# The Fundamentals of Deep Learning

## with Applications

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Metis
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(slides available at jonkrohn.com/talks)

# Outline

1 Antecedents
Case Study: A History of Biological & Artificial Vision
Building Blocks

2 Theory
Biological & Artificial Neurons
Neural Networks
Deep Neural Networks

3 Contemporary Applications
Convolutional Neural Networks
Long Short-Term Memory Recurrent Neural Networks
Deep Learning at untapt
Deep Reinforcement Learning

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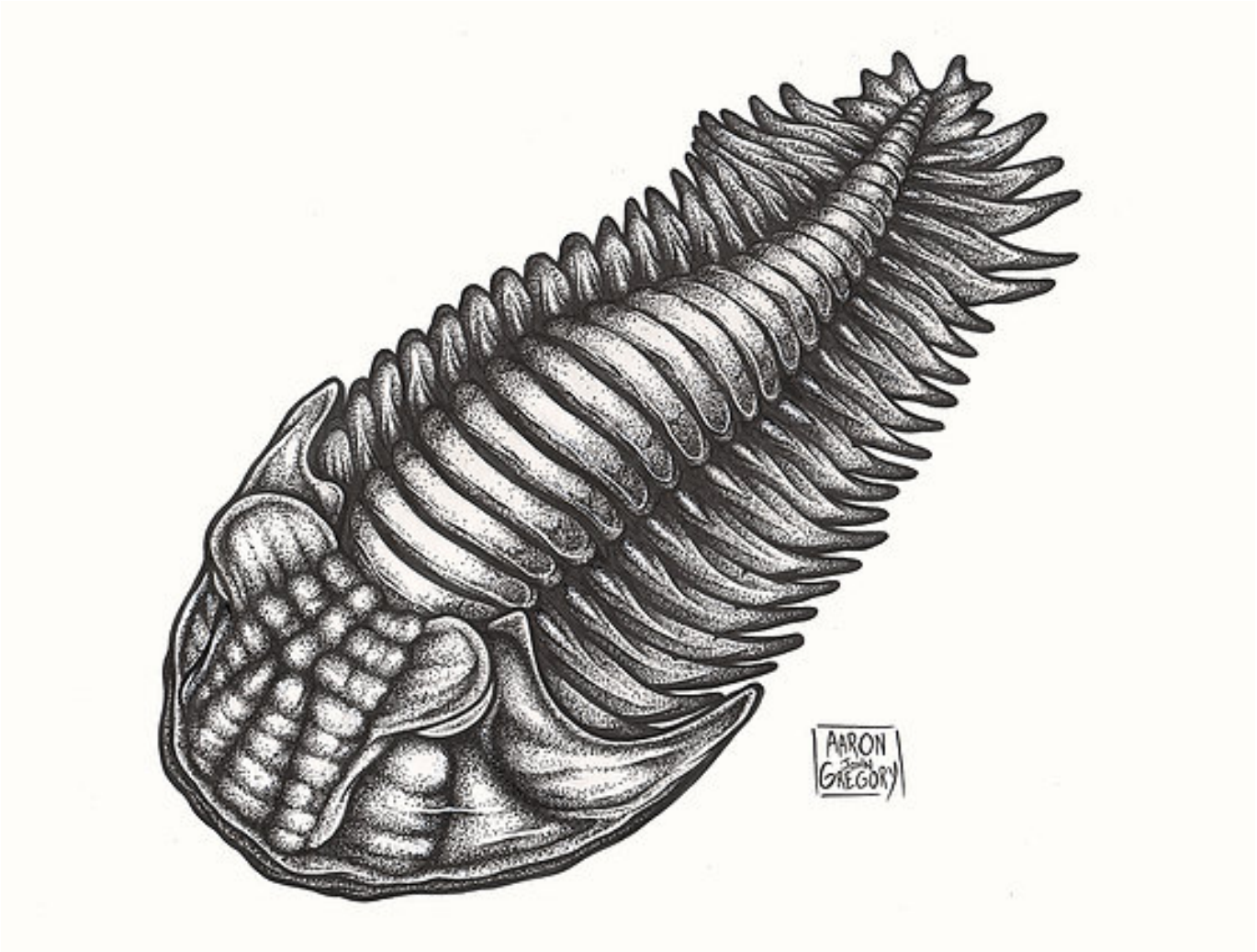
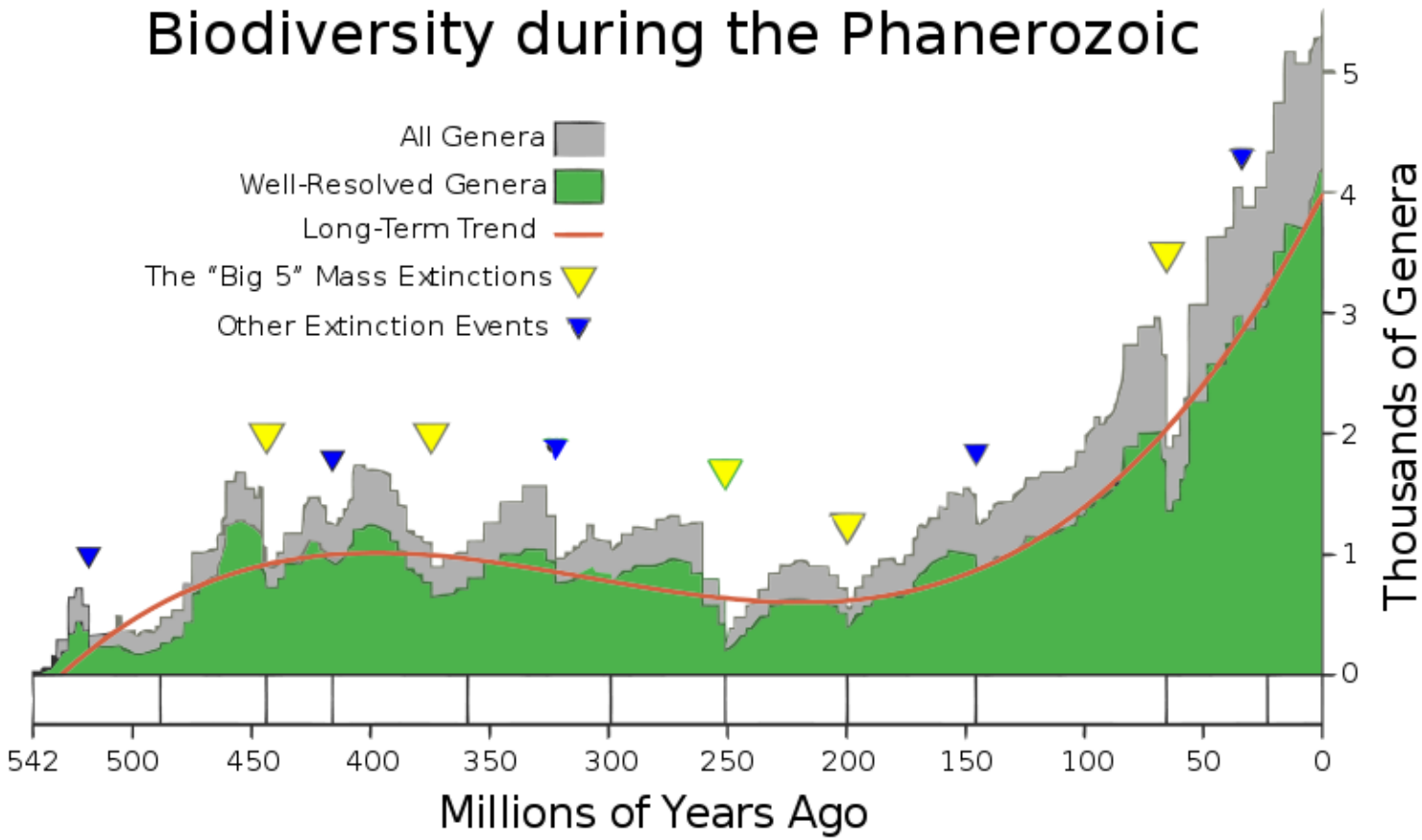
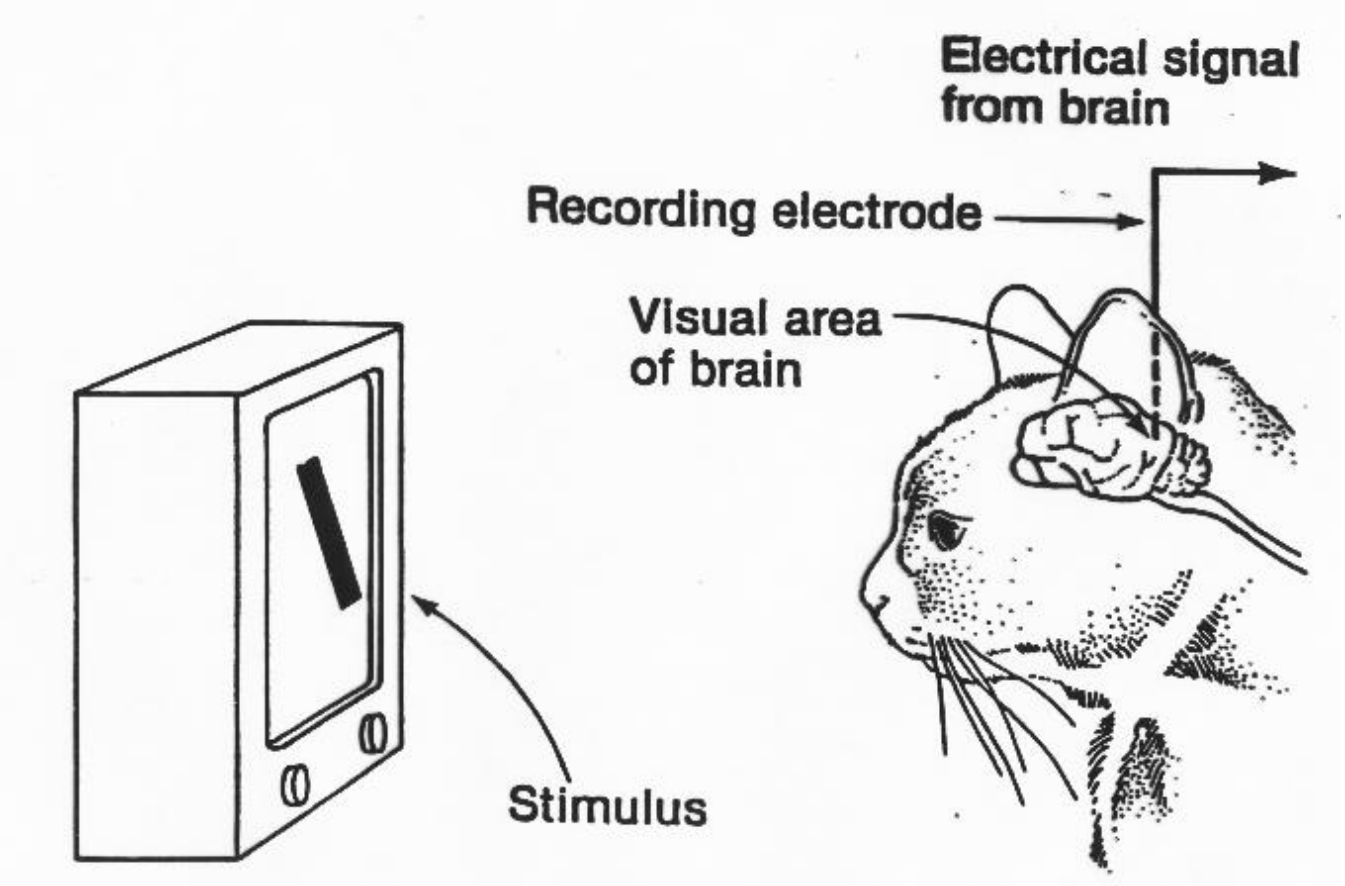
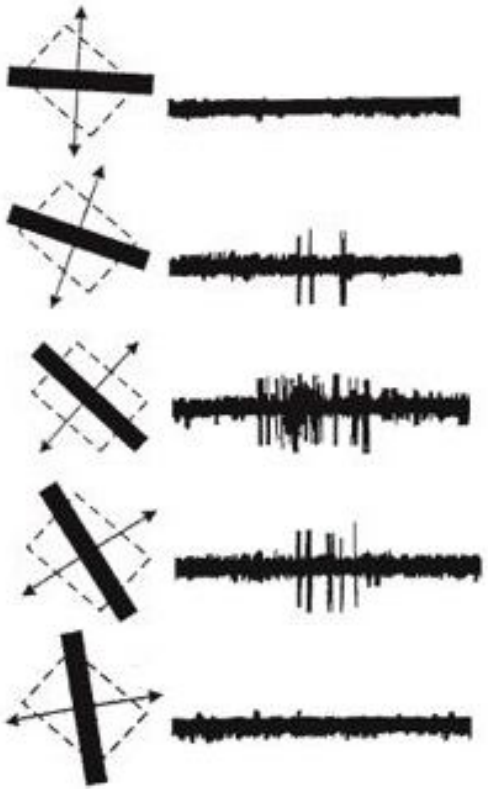
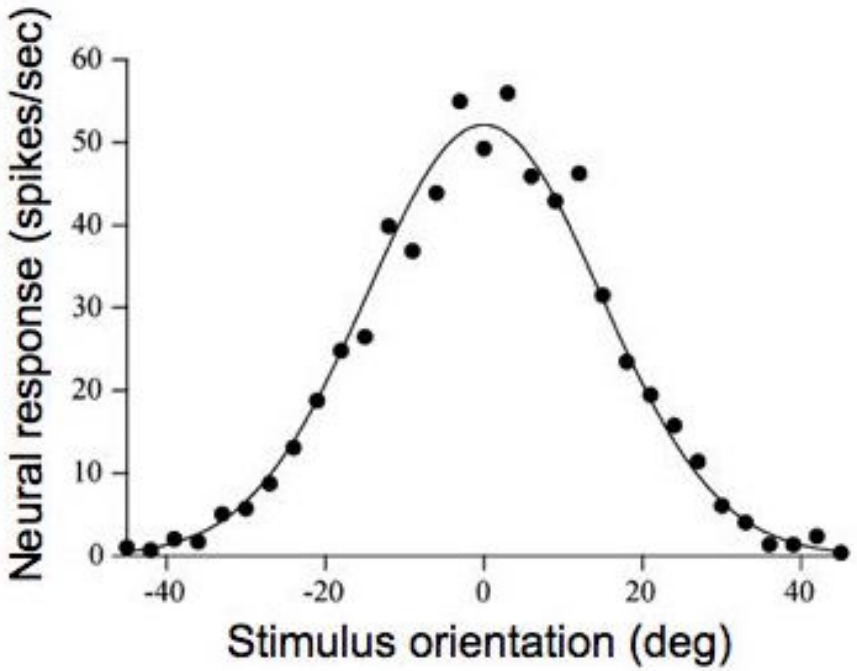

