



# Deep Learning: Searching for Images

Emily Fox & Carlos Guestrin  
Machine Learning Specialization  
University of Washington

# Visual product recommender

# I want to buy new shoes, but...



Too many  
options online...



# Text search doesn't help...



"Dress shoes"



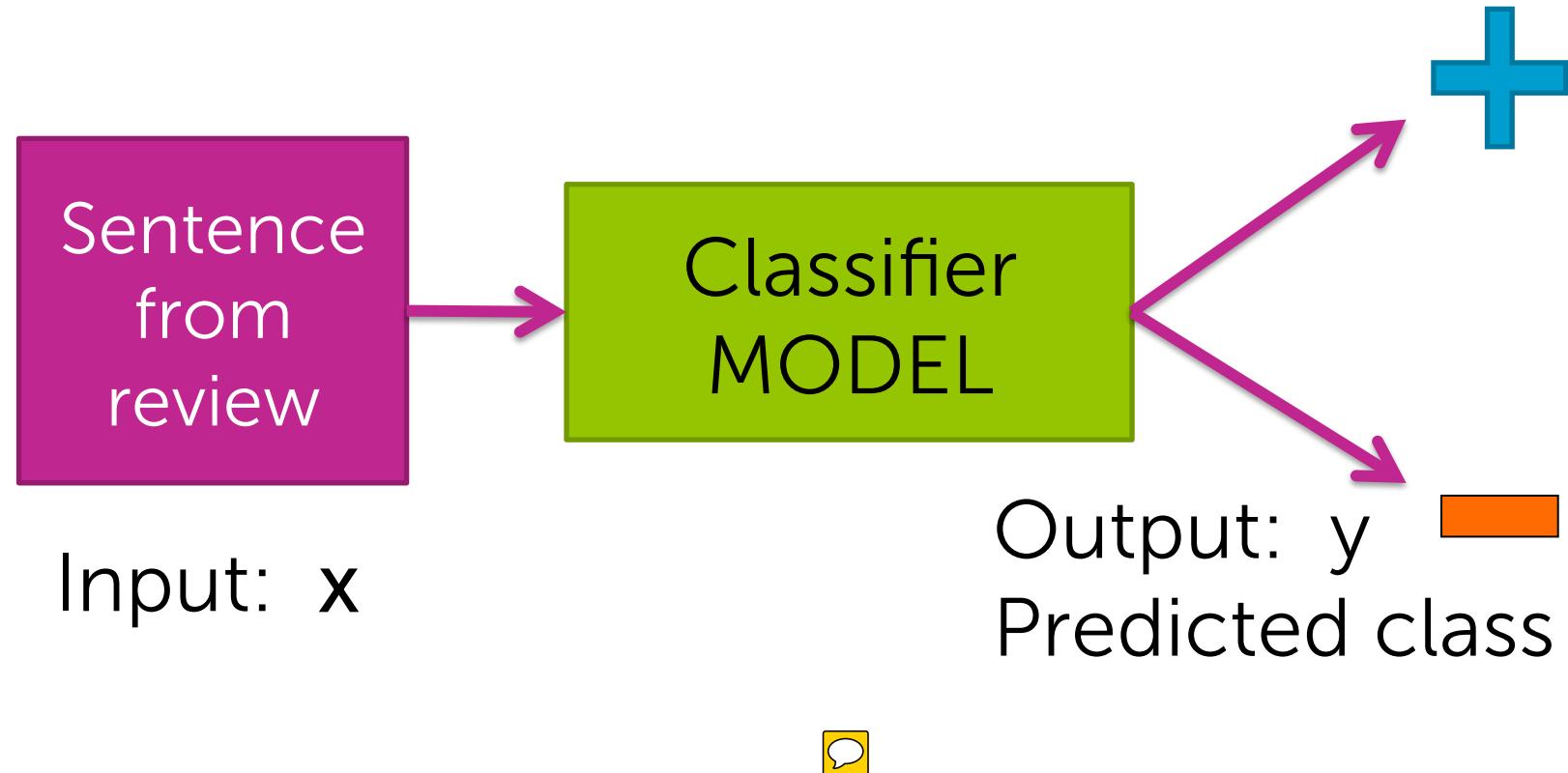
# Visual product search demo



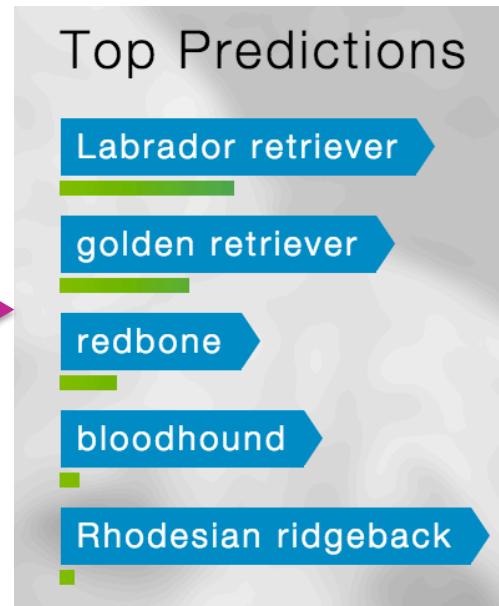
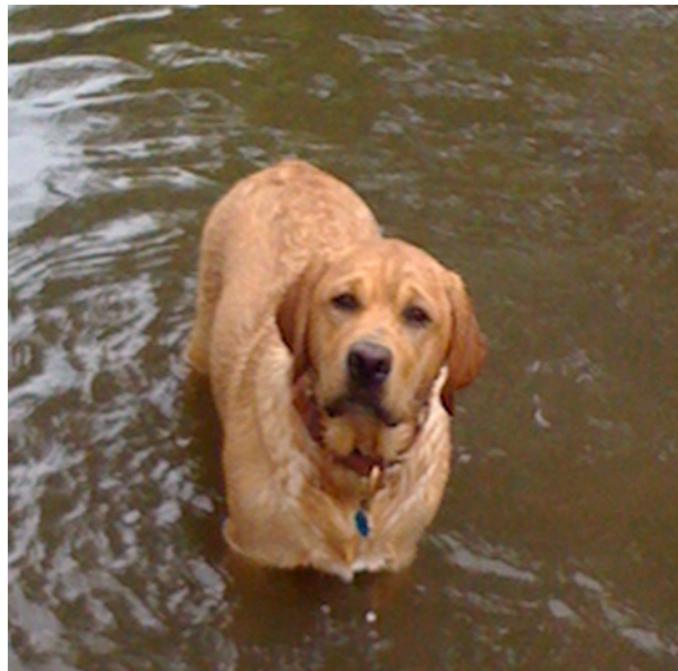
Features are key to  
machine learning



