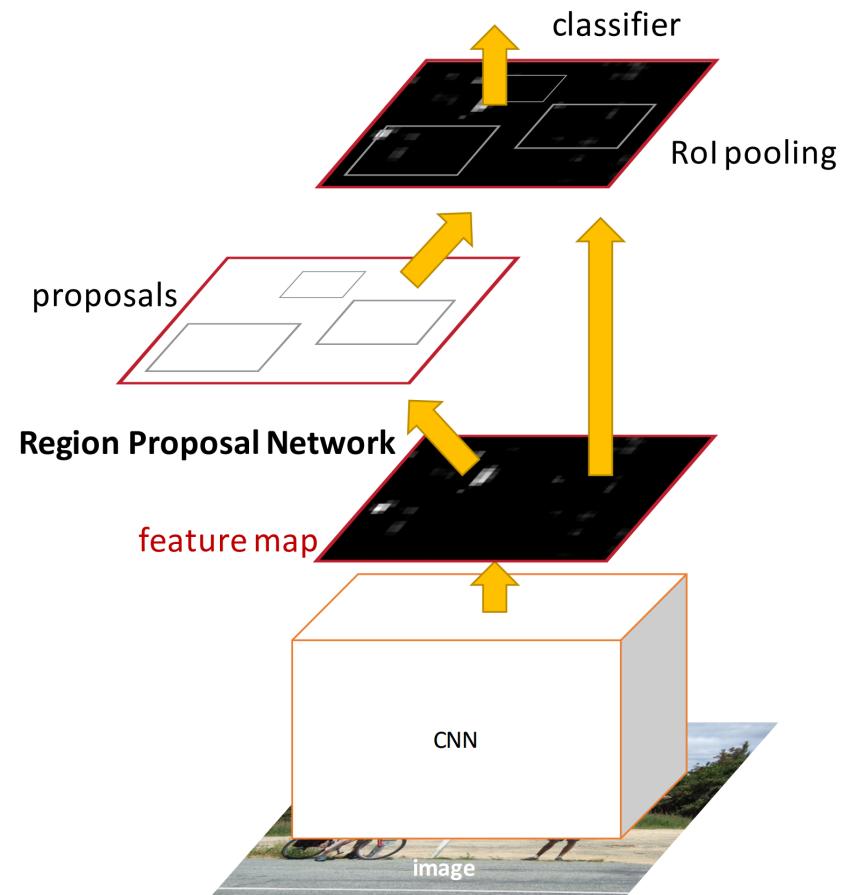


And explored their practical bottlenecks...

Moving parts lol



# And we bravely ventured beyond Image Classification...



And developed an understanding of cutting-edge research

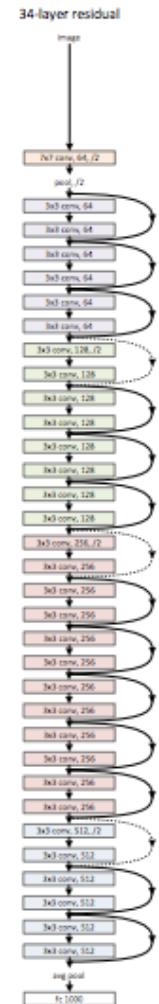
We saw **2015 & 2016** citations...  
e.g.

## Deep Residual Learning for Image Recognition

[He et al., CVPR 2016] (MSR)

## Inception-v4, Inception-ResNet and the Impact of Residual Connections on Learning

[Szegedy et al., 2016] (Google)



You are now ready.



You are now ready.



You are now ready.





Fei-Fei Li & Andrej Karpathy & Justin Johnson

Lecture 15 - 20

7 Mar 2016

**END**

## Course Instructors



Fei-Fei Li



Justin Johnson

## Teaching Assistants



Serena Yeung



Subhasis Das



Song Han



Albert Haque



Bharath Ramsundar



Hieu Pham



Irwan Bello



Namrata Anand



Lane McIntosh



Catherine Dong



Kyle Griswold