AARON
GREGORY


Biodiversity during the Phanerozoic
All Genera
Well-Resolved Genera
Long-Term Trend
The "Big 5" Mass Extinctions
Other Extinction Events
542
500
450
400
350
300
250
200
150
100
50
0
Millions of Years Ago
0
1
2
3
4
5
Thousands of Genera

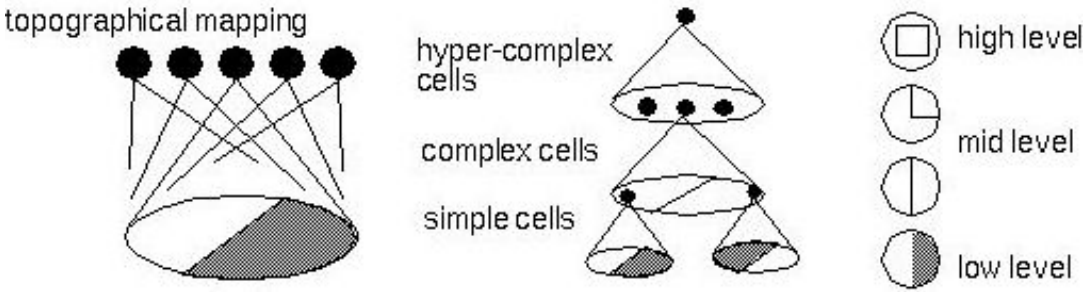
# Hubel & Wiesel (1959)

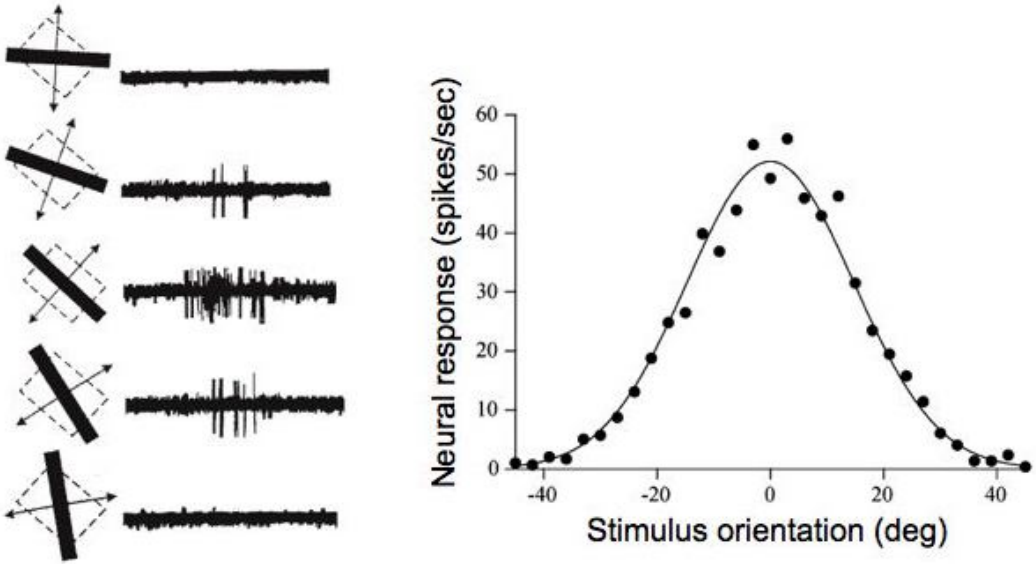







Hubel & Wiesel, 1968

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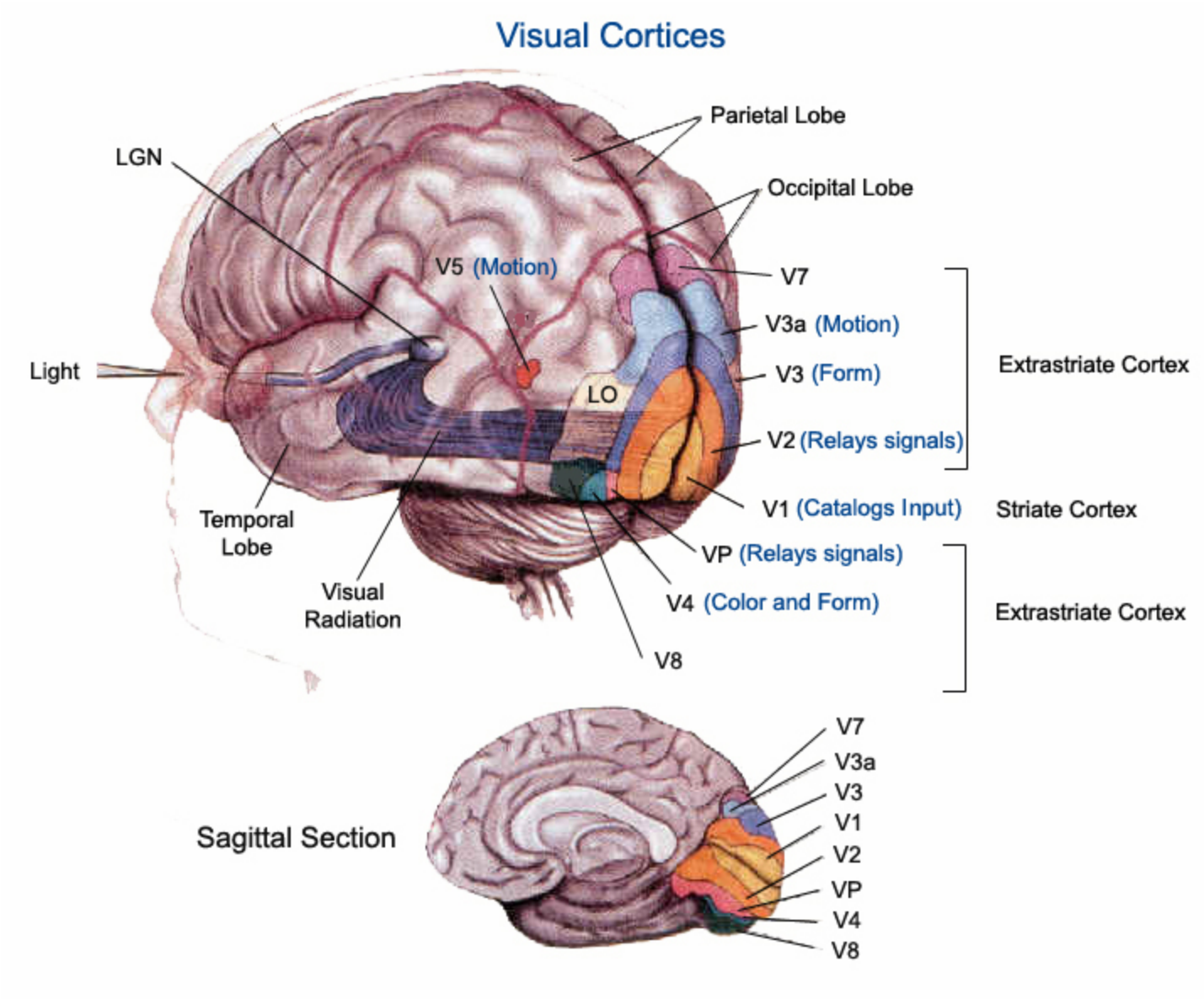
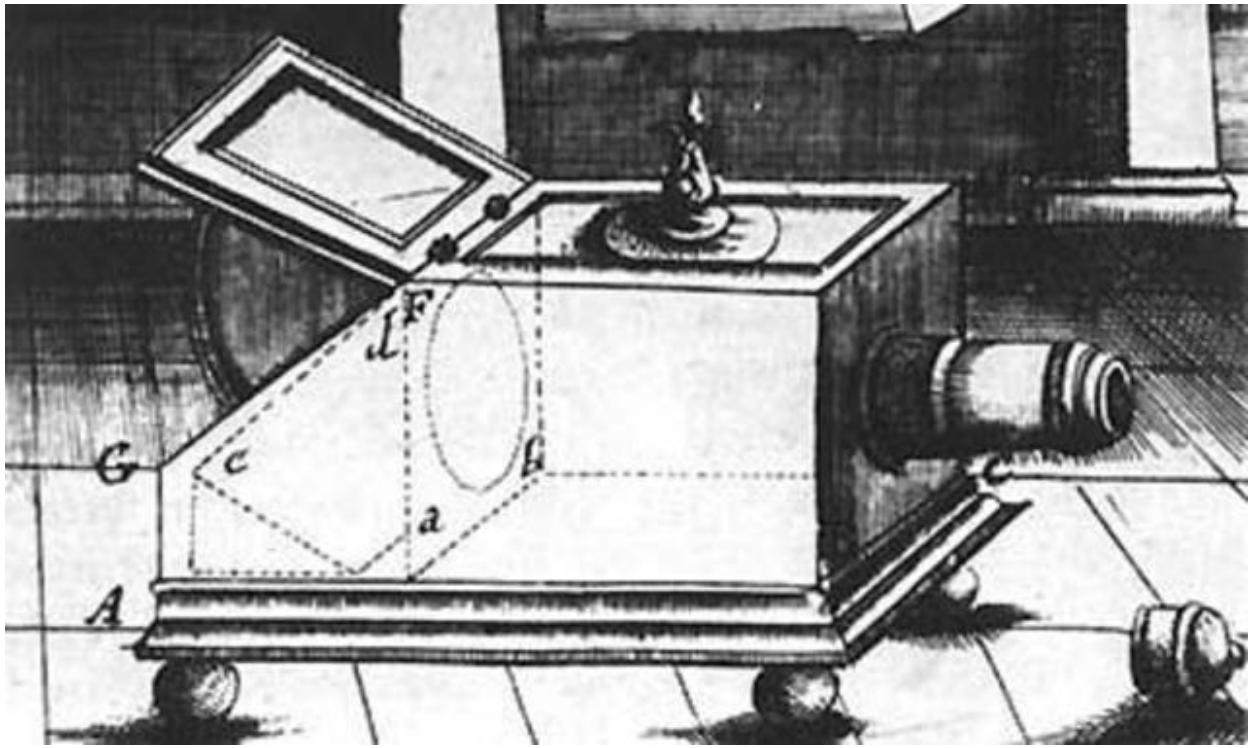

Visual Cortices
Parietal Lobe
LGN
Occipital Lobe
V5 (Motion)
V7
V3a (Motion)
Light
V3 (Form)
LO
Extrastriate Cortex
V2 (Relays signals)
V1 (Catalogs Input)
Striate Cortex
Temporal Lobe
VP (Relays signals)
Visual Radiation
V4 (Color and Form)
Extrastriate Cortex
V8
Sagittal Section
V7
V3a
V3
V1
V2
VP
V4
V8

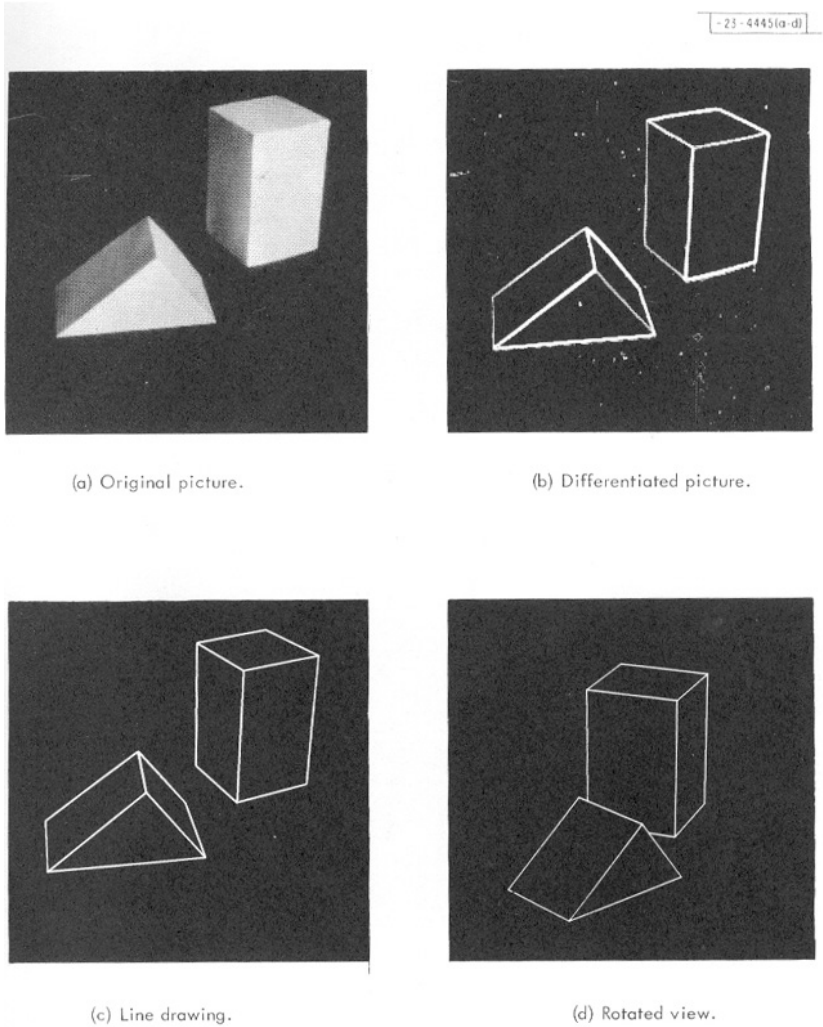
# Camera Obscura

## da Vinci (15th Century)



# Block World

## Larry Roberts (1965)



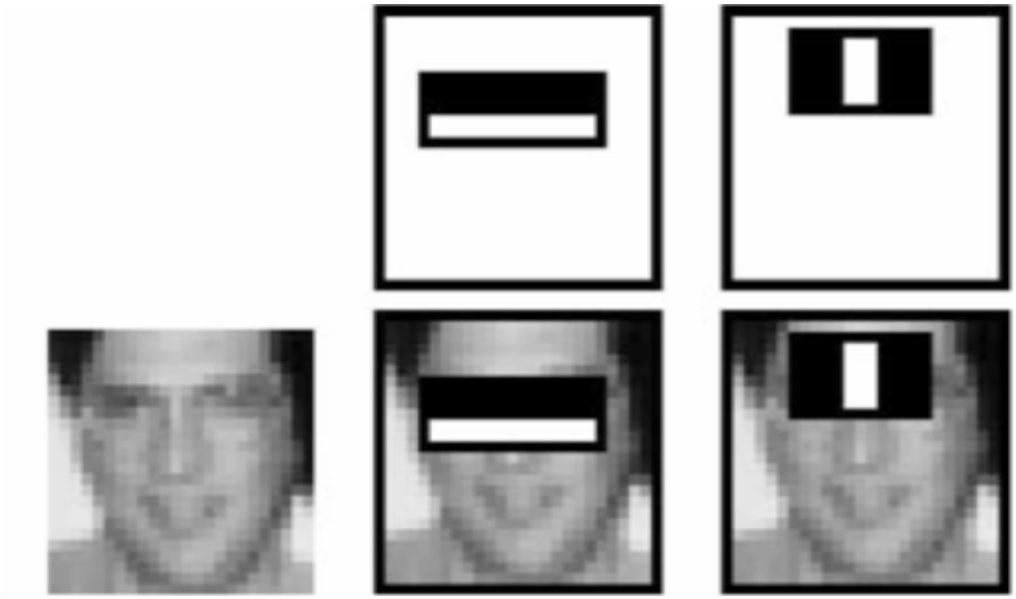

(a) Original picture.