# Goal: revisit classifiers, but using more complex, non-linear features



# Image classification



Input:  $x$   
Image pixels

Output:  $y$   
Predicted object

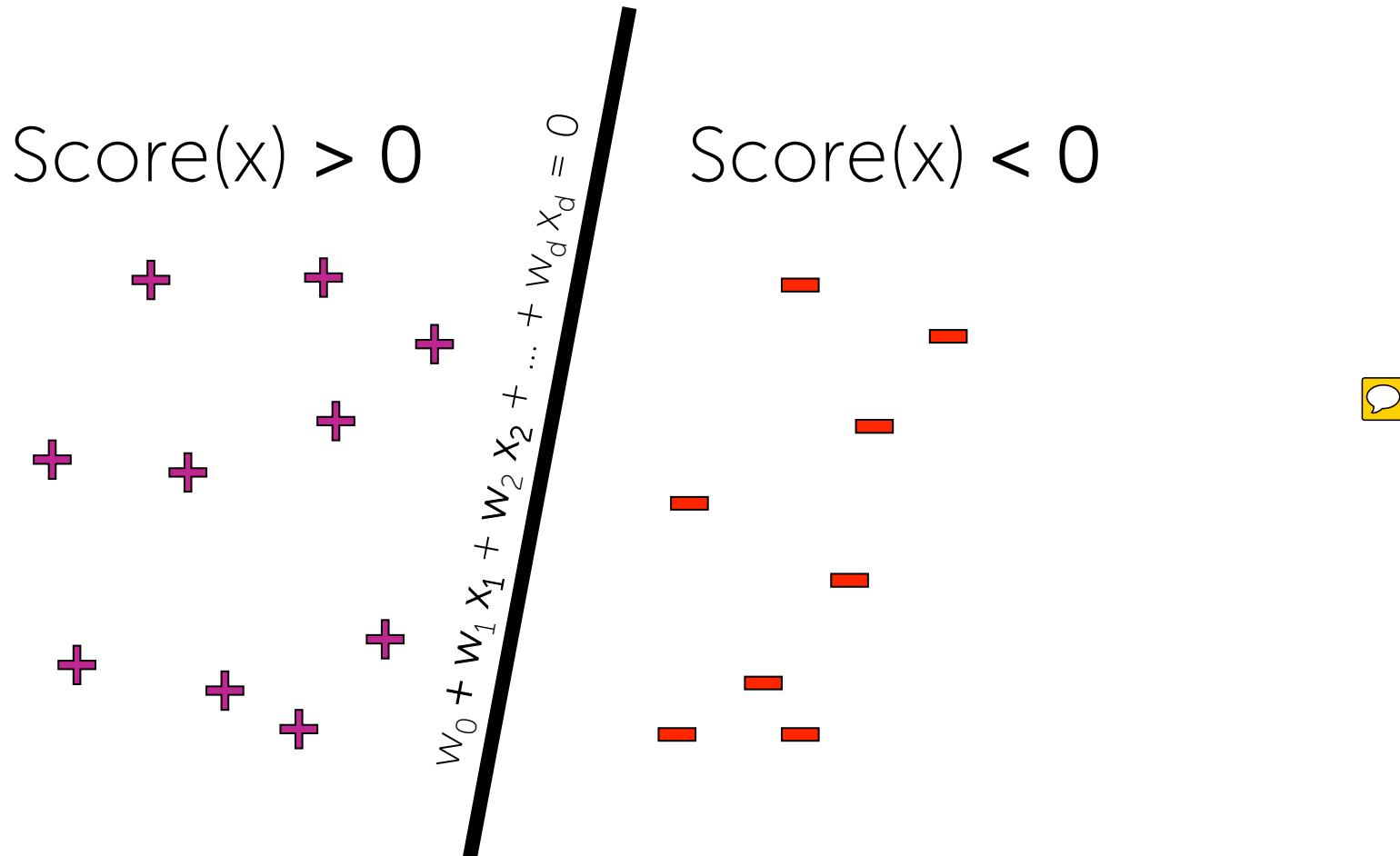
# Neural networks



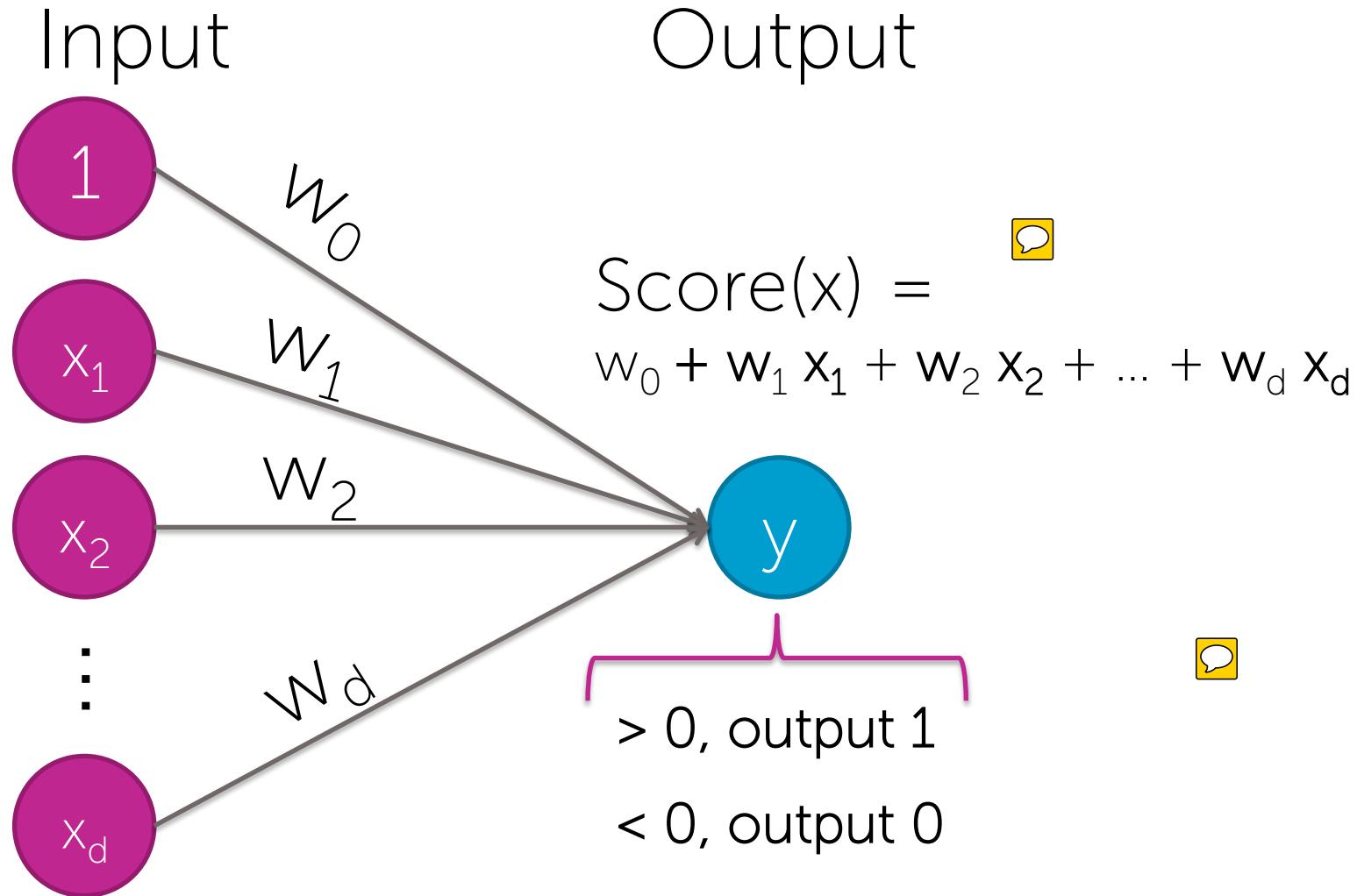
Learning **\*very\***  
non-linear features

# Linear classifiers

$$\text{Score}(x) = w_0 + w_1 x_1 + w_2 x_2 + \dots + w_d x_d$$



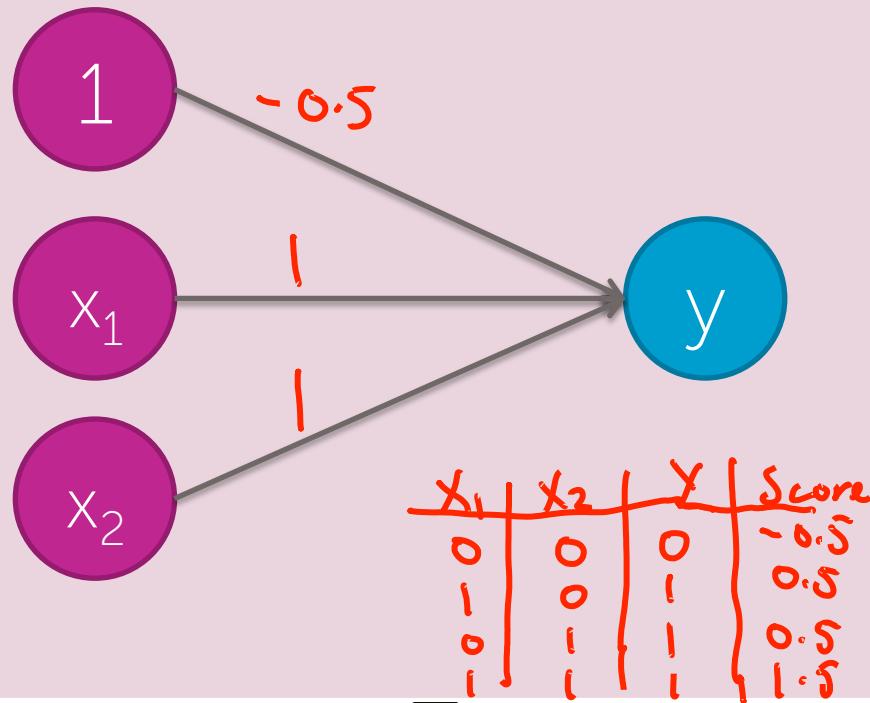
# Graph representation of classifier: useful for defining neural networks