(b) Differentiated picture.

(c) Line drawing.

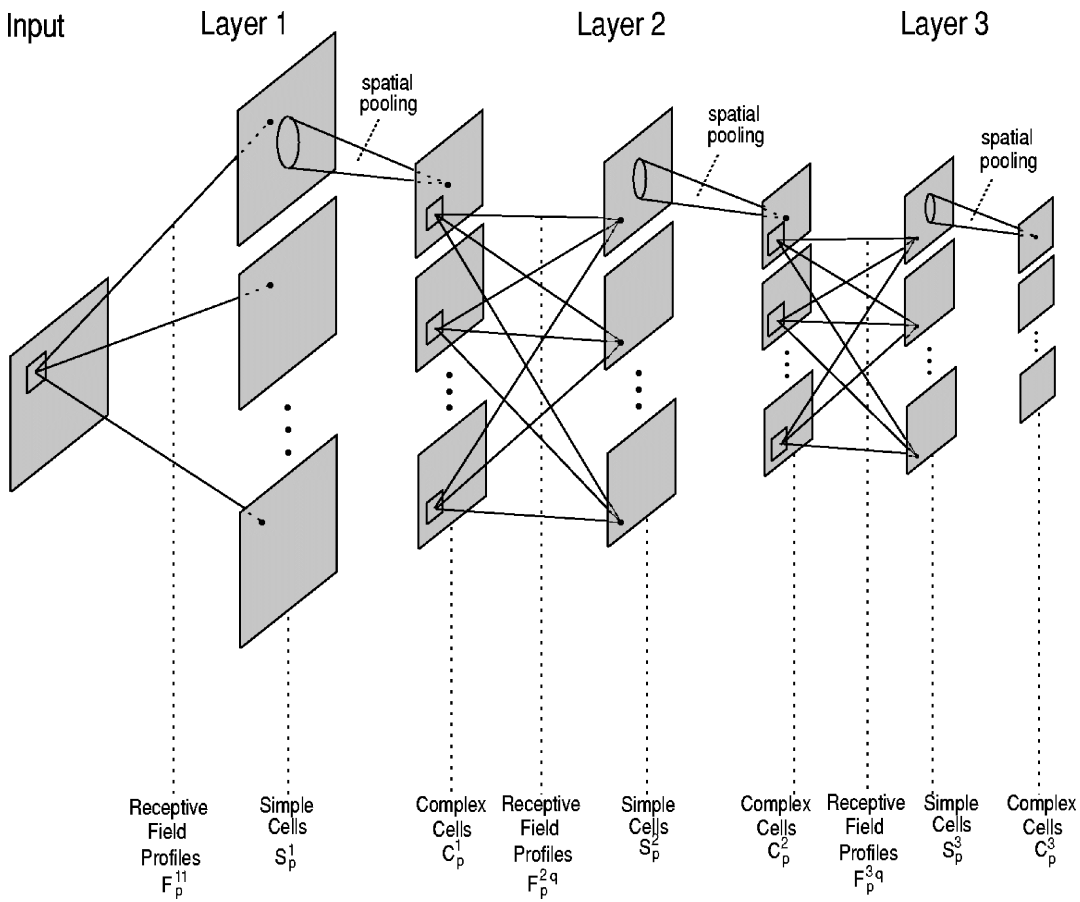
(d) Rotated view.

# Viola & Jones (2001)



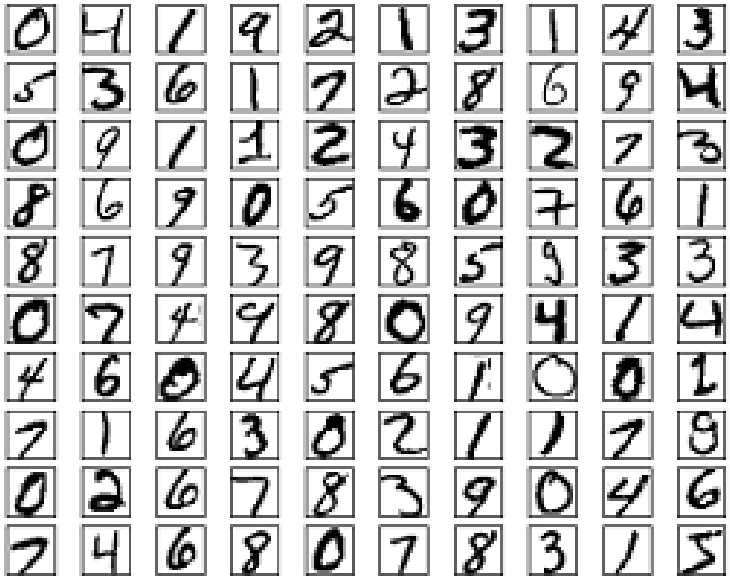
# Neurocognitron

## Fukushima (1980)



# MNIST Digits & LeNet-5

## LeCun, Boutou, Bengio & Haffner (1998)





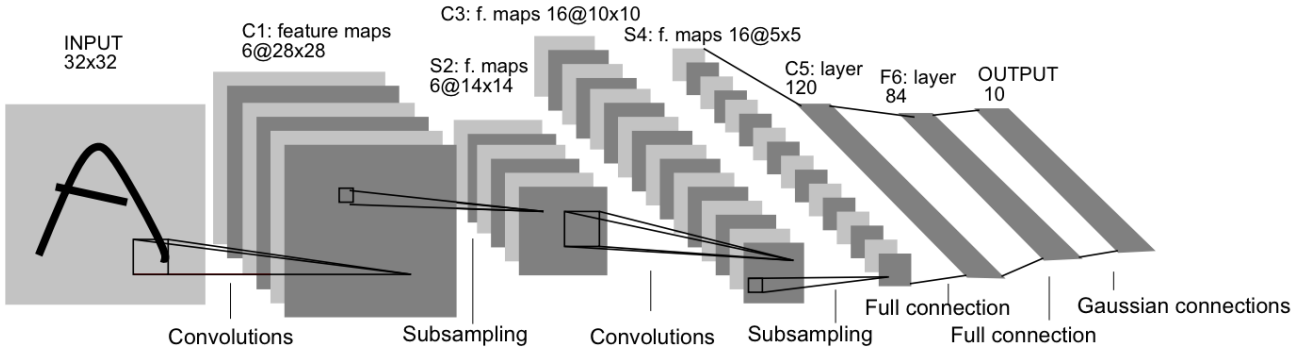
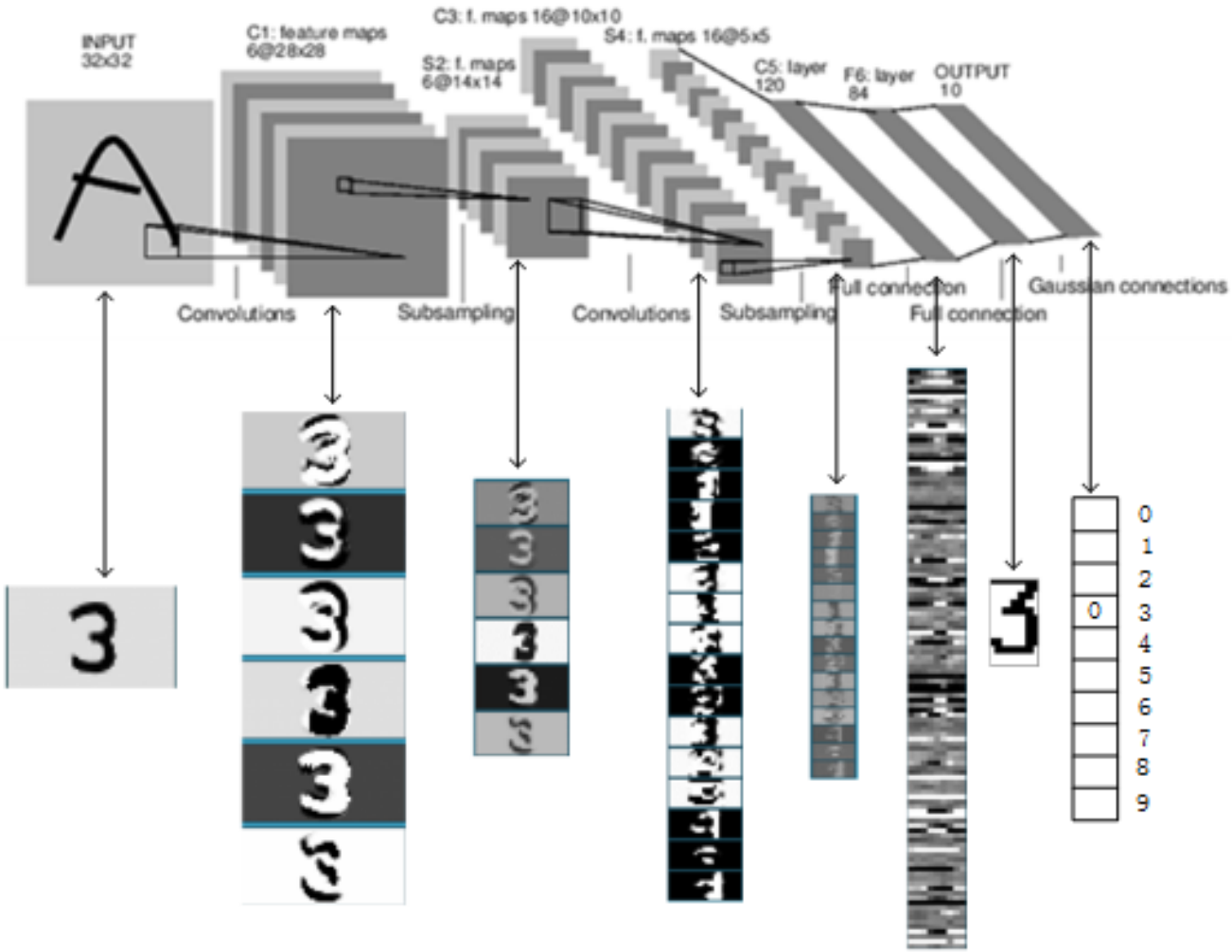



Fig. 2. Architecture of LeNet-5, a Convolutional Neural Network, here for digits recognition. Each plane is a feature map, i.e. a set of units whose weights are constrained to be identical.