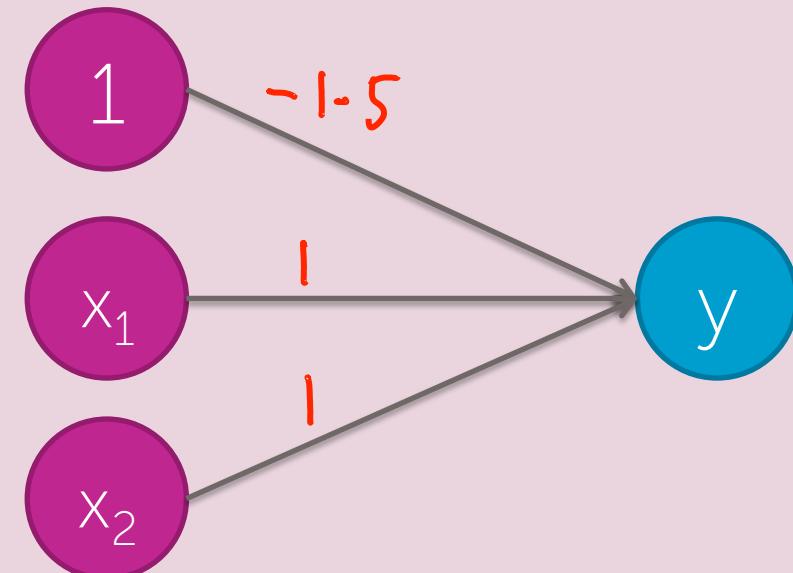


# What can a linear classifier represent?

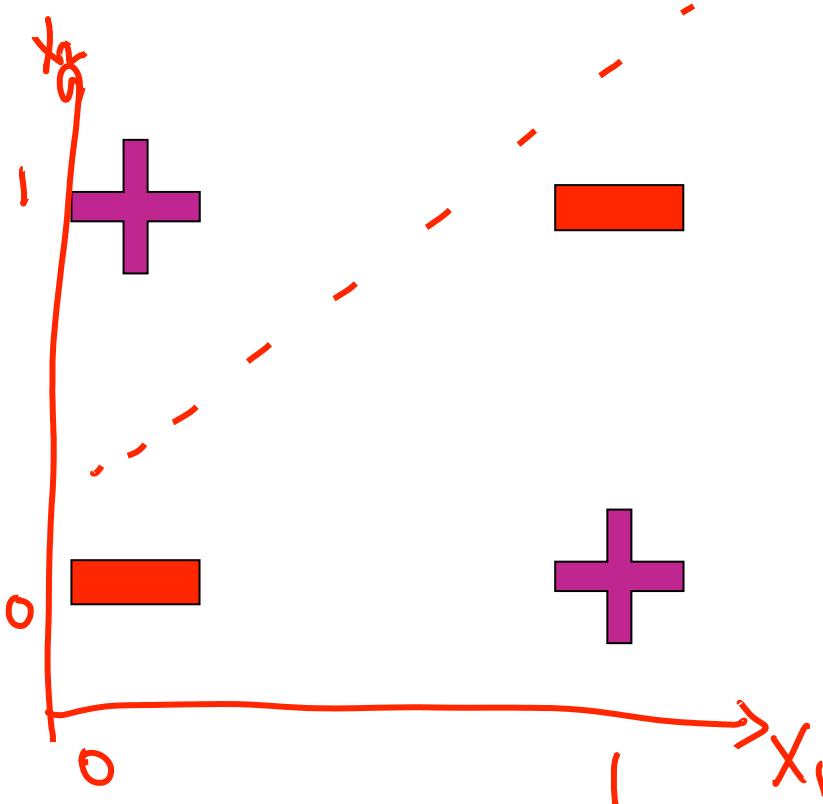
$x_1 \text{ OR } x_2$



$x_1 \text{ AND } x_2$



# What can't a simple linear classifier represent?



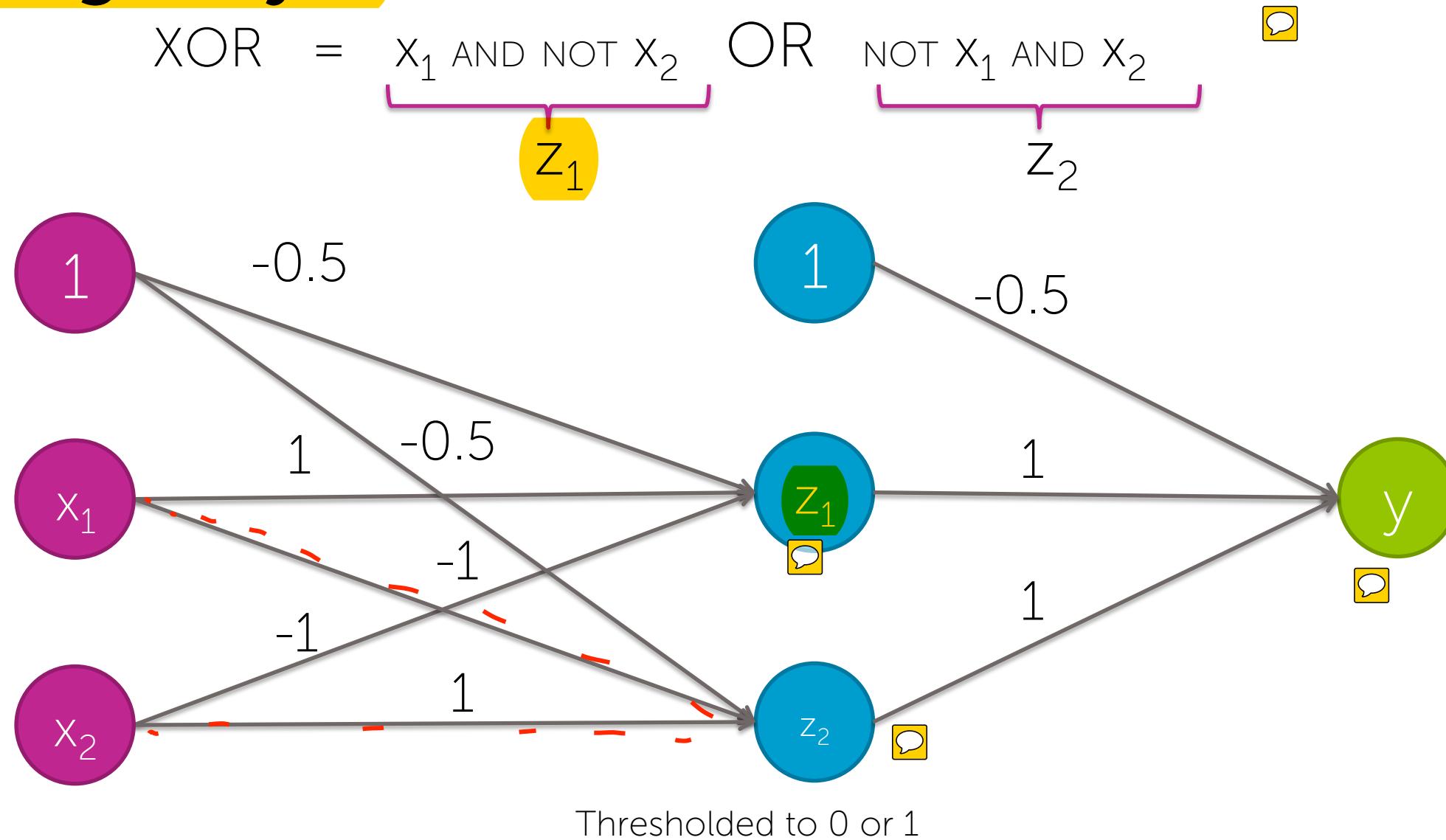
XOR

the counterexample  
to everything

Need non-linear features

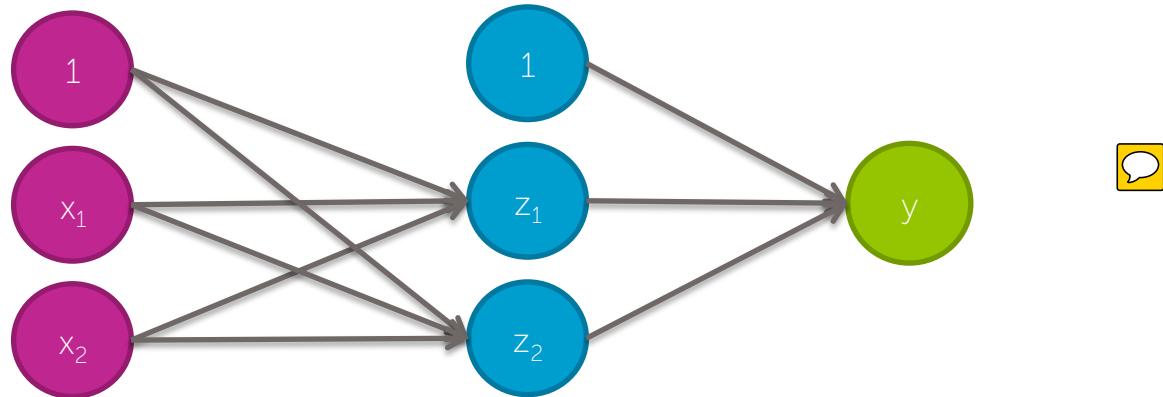
# Solving the XOR problem:

## Adding a layer



# A neural network

- Layers and layers and layers of linear models and non-linear transformations

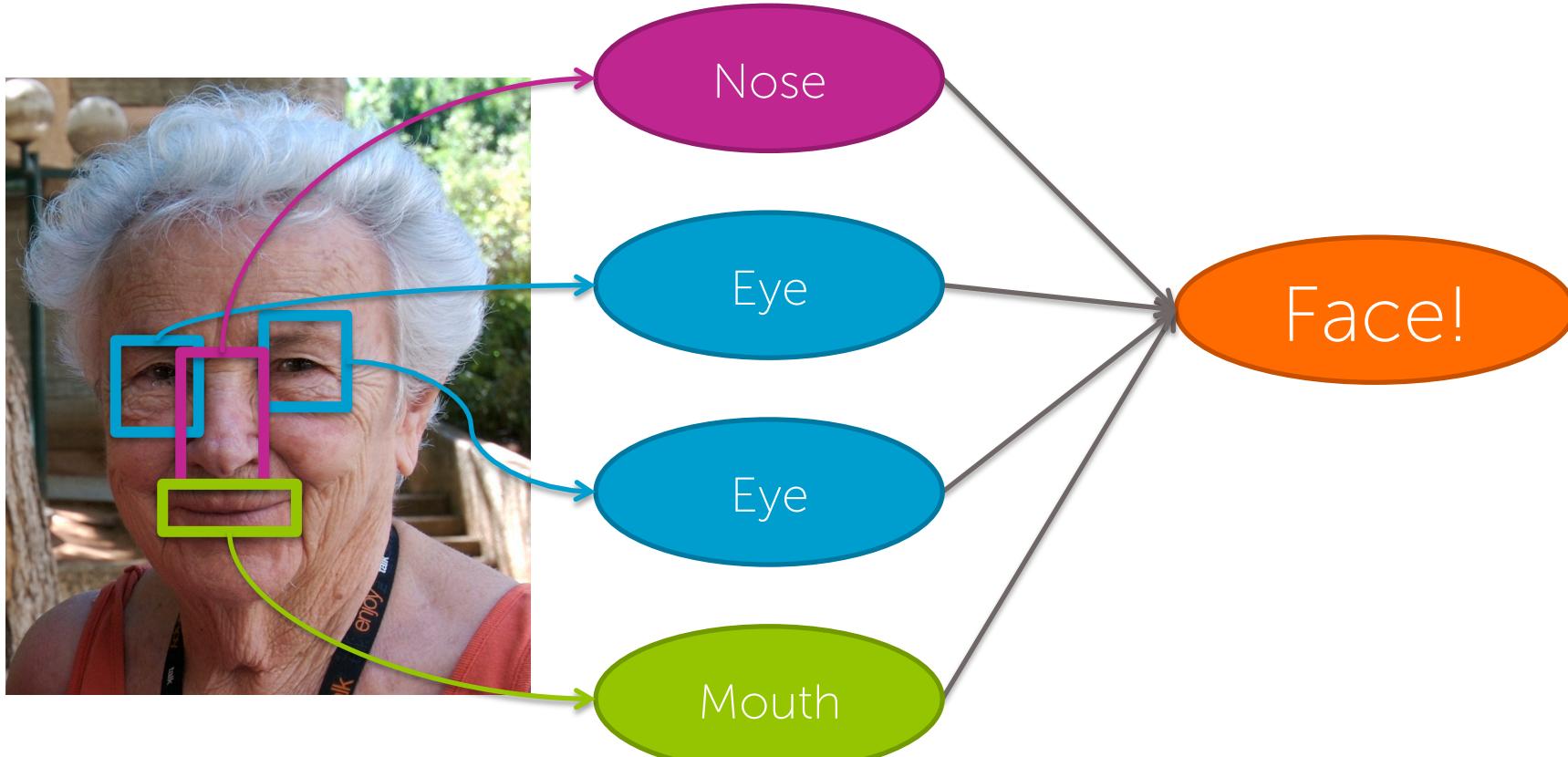


- Around for about 50 years
  - Fell in “disfavor” in 90s
- In last few years, big resurgence
  - Impressive accuracy on several benchmark problems
  - Powered by huge datasets, GPUs, & modeling/learning alg improvements

# Application of deep learning to computer vision

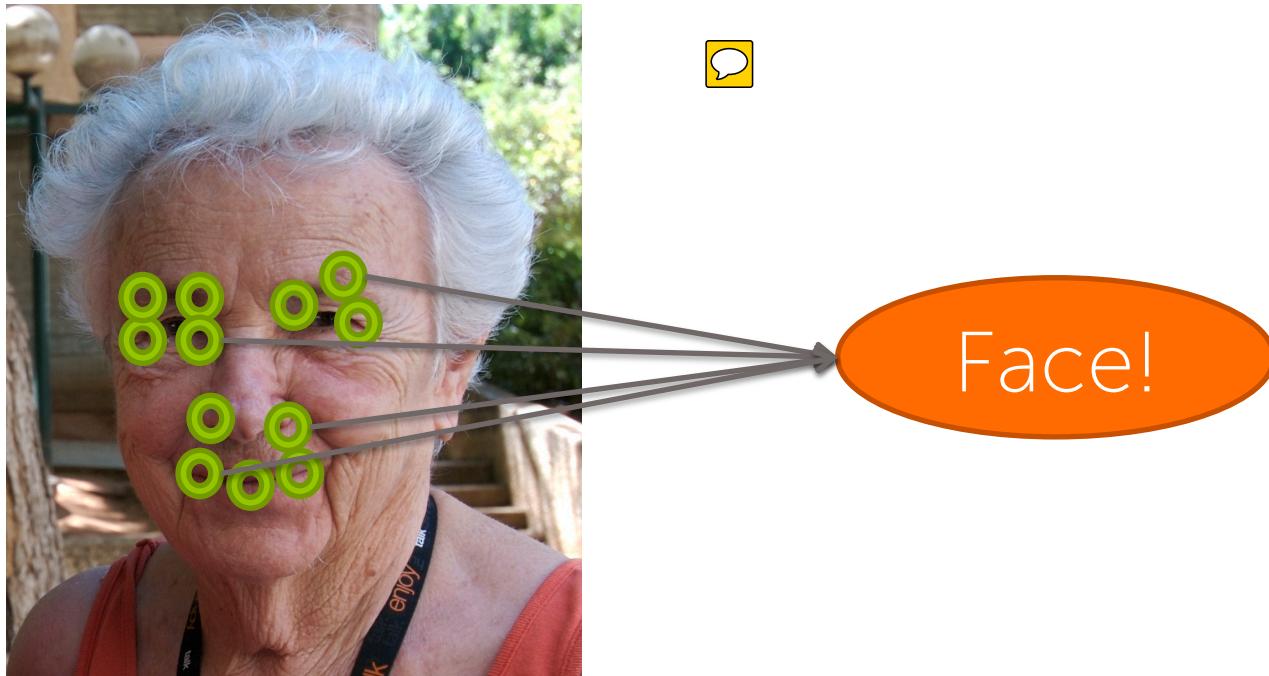
# Image features

- Features = local detectors
  - Combined to make prediction
  - (in reality, features are more low-level)

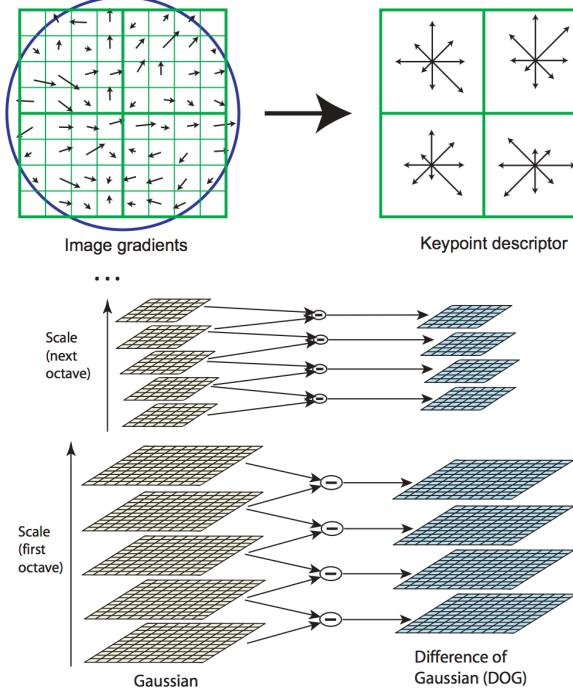


# Typical local detectors look for locally “interesting points” in image

- *Image features*: collections of locally interesting points
  - Combined to build classifiers



# Many hand created features exist for finding interest points...



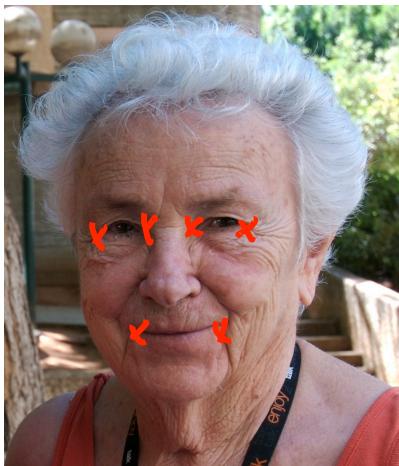
SIFT [Lowe '99]

- *Spin Images*  
[Johnson & Herbert '99]
- *Textons*  
[Malik et al. '99]
- *RIFT*  
[Lazebnik '04]
- *GLOH*  
[Mikolajczyk & Schmid '05]
- *HoG*  
[Dalal & Triggs '05]
- ...

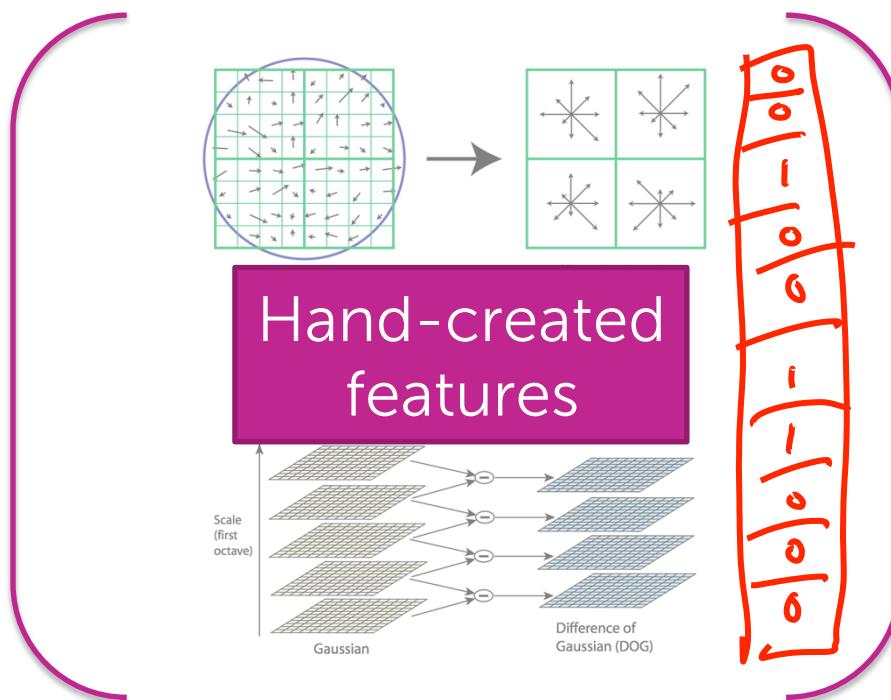


# Standard image classification approach

Input



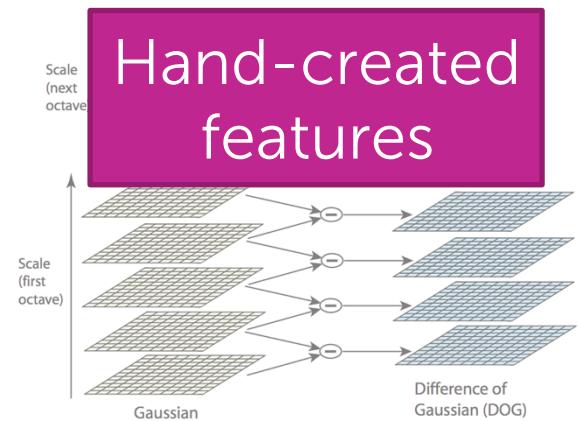
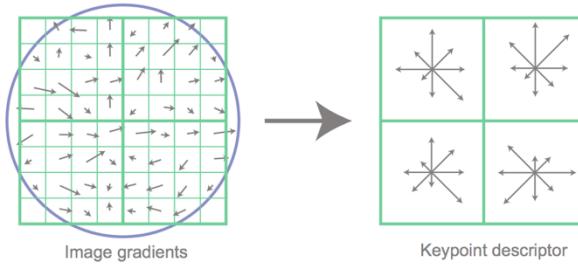
Extract features



Use simple classifier  
e.g., logistic regression, SVMs

Face?

# Many hand created features exist for finding interest points...



SIFT [Lowe '99]

- *Spin Images*  
[Johnson & Herbert '99]
- *Textons*  
[Malik et al. '99]
- *RIFT*  
[Lazebnik '04]
- *GLOH*  
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- *HoG*  
[Dalal & Triggs '05]
- ...

... but very painful to design

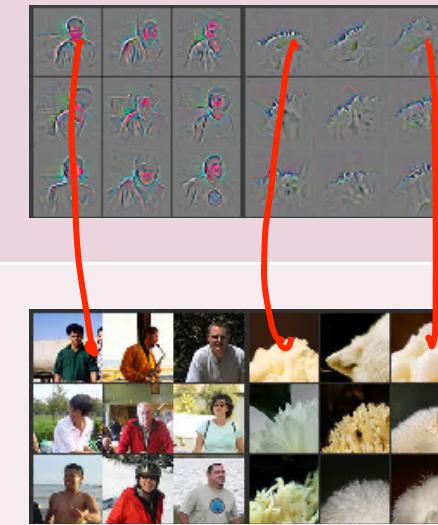
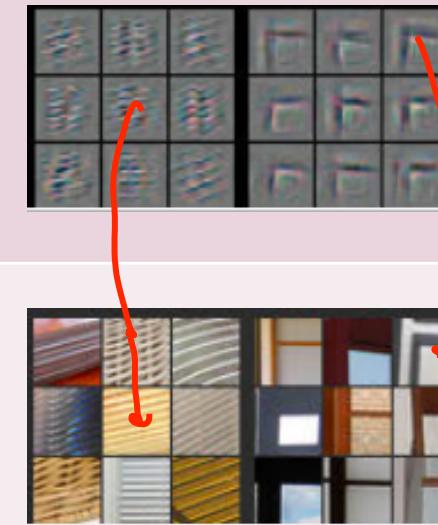
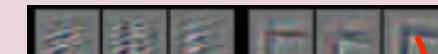
# Deep learning: *implicitly learns features*



Example detectors learned



Example interest points detected



[Zeiler & Fergus '13]

# Deep learning performance



# Sample results using deep neural networks

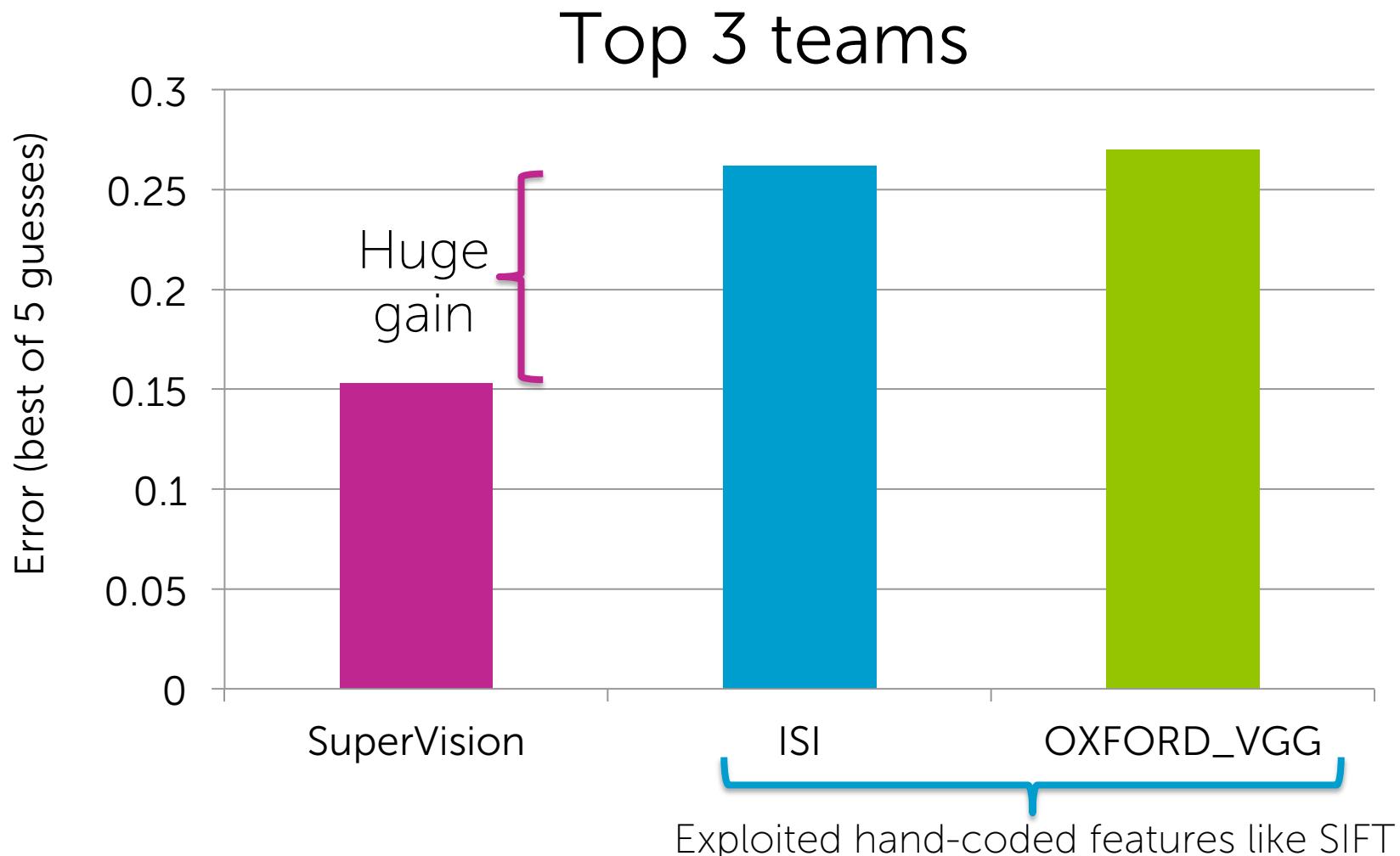
- German traffic sign recognition benchmark
  - 99.5% accuracy (IDSIA team)



- House number recognition
  - 97.8% accuracy per character [Goodfellow et al. '13]

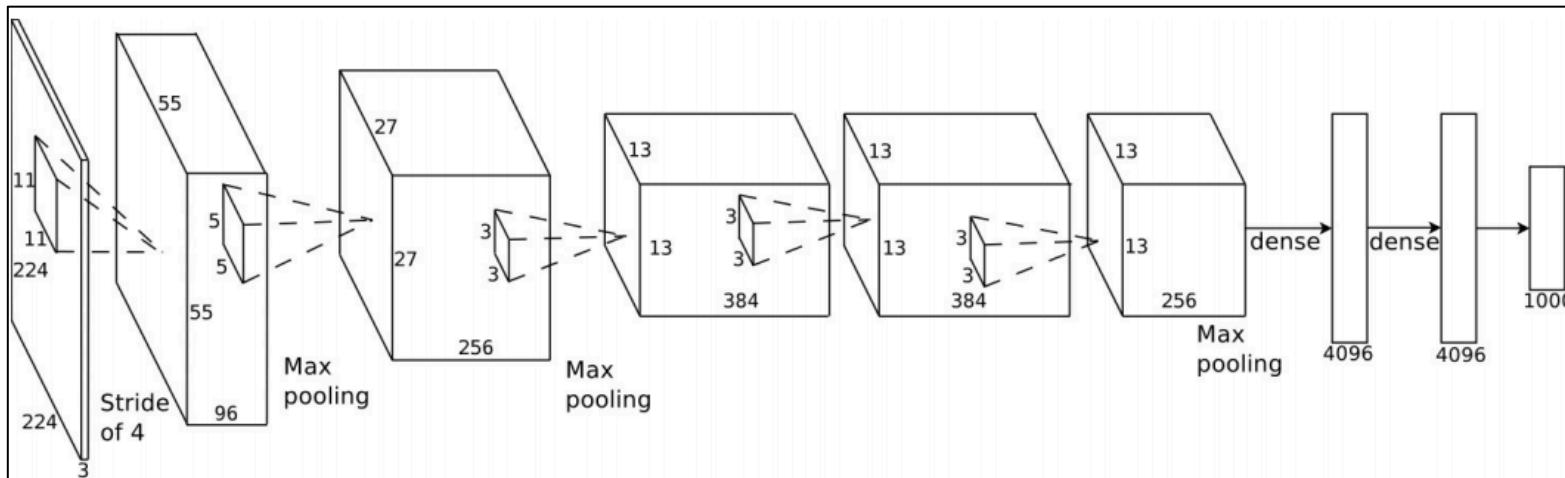


# ImageNet 2012 competition: 1.2M training images, 1000 categories



# ImageNet 2012 competition: 1.2M training images, 1000 categories

Winning entry: SuperVision  
8 layers, 60M parameters [Krizhevsky et al. '12]