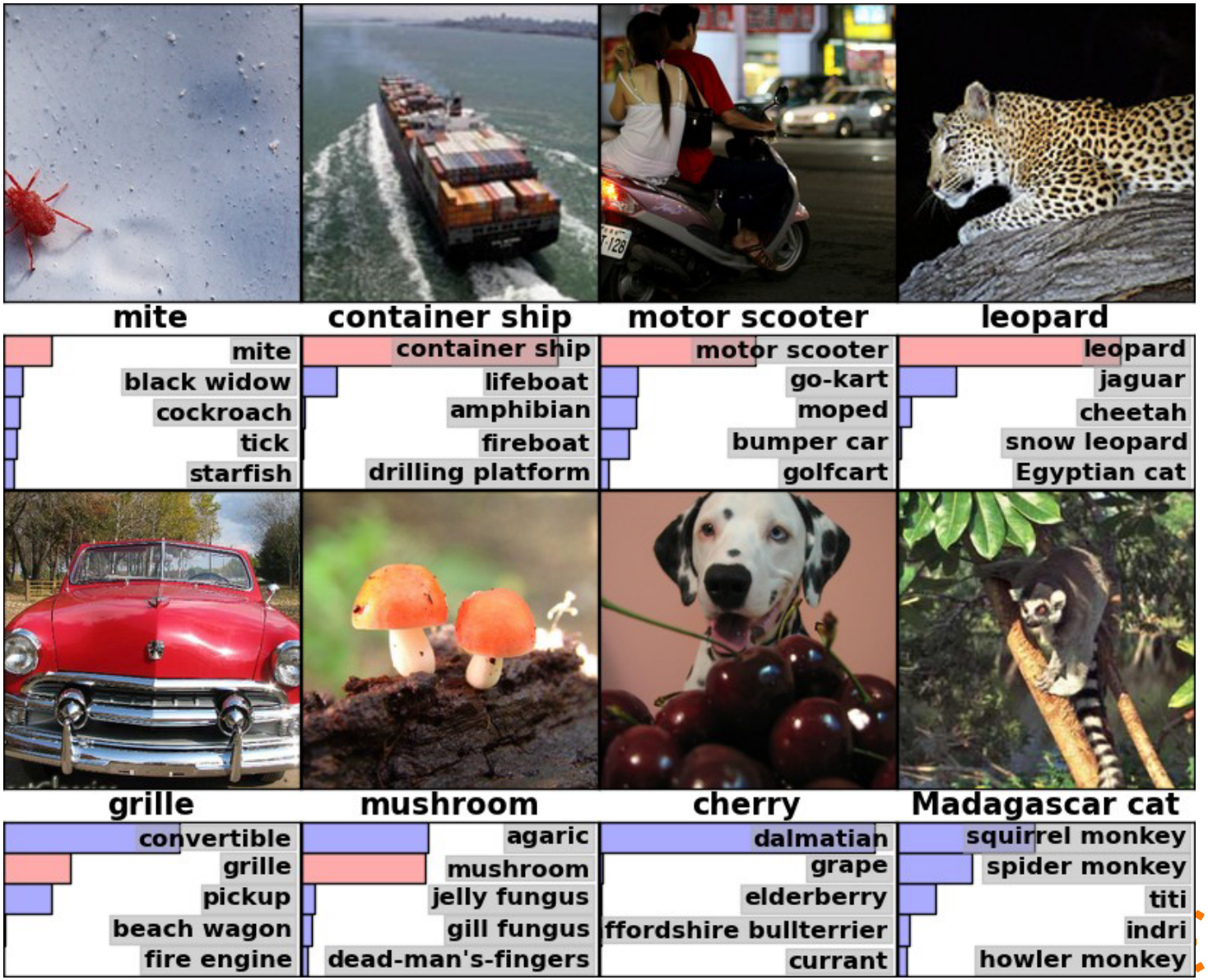
# LeNet-5

## LeCun, Boutou, Bengio & Haffner (1998)



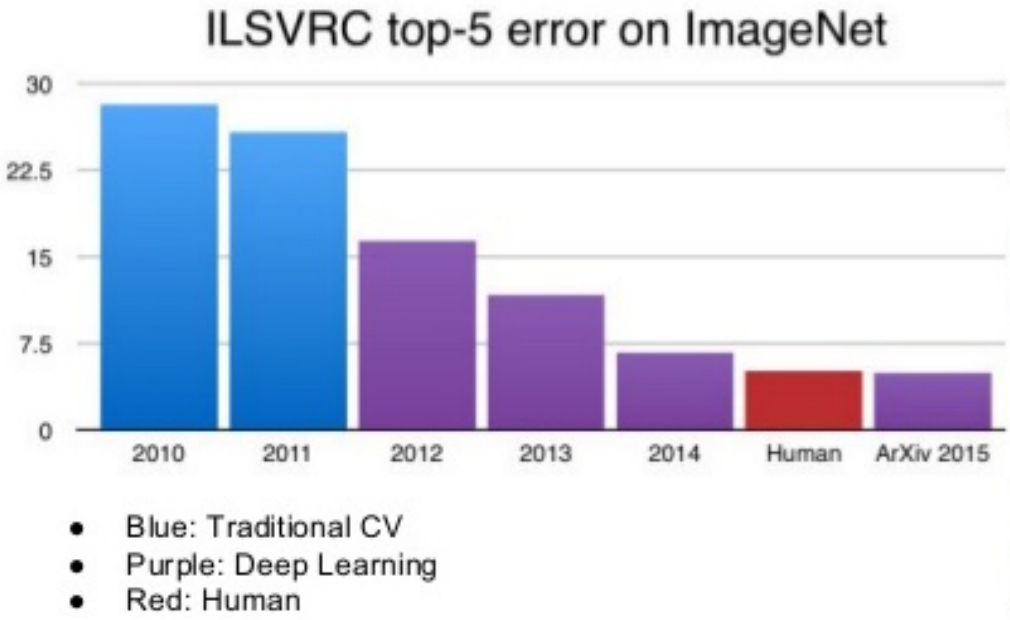
# ImageNet

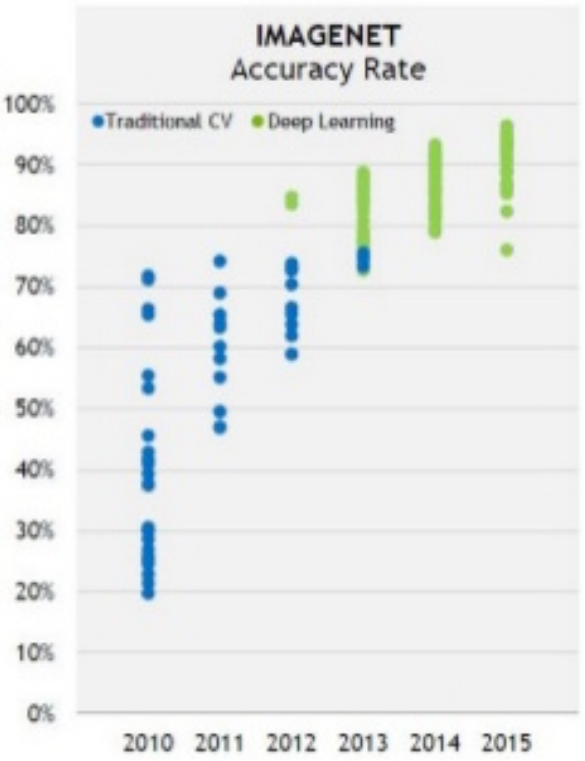
## Fei-Fei Li et al. (2009), 14m images, 22k categories



# ImageNet Classification Error

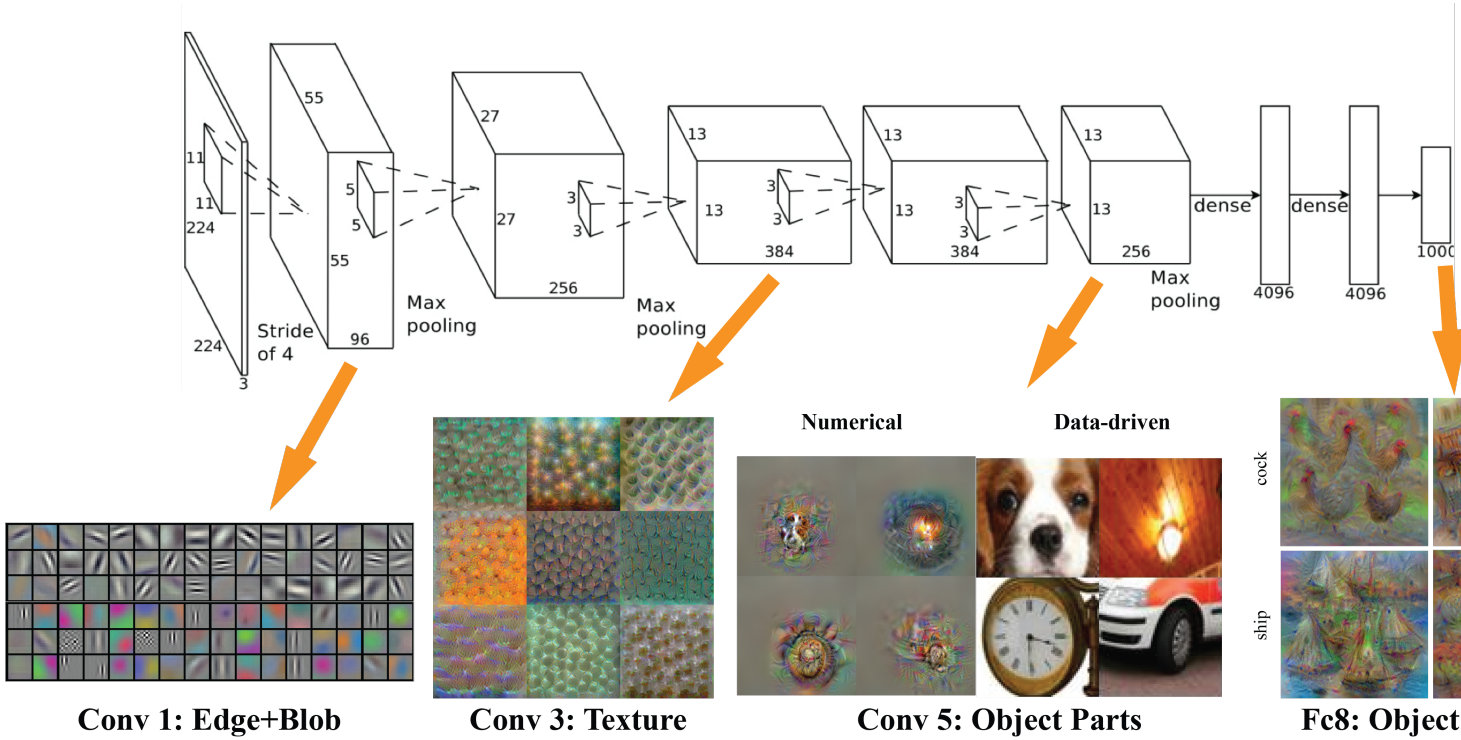
## ILSVRC: 1.4m, 1k object classes



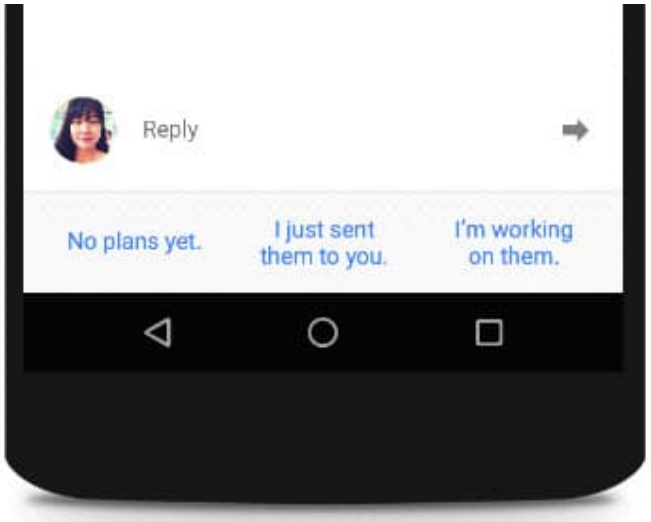



# AlexNet

## Krizhevsky, Sutskever & Hinton (2012)




mark zuckerberg
Mark Zuckerberg
11,814 like this. · Business P...


Reply
No plans yet.
I just sent them to you.
I'm working on them.


"Remind me about this when I get home"
tap to edit
OK, I'll remind you when you arrive at home:
Reminder
11 Hot Beach Escapes - Jetsetter
Arriving: Home
Remove

# Sunspring

## Sharp & Goodwin (2016)

INT. SHIP

We see H pull a book from a shelf, flip through it while speaking, and then put it back.

H
In a future with mass unemployment, young people are forced to sell blood. That's the first thing I can do.

H2
You should see the boys and shut up. I was the one who was going to be a hundred years old.

H
I saw him again. The way you were sent to me... that was a big honest idea. I am not a bright light.

C
Well, I have to go to the skull. I don't know.

He picks up a light screen and fights the security force of the particles of a transmission on his face.

H
(continuing)
What do you mean?

C
(smiles)
I don't know anything about any of this.

H
(to Hauk, taking his eyes from his mouth)
Then what?

H2
There's no answer.

C
(frowning)
We're going to see the money.

H
(reading)
"All right, you can't tell me that."

Steps back. Coffey is still going through.

C
I was coming to that thing because you were so pretty.

H
I don't know. I don't know what you're talking about.

C
That's right.

H
So what are you doing?

H2
I don't want to be honest with you.

He looks at him for a moment, then smiles at him.

H
You don't have to be a doctor.

H2
I am not sure. I don't know what you're talking about.

H
I want to see you too.

H2
What do you mean?

He starts to shake.

H
I'm sorry, but I'm sure you wouldn't even touch me.

H2
I don't know what you're talking about.

H
The principle is completely constructed for the same time.

H2
(smiling)
It was all about you to be true.

H
You didn't even see the movie with the rest of the base.

H2
I don't know.

H
I don't care.

H2
I know that it's a consequence. Whatever you want to know about the presence of the story, I'm a little bit of a boy on the floor.

H
I don't know. I just have to ask you to explain to me what you say.

H2
What do you mean?

H
Because I don't know what you're talking about.

H2
That was all the time.

H
I know that.

H2
I don't know.

H
(angry)
It would be a good time. I think I could have been my life.

H (CONT'D)
It may never be forgiven, but that is just too bad. I have to leave, but I'm not free of the world.

C
Yes. Perhaps I should take it from here. I'm not going to do something.

H
You can't afford to take this anywhere. It's not a dream. But I've got a good time to stay there.

C
Well, I think you can still be back on the table.

H
Mmm. It's a damn thing scared to say. Nothing is going to be a thing but I was the one that got on this rock with a child and then I left the other two.

He is standing in the stars and sitting on the floor. He takes a seat on the counter and pulls the camera over to his back. He stares at it. He is on the phone. He cuts the shotgun from the edge of the room and puts it in his mouth. He sees a black hole in the floor leading to the man on the roof.

He comes up behind him to protect him. He is still standing next to him.

He looks through the door and the door closes. He looks at the bag from his backpack, and starts to cry.

T
Well, there's the situation with me and the light on the ship. The guy was trying to stop me. He was like a baby and he was gone. I was worried about him. But even if he would have done it all. He couldn't come any more. I didn't mean to be a virgin. I mean, he was weak. And I thought I'd change my mind. He was crazy to take it out. It was a long time ago. He was a little late. I was going to be a moment. I just wanted to tell you that I was much better than he did. I had to stop him and I couldn't even tell. I didn't want to hurt him. I'm sorry. I know I don't like him. I can go home and be so bad and I love him. So I can get him all the way over here and find the square and go to the game with him and she won't show up. Then I'll check it out. But I'm going to see him when he gets to me. He looks at me and he throws me out of his eyes. Then he said he'd go to bed with me.

# Sunspring

## Sharp & Goodwin (2016)

[video]

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# Hardware

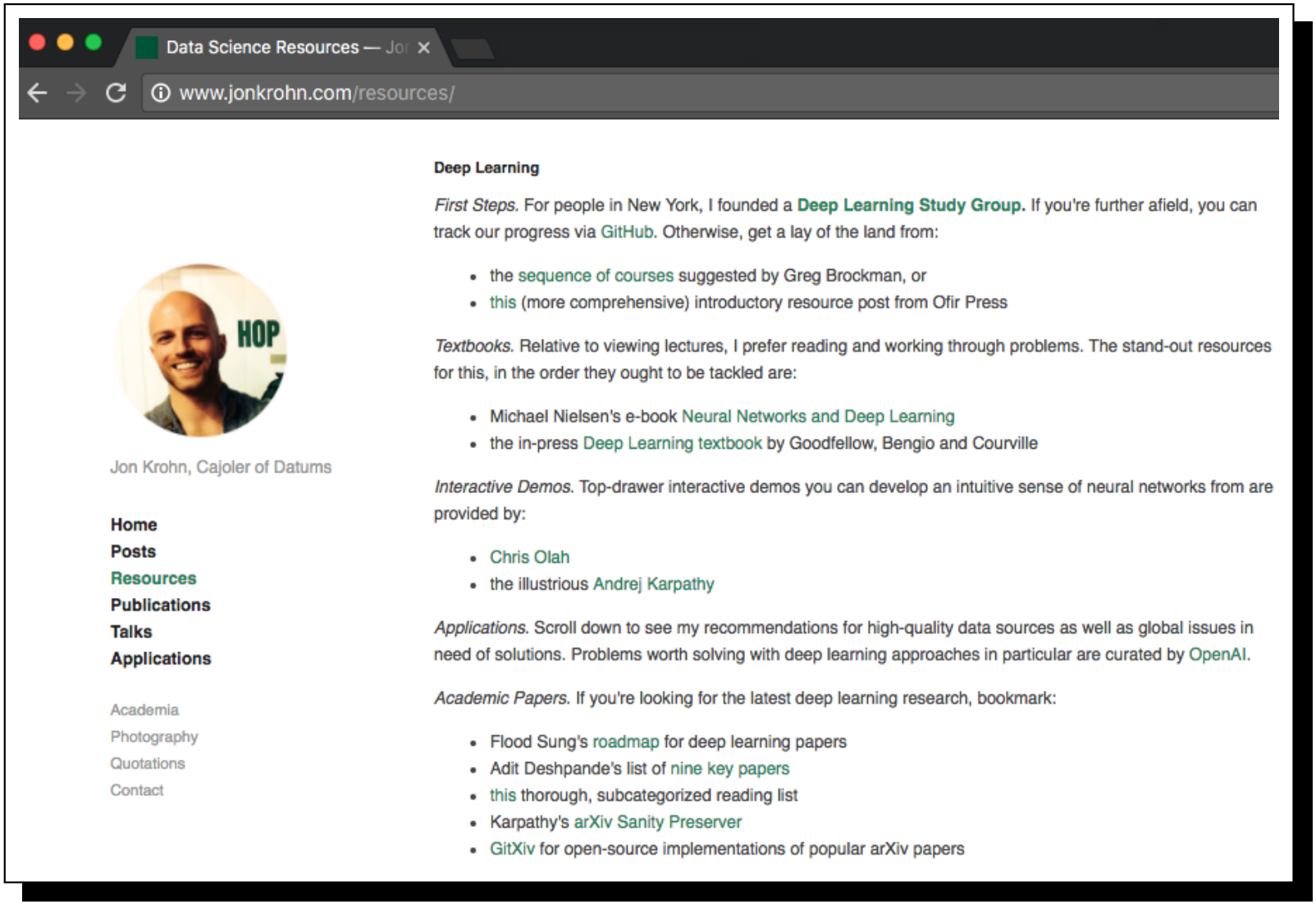
- local machine
- build your own server
- AWS / Google Cloud Platform
- GPU(s) / TPU(s)