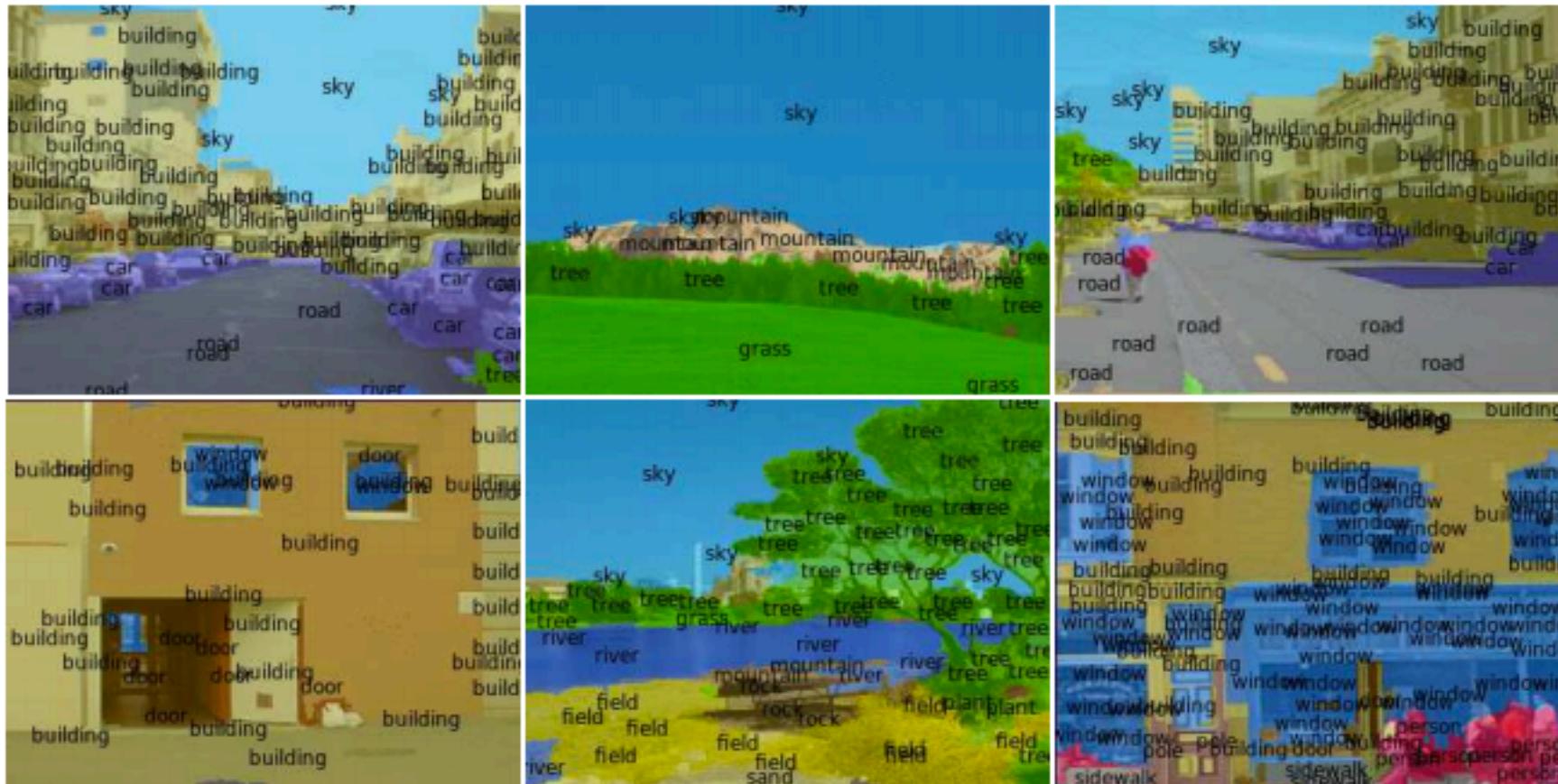


Achieving these amazing results required:

- New learning algorithms
- GPU implementation

# Deep learning in computer vision

# Scene parsing with deep learning



[Farabet et al. '13]

# Retrieving similar images

Input Image



Nearest neighbors



# Challenges of deep learning

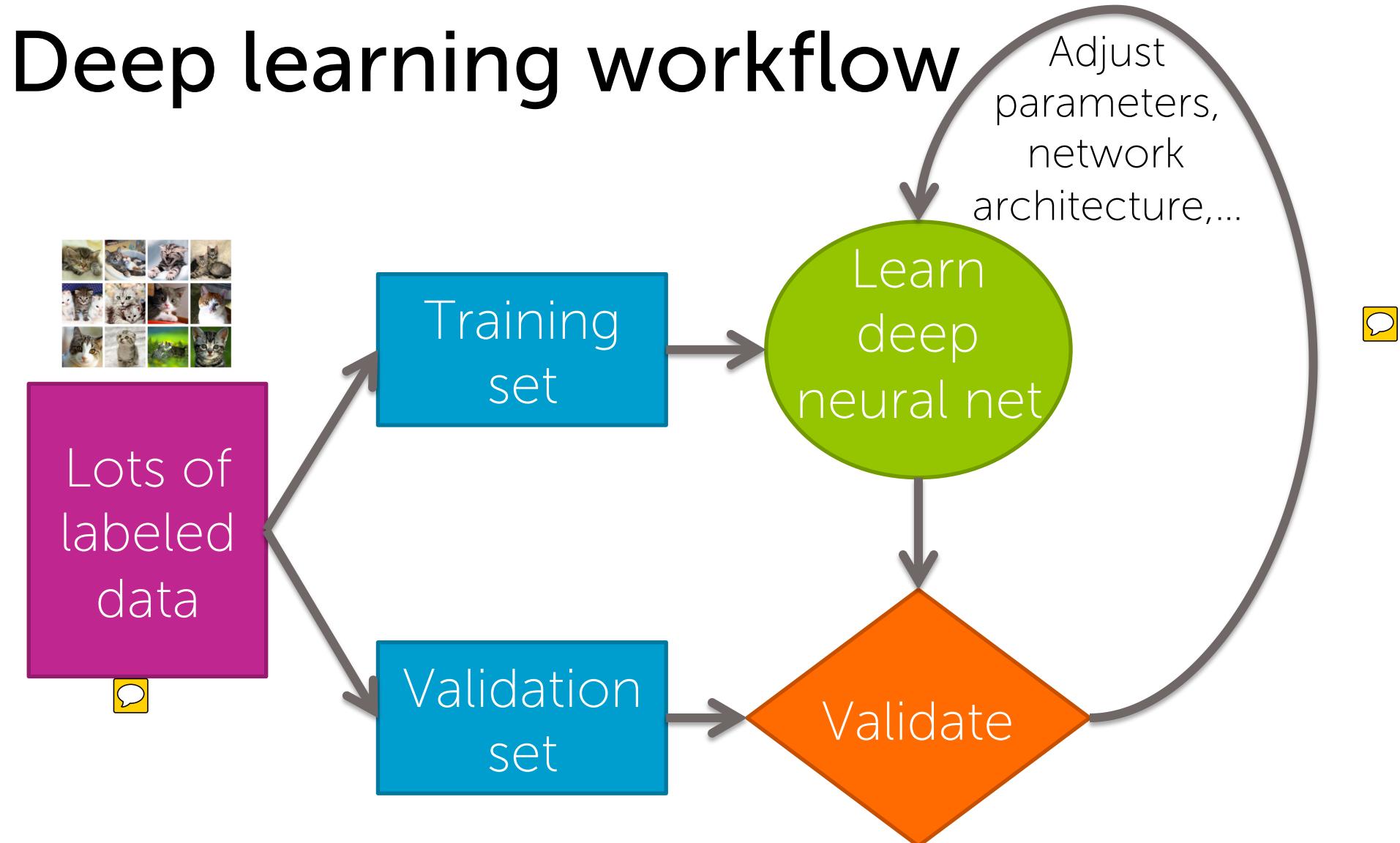
# Deep learning score card

## Pros

- Enables learning of features rather than hand tuning
- Impressive performance gains
  - Computer vision
  - Speech recognition
  - Some text analysis
- Potential for more impact

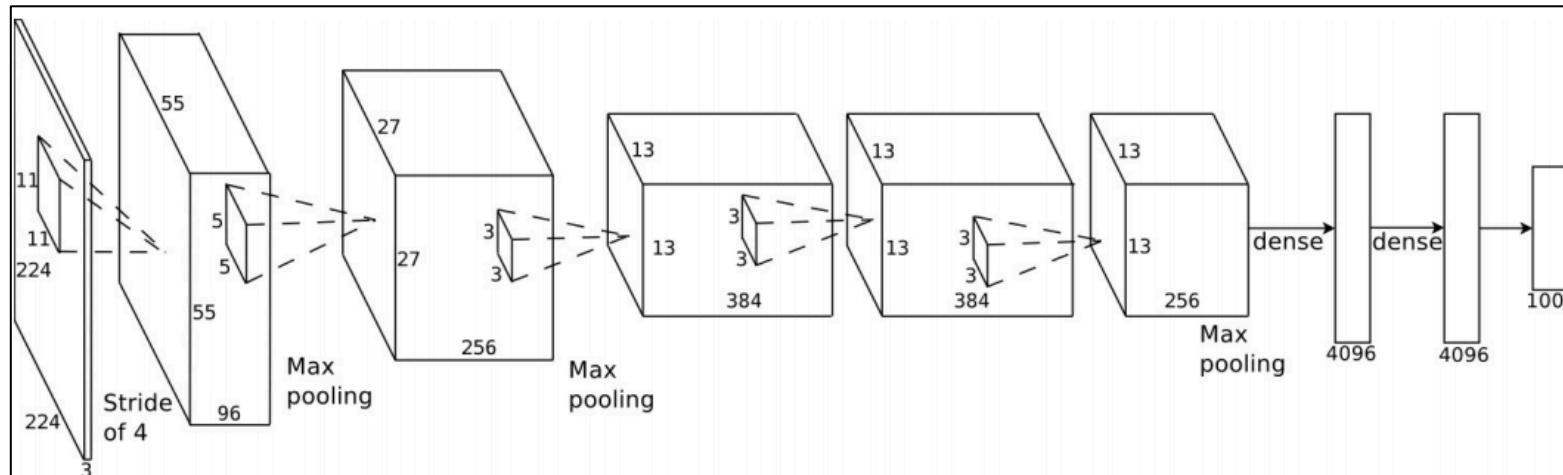


# Deep learning workflow



# Many tricks needed to work well...

Different types of layers, connections,...  
needed for high accuracy



[Krizhevsky et al. '12]

# Deep learning score card

## Pros

- Enables learning of features rather than hand tuning
- Impressive performance gains
  - Computer vision
  - Speech recognition
  - Some text analysis
- Potential for more impact

## Cons

- Requires a lot of data for high accuracy
- Computationally really expensive
- Extremely hard to tune
  - Choice of architecture
  - Parameter types
  - Hyperparameters
  - Learning algorithm
  - ...



Computational cost + so many choices

=

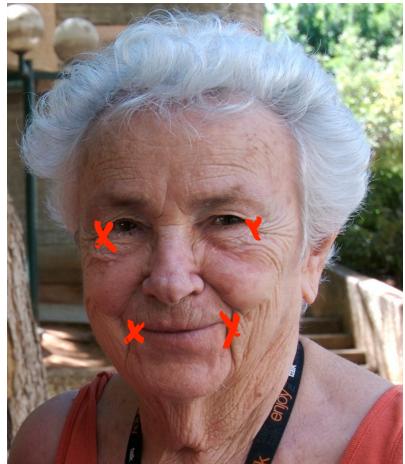
incredibly hard to tune

Deep features: 

Deep learning  
+  
Transfer learning

# Standard image classification approach

Input

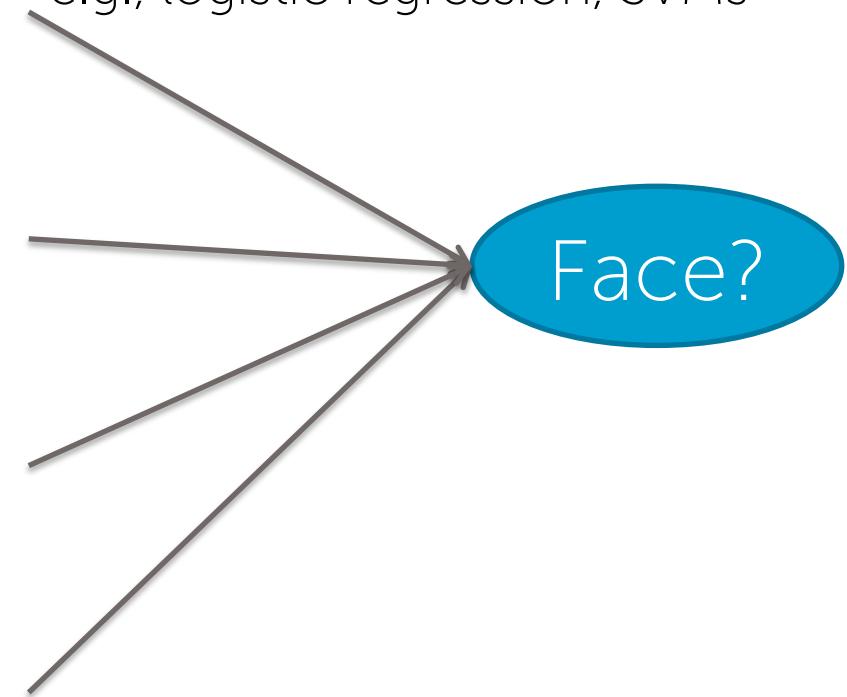


Extract features



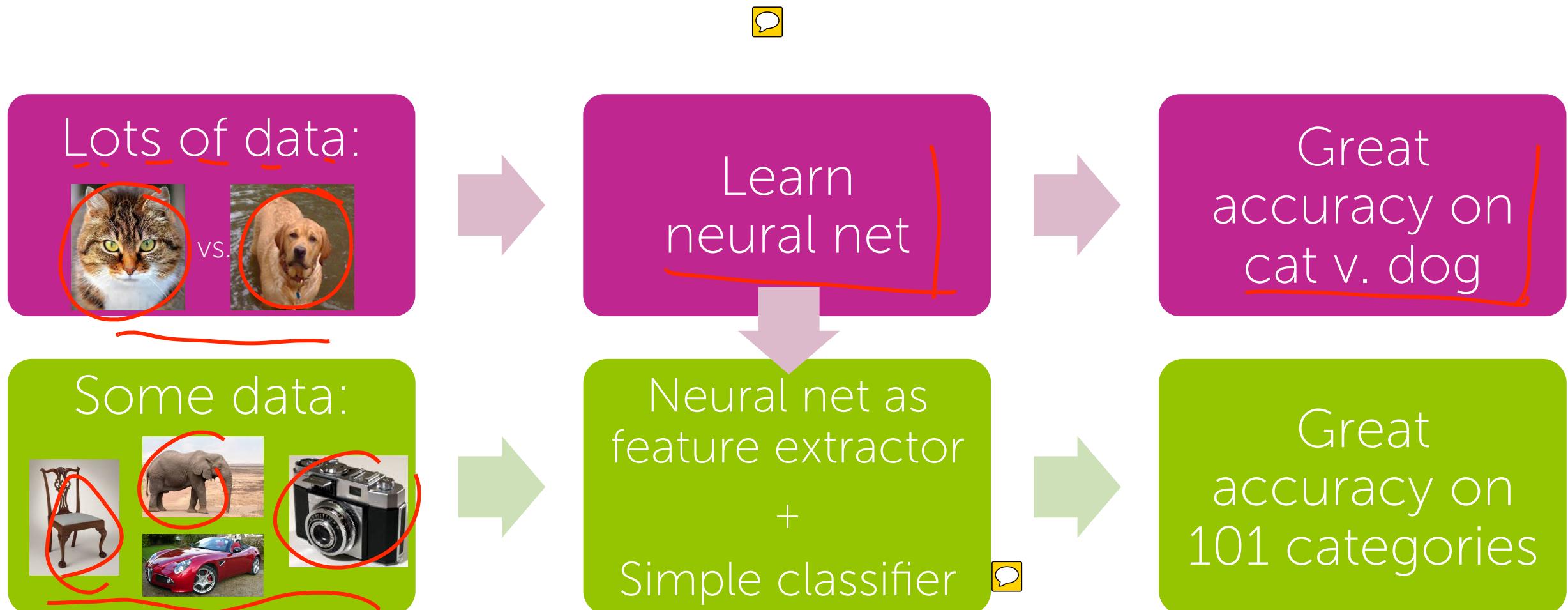
Can we learn features from data, even when we don't have data or time?

Use simple classifier  
e.g., logistic regression, SVMs



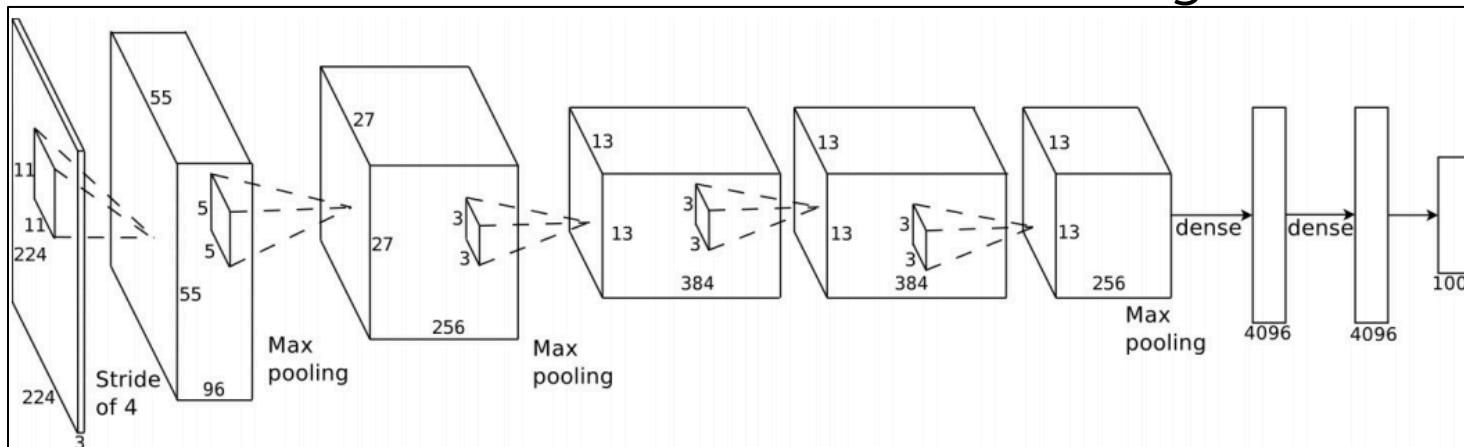
# Transfer learning: Use data from one task to help learn on another