# Popular Libraries

## based on Johnson (2016) in Stanford *CS231n* l.12

| | **Caffe** | **Torch** | **Theano** | **TensorFlow** |
|---|---|---|---|---|
| *Language* | C++, Python | Lua | Python | Python |
| *Pretrained* | Yes++ | Yes++ | Yes (Lasagne) | Inception |
| *Parallel GPUs: Data* | Yes | Yes | Yes | Yes |
| *Parallel GPUs: Model* | No | Yes | Experimental | Yes (best) |
| *Readable Source Code* | Yes (C++) | Yes | No | No |
| *Good at RNN* | No | Mediocre | Yes | Yes (best) |
| *Higher-Level APIs* | No | No | Keras | Keras and TFLearn |

# [Human Learning Resources]



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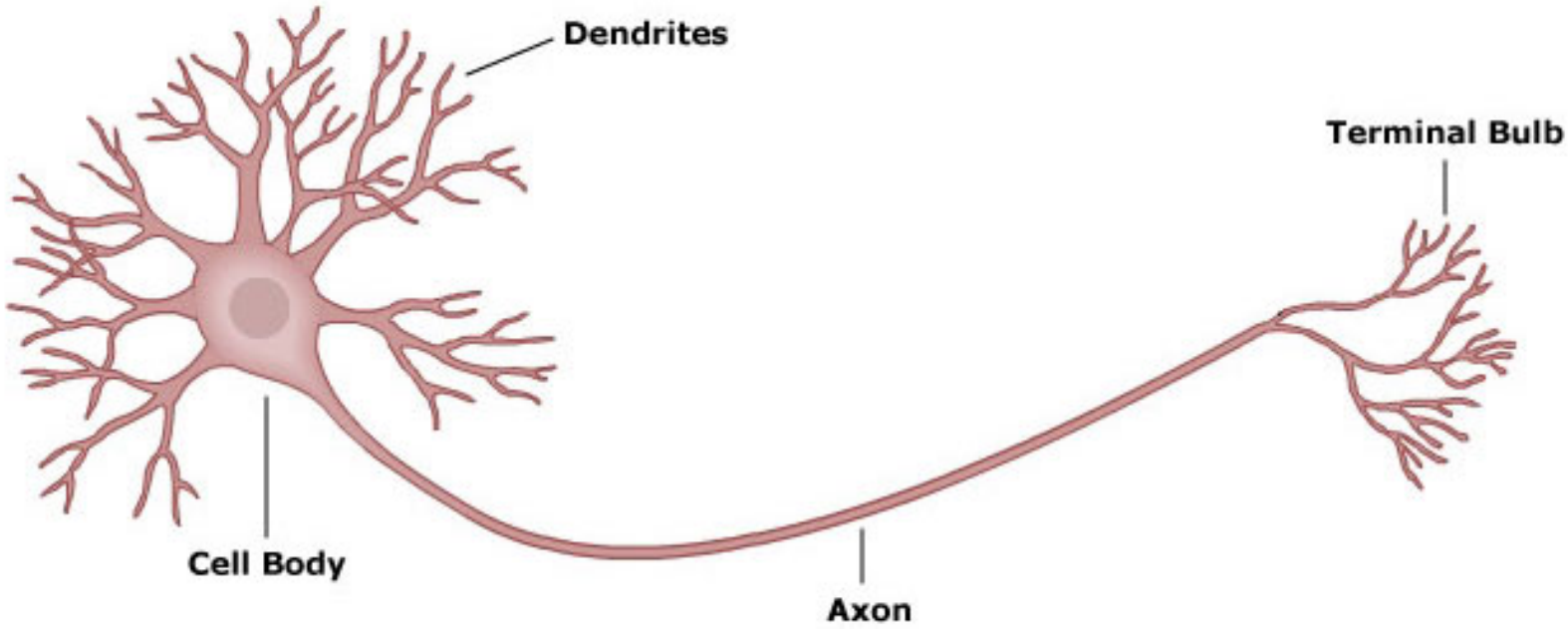
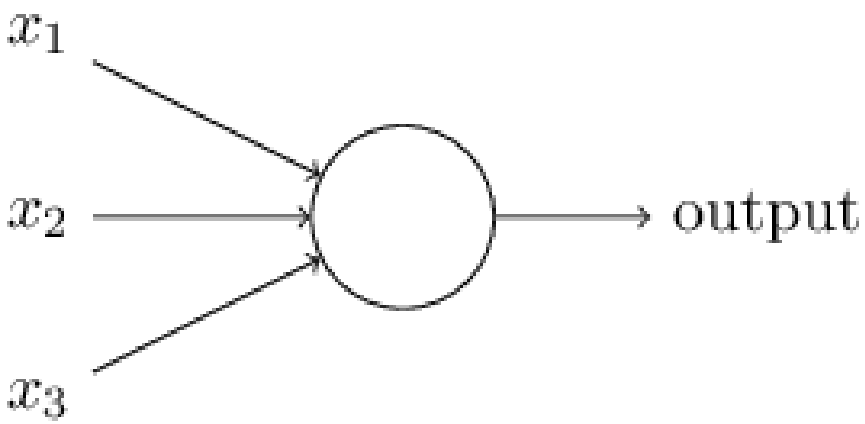
# Biological Neuron Morphology



# Perceptron

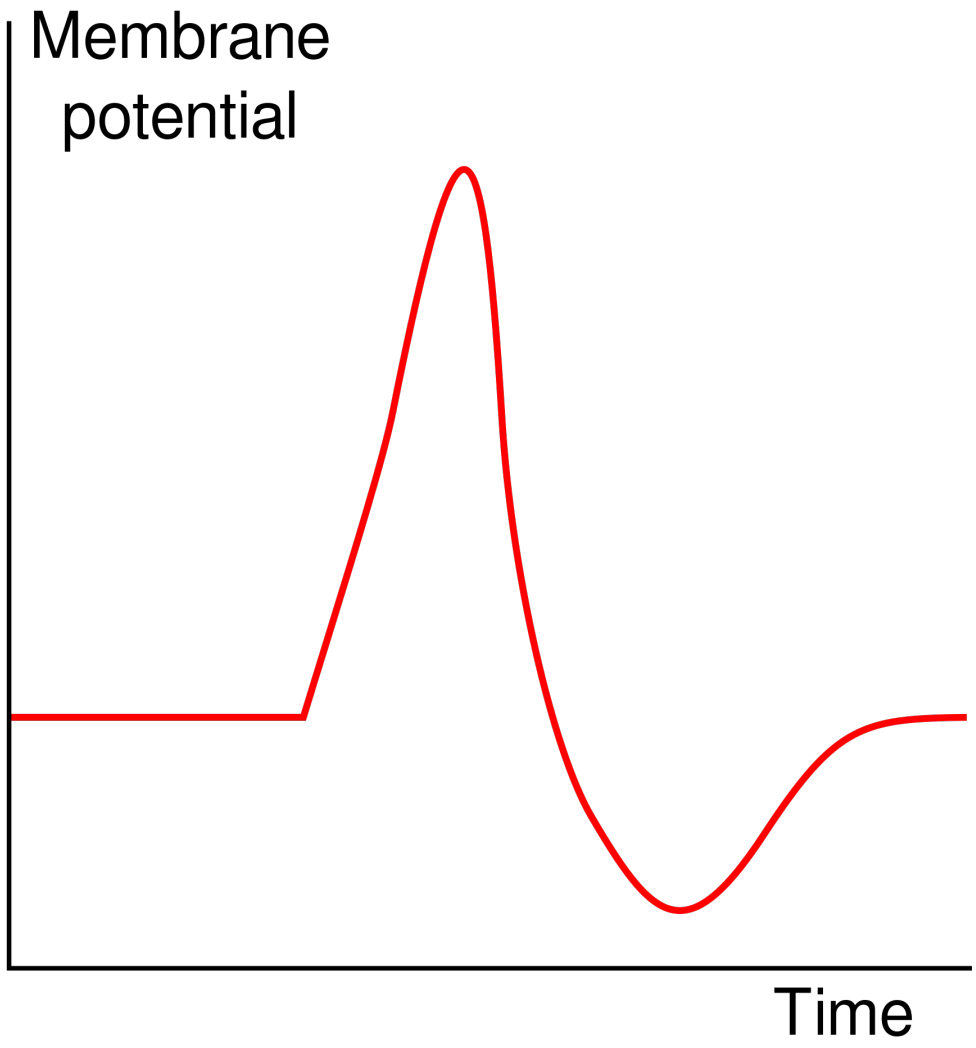
## Rosenblatt (1957)




$$\text{output} = \begin{cases} 0 & \text{if } \sum_j w_j x_j \leq \text{threshold} \\ 1 & \text{if } \sum_j w_j x_j > \text{threshold} \end{cases}$$

# Biological Neuron Physiology

## The *Binary* Action Potential



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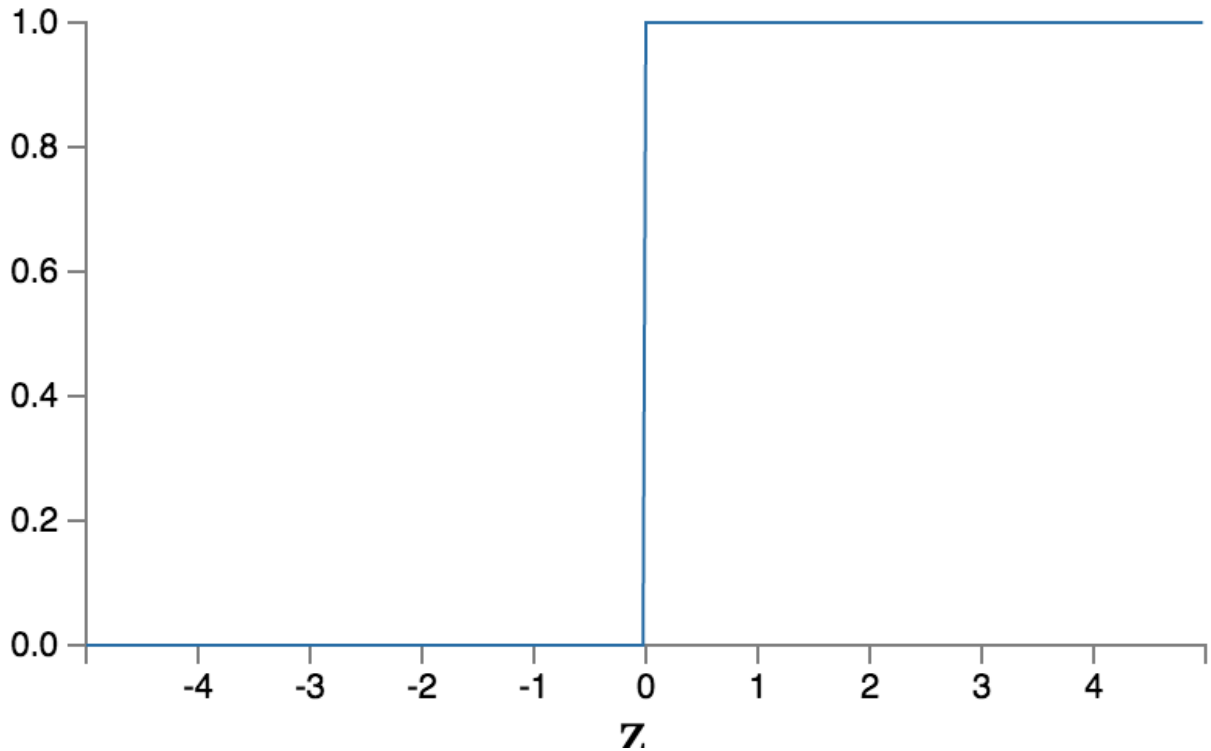
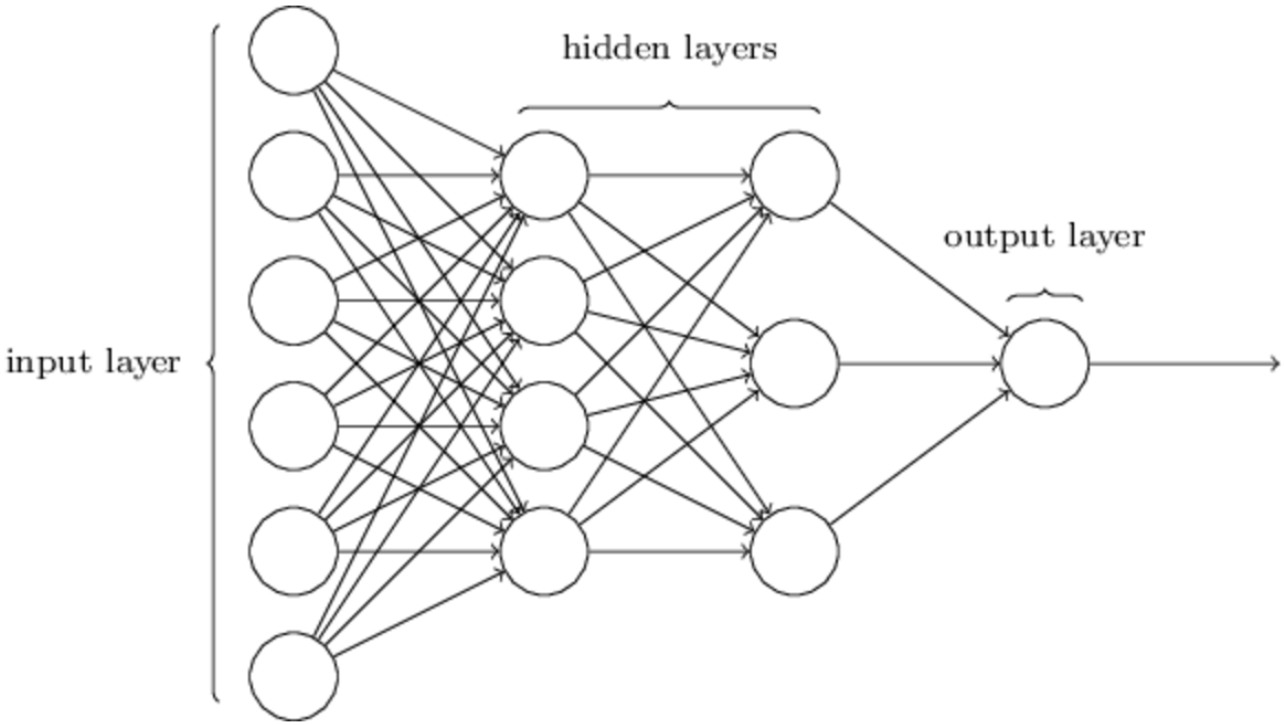