Old idea, explored for deep learning by Donahue et al. '14 & others



# What's learned in a neural net

Neural net trained for Task 1: cat vs. dog



More generic  
Can be used as feature extractor

Very specific  
to Task 1  
Should be ignored  
for other tasks

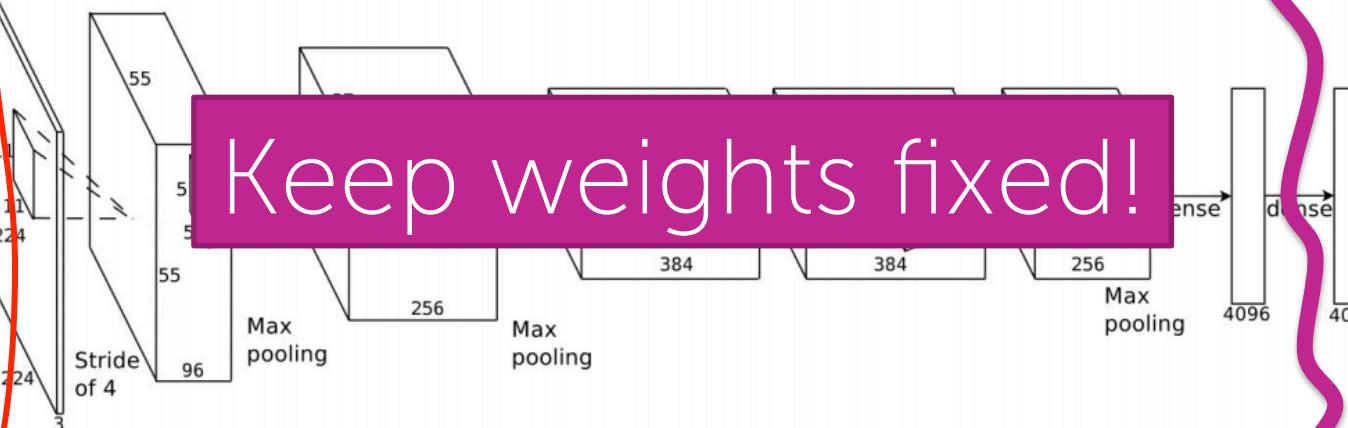
# Transfer learning in more detail...

For Task 2, predicting 101 categories,  
learn only end part of neural net



Neural net trained for Task 1: cat vs. dog

Keep weights fixed!



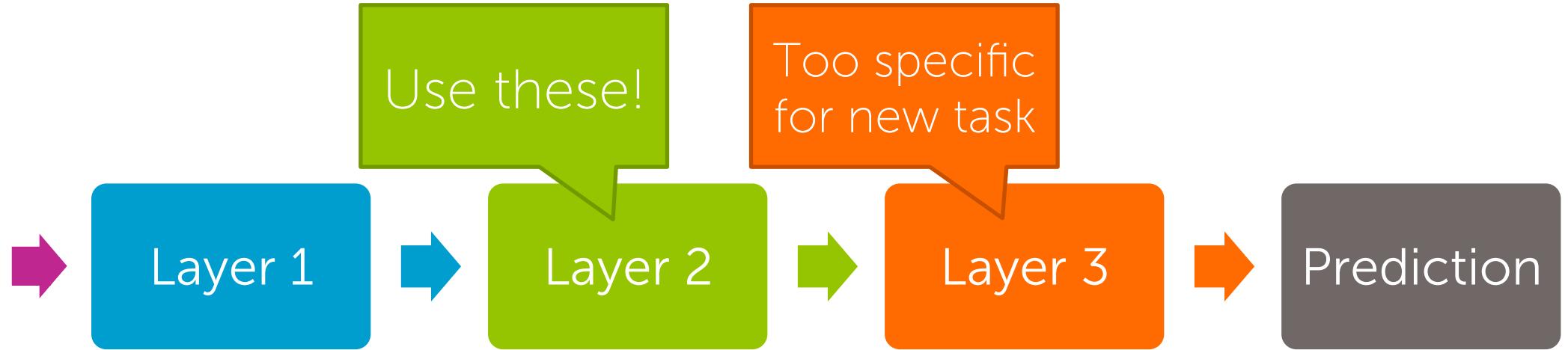
More generic  
Can be used as feature extractor

Very specific  
to Task 1  
Should be ignored  
for other tasks



Use simple classifier  
e.g., logistic regression,  
SVMs, nearest neighbor,...

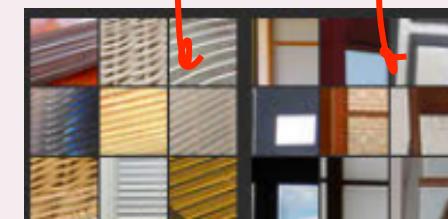
# Careful where you cut: *latter layers may be too task specific*



Example  
detectors  
learned

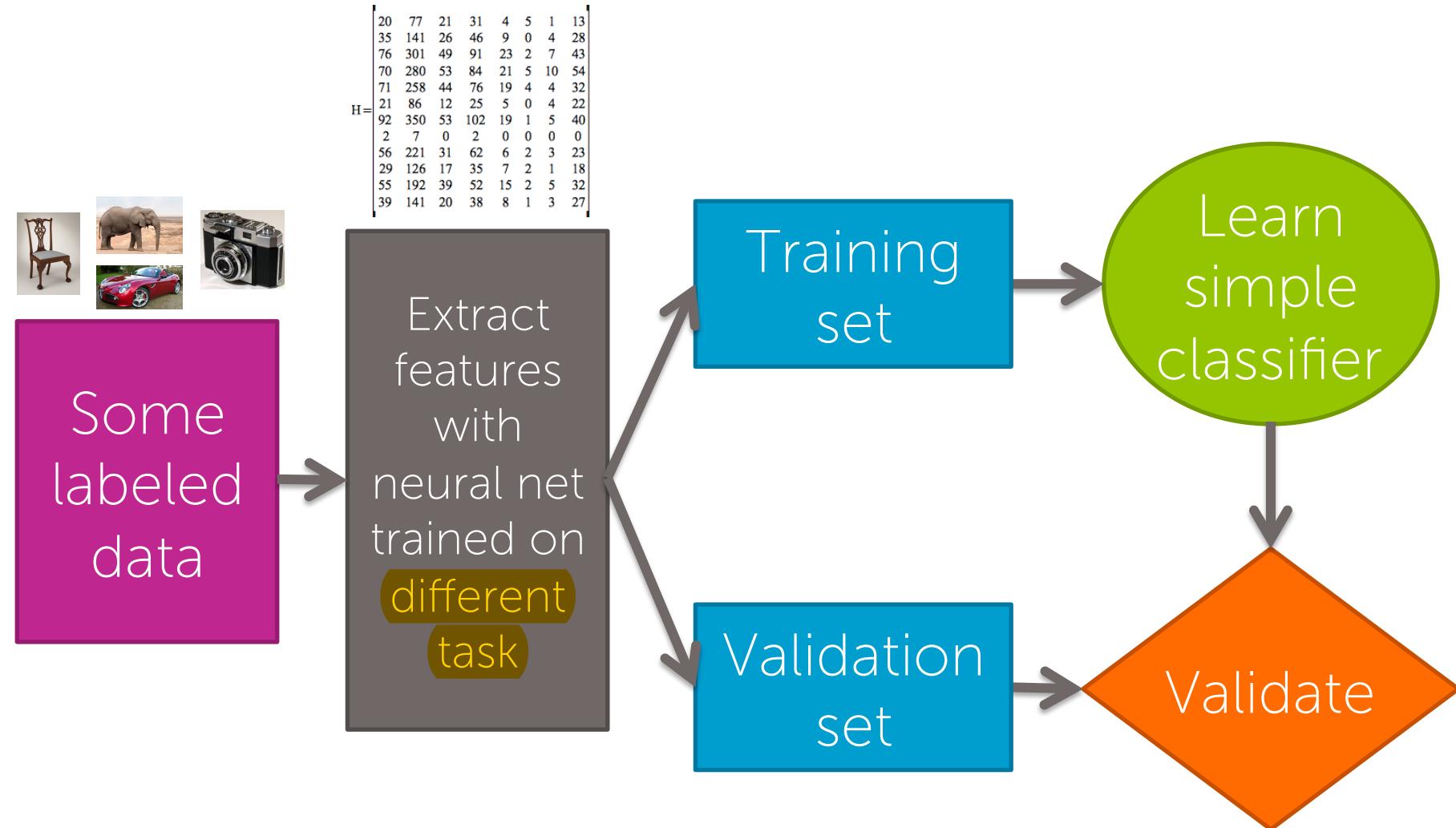


Example  
interest  
points  
detected



[Zeiler & Fergus '13]

# Transfer learning with deep features workflow



# How general are deep features?

comology



# Summary of deep learning

# What you can do now...

- Describe multi-layer neural network models
- Interpret the role of features as local detectors in computer vision
- Relate neural networks to hand-crafted image features
- Describe some settings where deep learning achieves significant performance boosts
- State the pros & cons of deep learning model
- Apply the notion of transfer learning
- Use neural network models trained in one domain as features for building a model in another domain
- Build an image retrieval tool using deep features