# Multi-Layer Perceptron



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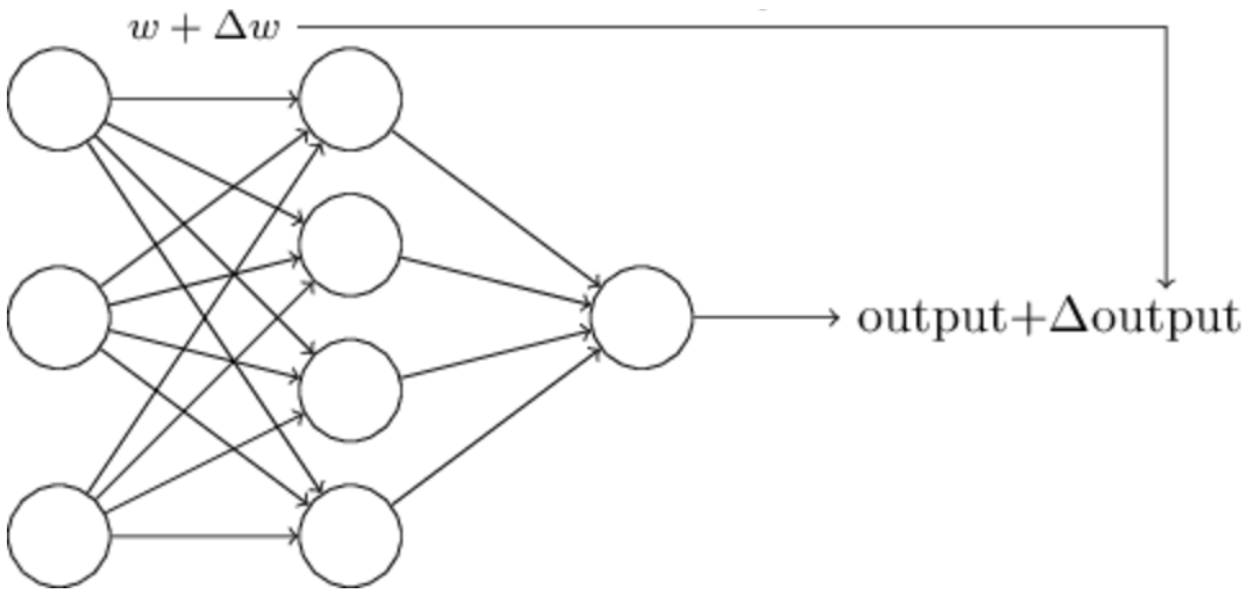
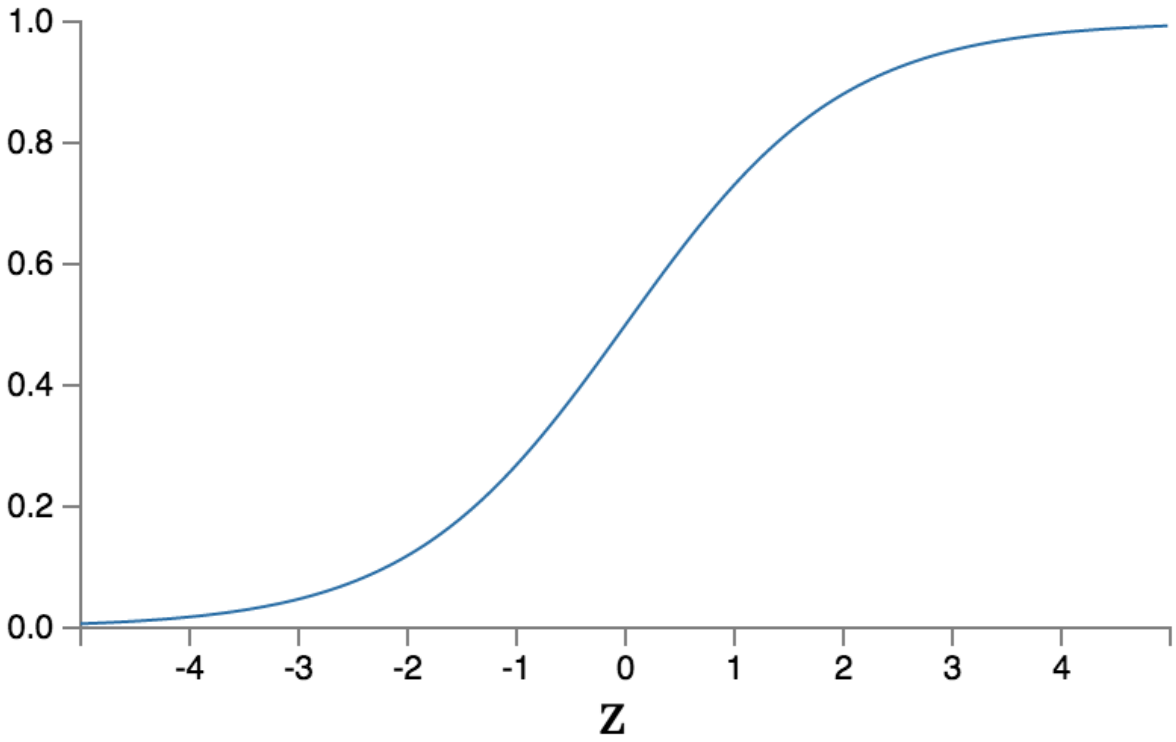
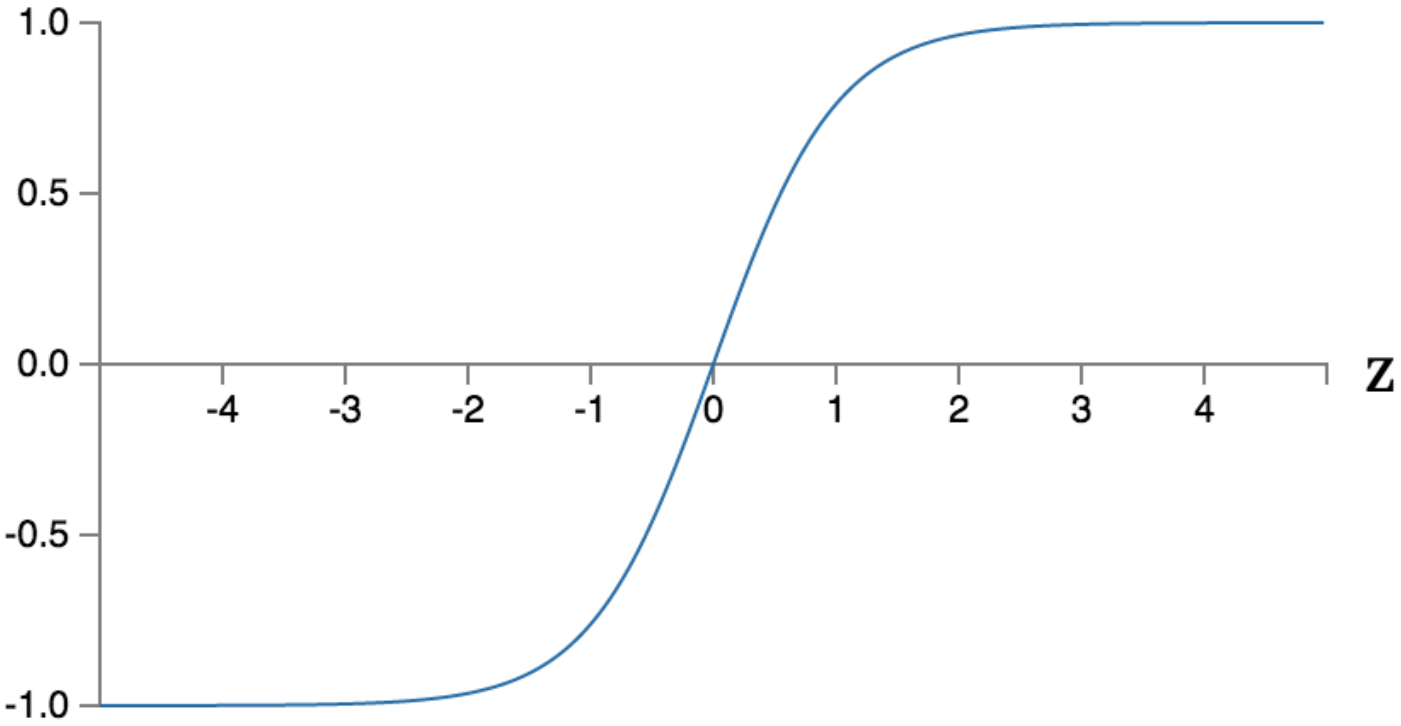


# Sigmoid Neuron




$$\frac{1}{1 + \exp(-\sum_j w_j x_j - b)}$$

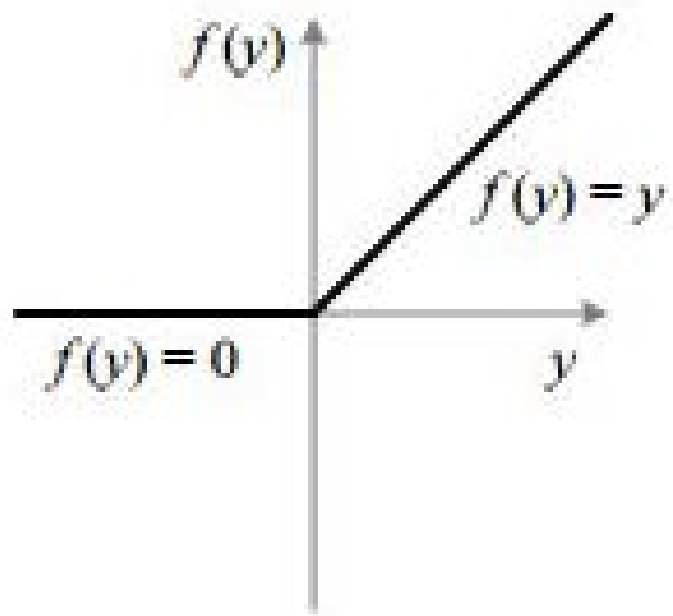
# *tanh* Neuron

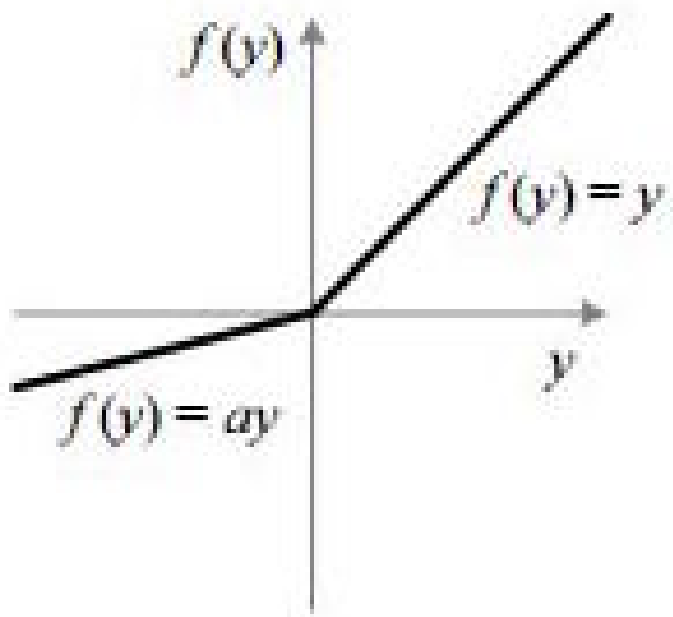



$$\sigma(z) = \frac{1 + \tanh(z/2)}{2}$$

# ReLU: Rectified Linear Units

## Nair & Hinton (2010); Maas, Hannun & Ng (2014)



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Neural Nets
Deep Neural Nets
Application
ConvNets
LSTMs
untapt
Reinforcement

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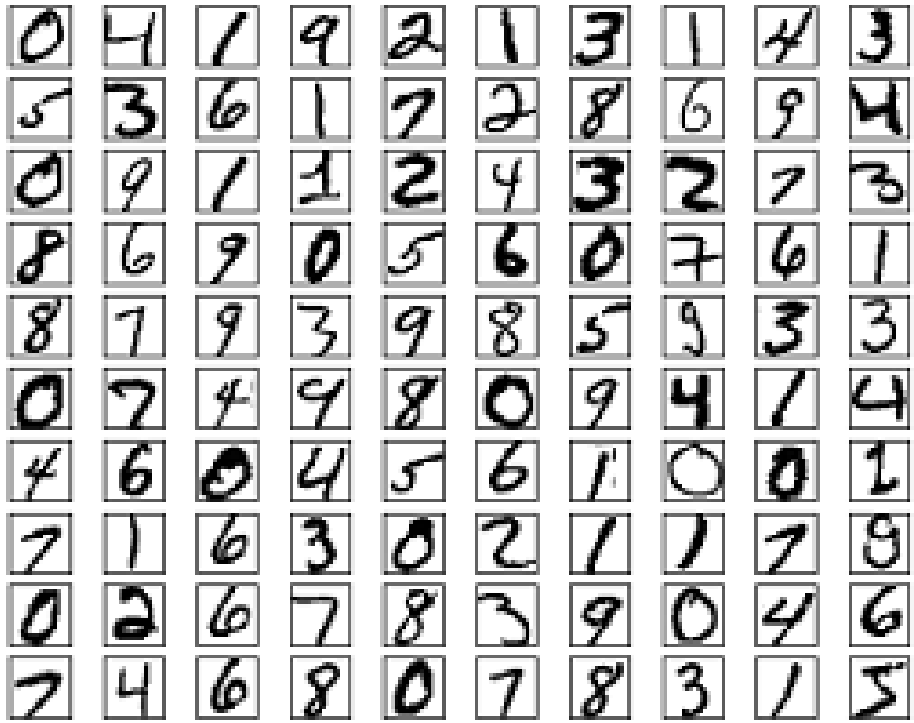
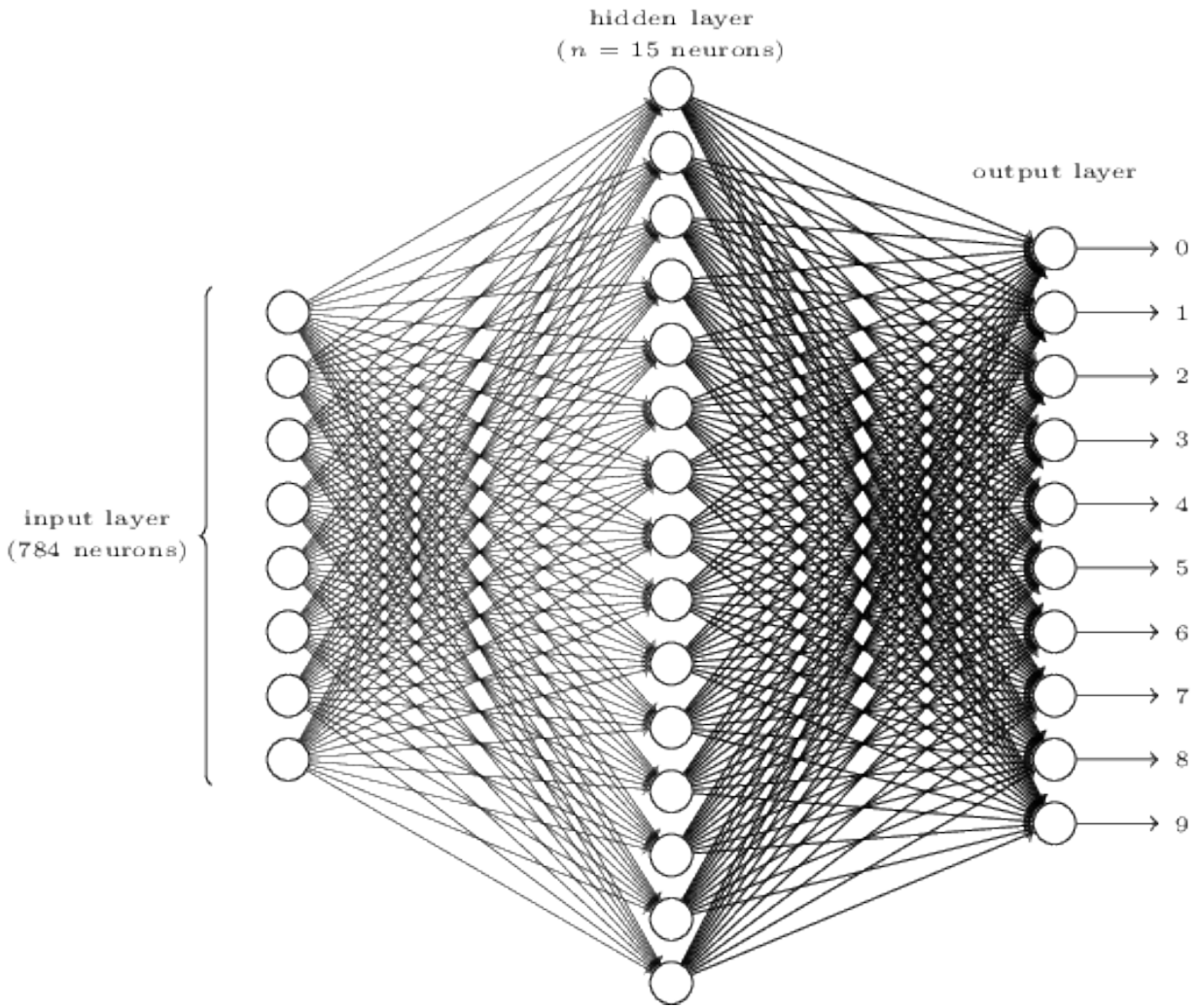
# MNIST

## LeCun, Cortes & Burges



# Fully-Connected Neural Net

## Single Hidden Layer



# TensorFlow Playground

[demo]

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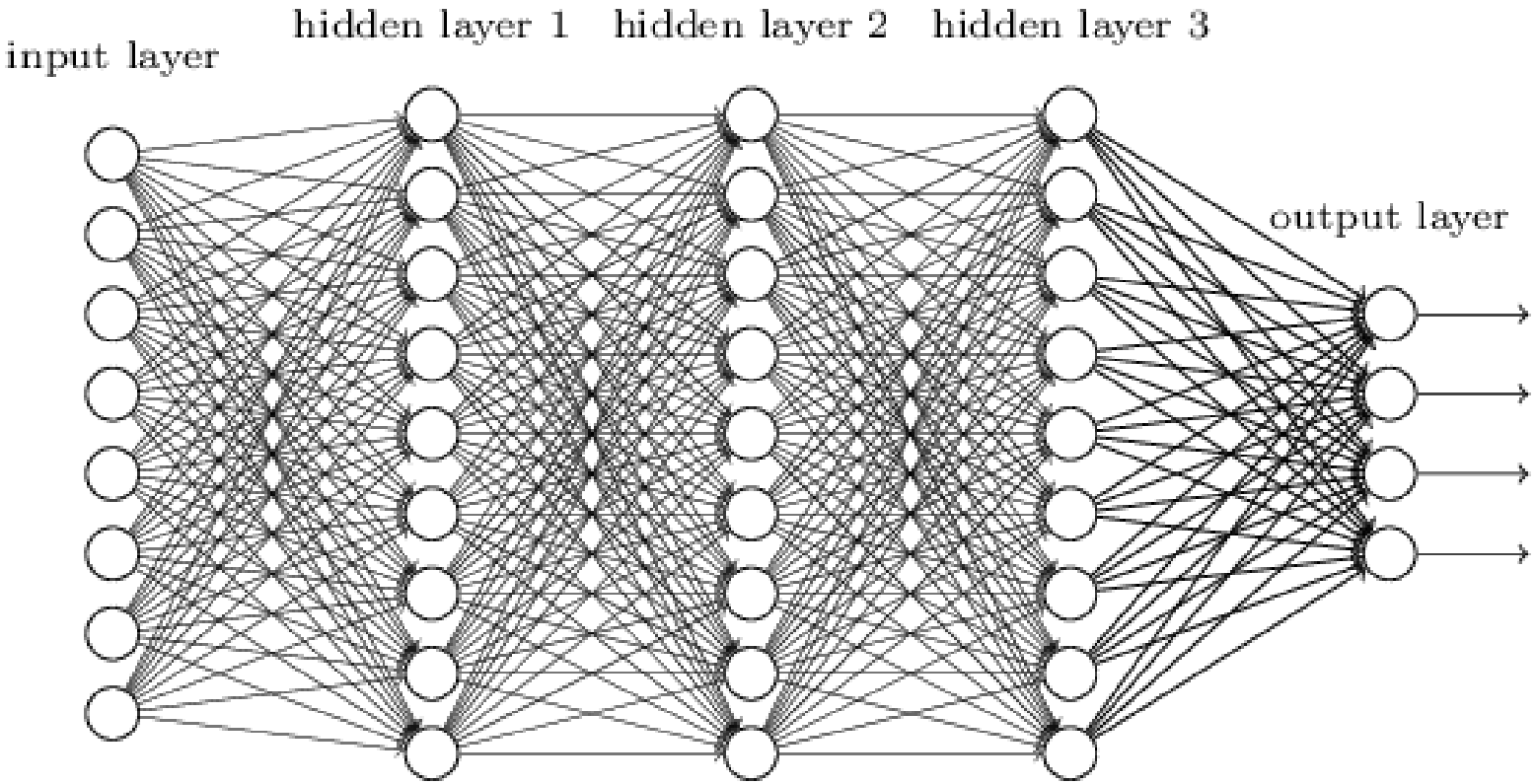
# Deep Fully-Connected Net

## 3 (or more) Hidden Layers



# TFLearn

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|---|---|---|---|---|
| *Language* | C++, Python | Lua | Python | Python |
| *Pretrained* | Yes++ | Yes++ | Yes (Lasagne) | Inception |
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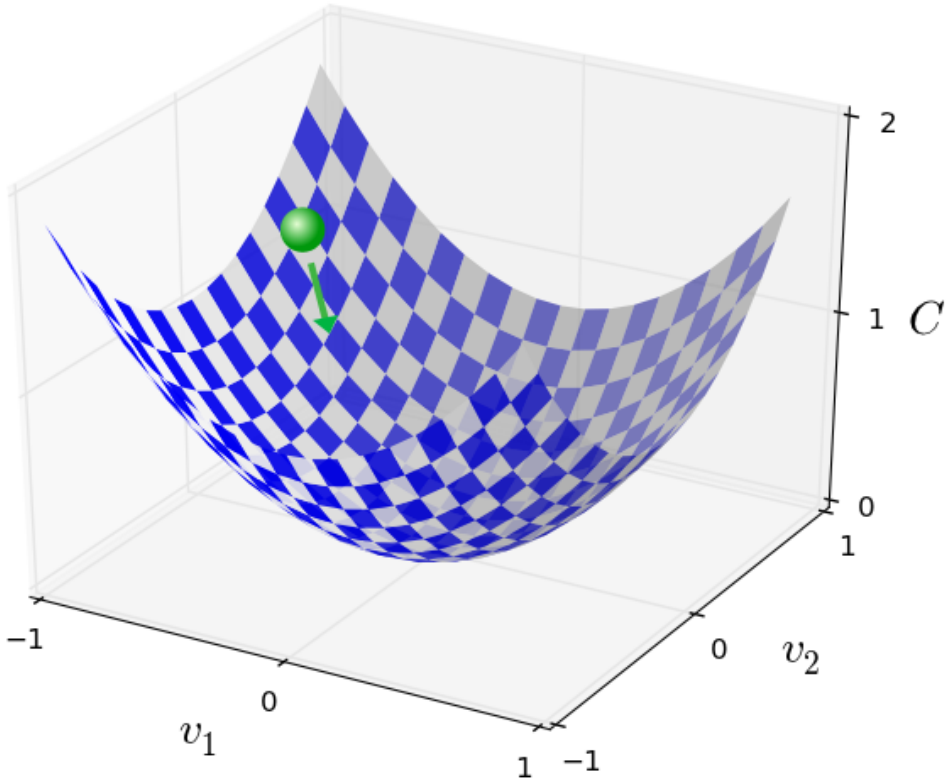
# A Simple Deep Net in TFLearn

[notebook]

# Synaptic Pruning

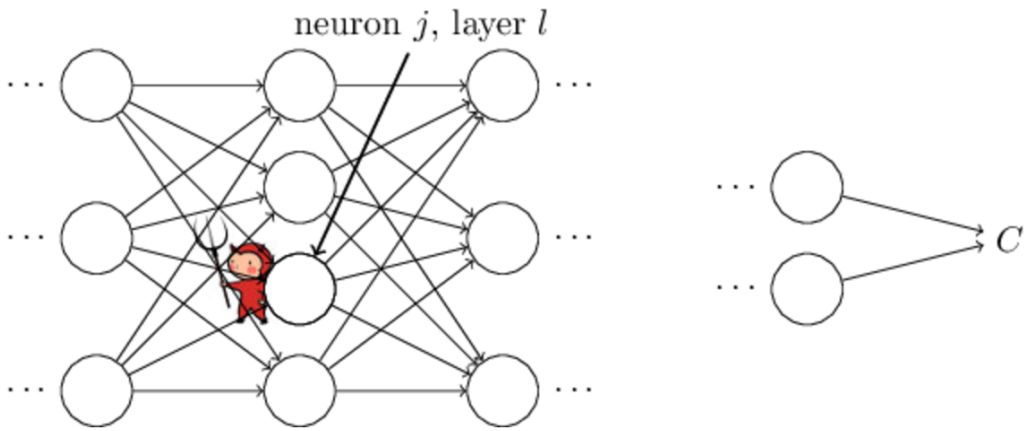
# (Stochastic) Gradient Descent

## Adam = AdaGrad + RMSprop



# Backpropagation

## computes error & gradient of cost function




$$\delta^L = \nabla_a C \odot \sigma'(z^L) \qquad \text{(BP1)}$$

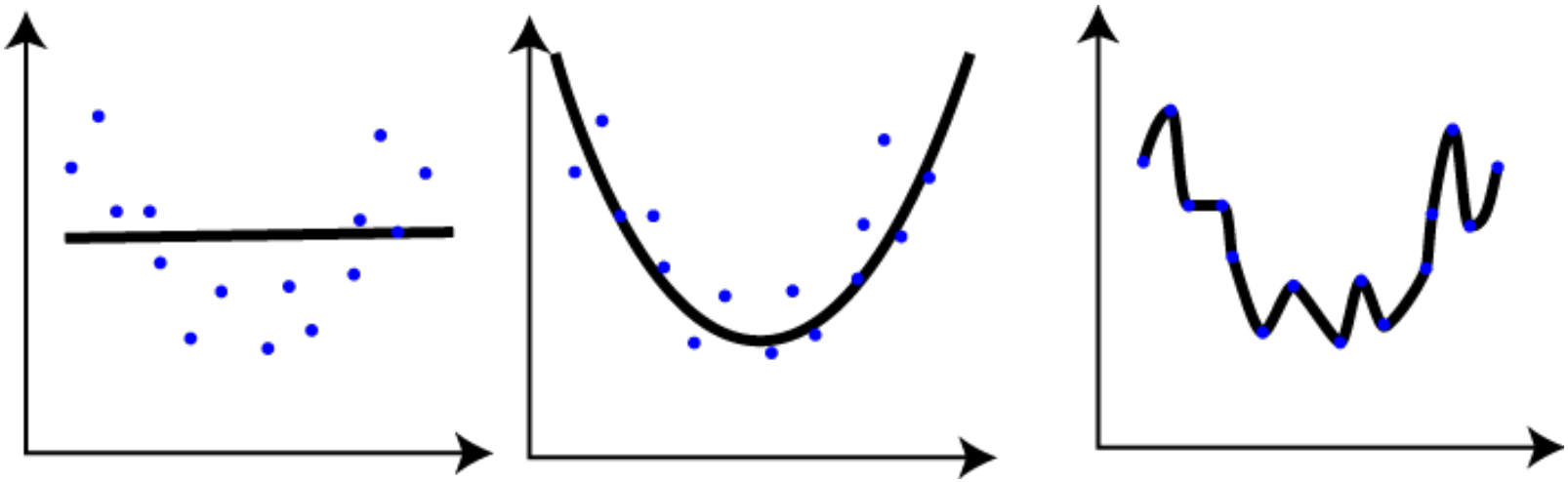
$$\delta^l = ((w^{l+1})^T \delta^{l+1}) \odot \sigma'(z^l) \qquad \text{(BP2)}$$

$$\frac{\partial C}{\partial b^l_j} = \delta^l_j \qquad \text{(BP3)}$$

$$\frac{\partial C}{\partial w^l_{j\,k}} = a^{l-1}_k \delta^l_j \qquad \text{(BP4)}$$

# Overfitting

## ...and avoiding it



- L1/L2 regularization
- dropout
- artificial data set expansion

# Improving Neural Networks

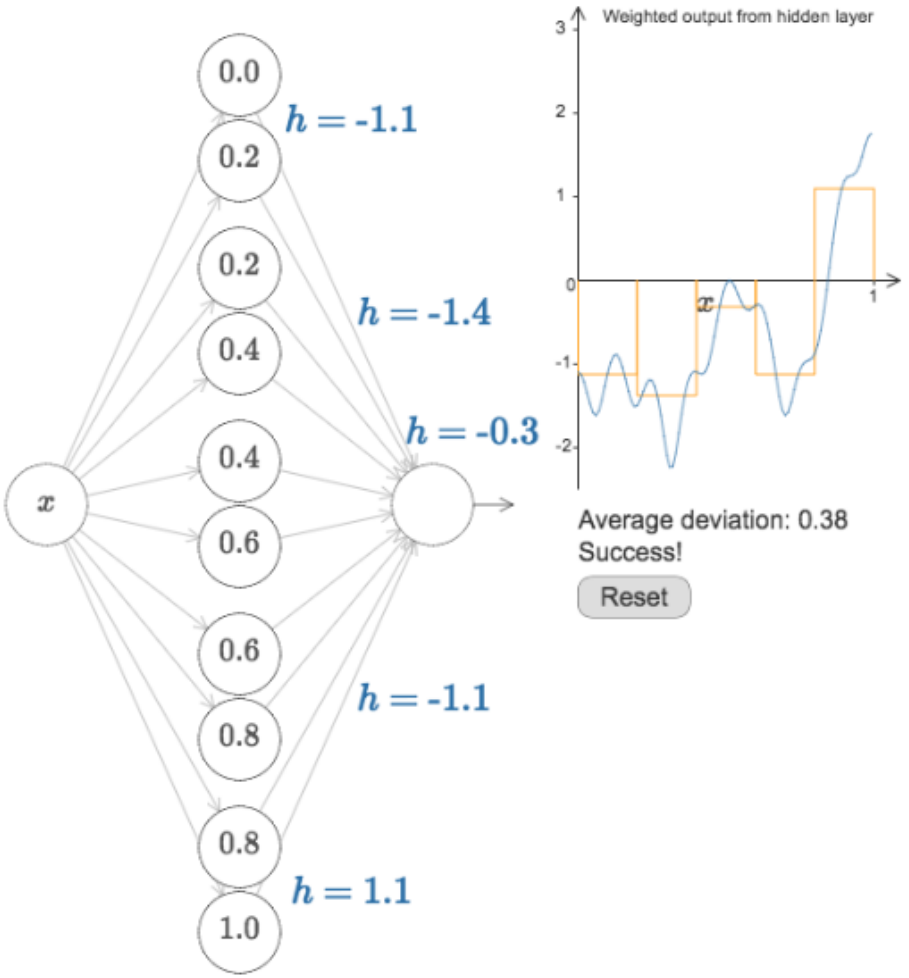
## Mostly Hyperparameter Tuning

- problem simplification
- number and width of layers
- cost fxn: quadratic, cross-entropy, log-likelihood, &c.
- more epochs, early stopping
- clever initialization of weights and biases
- learning rate $\eta$, variable schedule
- regularization parameter $\lambda$
- mini-batch size
- automation, e.g., with Spearmint

[Summary Blog Post]

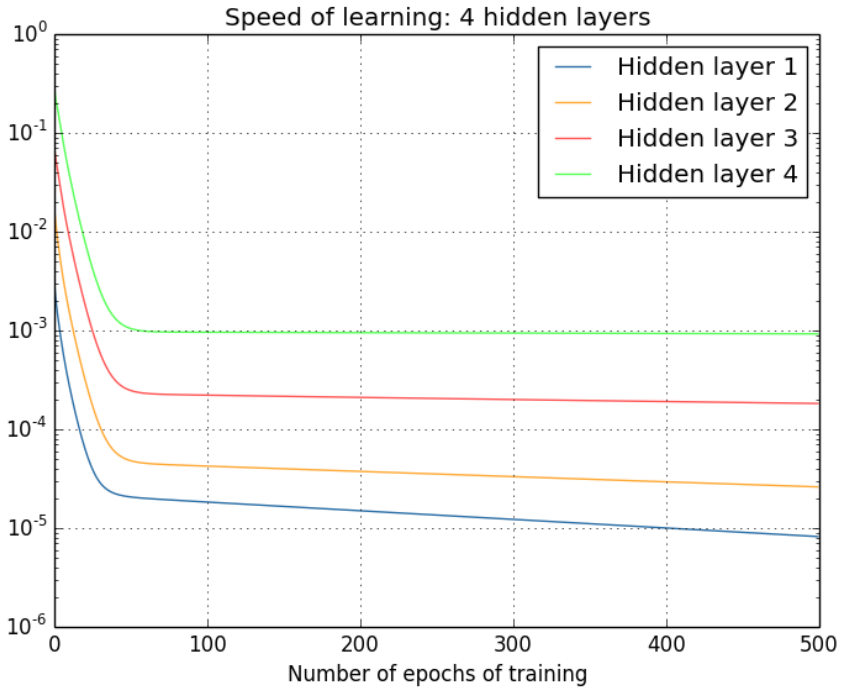
# Universality

## Solve Any Continuous Function (Nielsen, 2015)

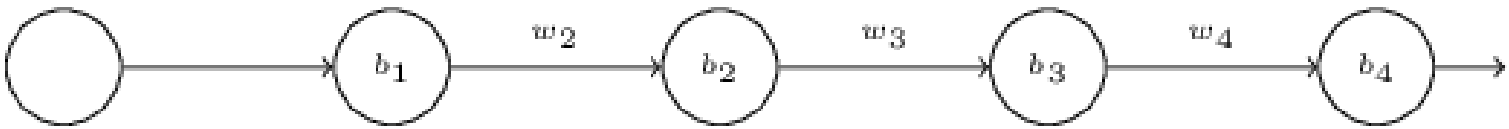


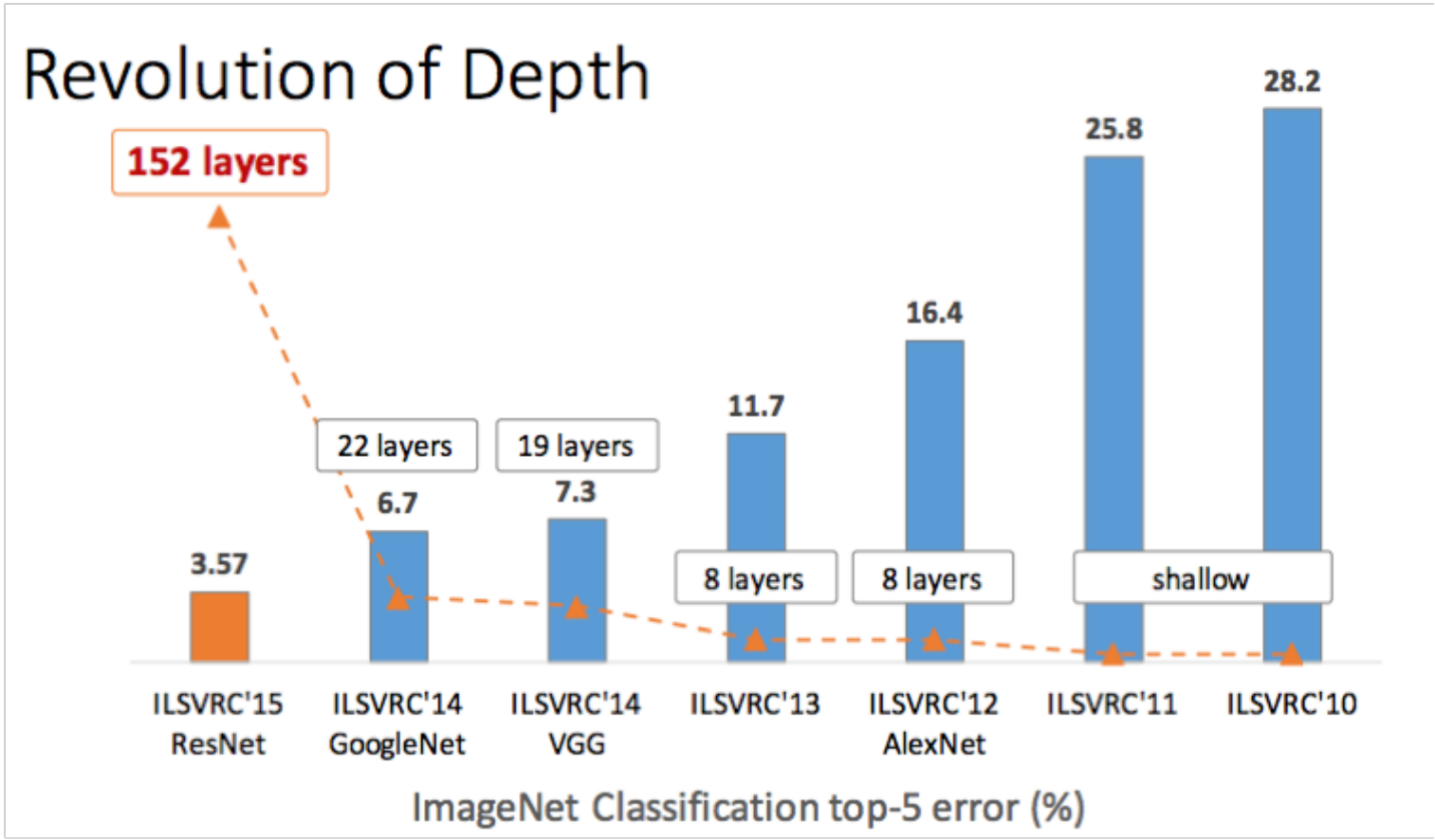
# Unstable Gradient

## Typically *Vanishes* (but can *Explode*)



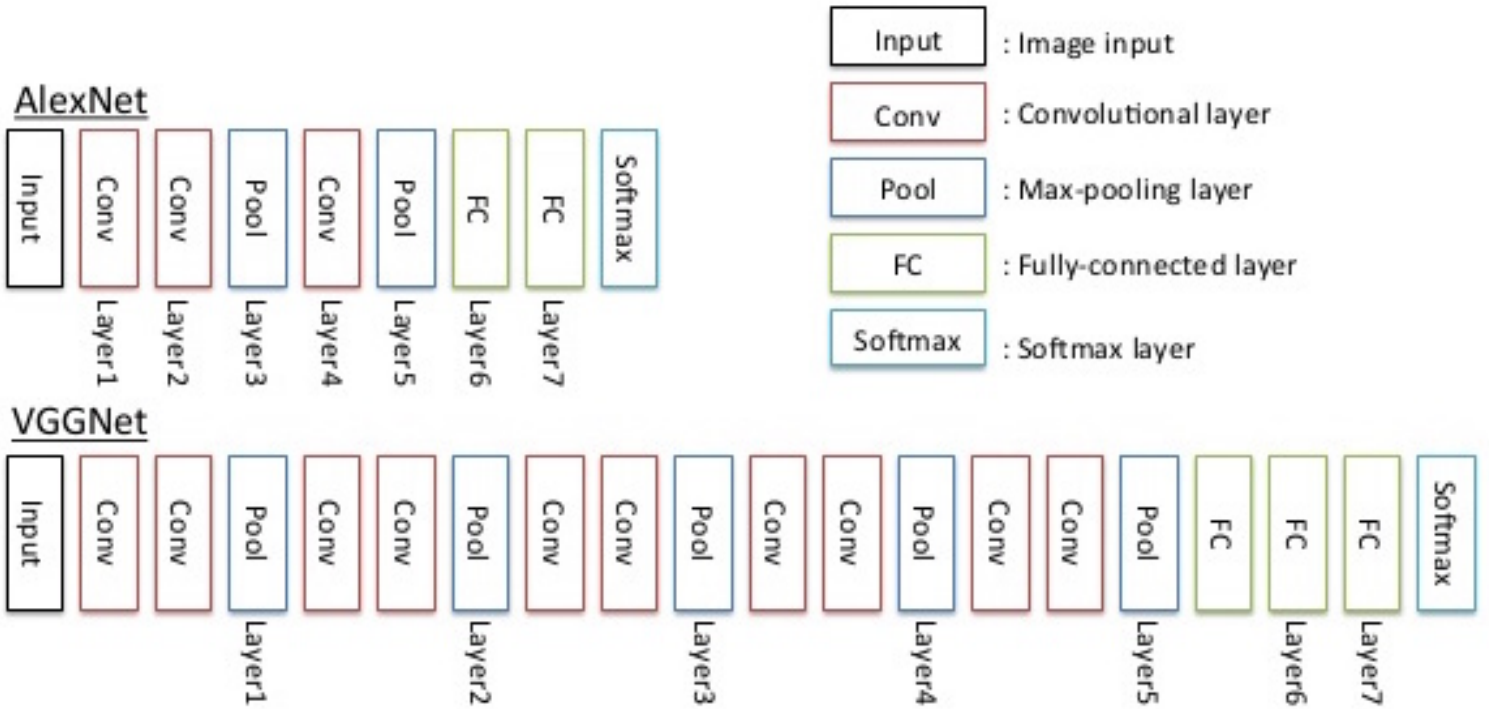

$$\frac{\partial C}{\partial b_1} = \sigma'(z_1) \times w_2 \times \sigma'(z_2) \times w_3 \times \sigma'(z_3) \times w_4 \times \sigma'(z_4) \times \frac{\partial C}{\partial a_4}$$




Revolution of Depth
152 layers
22 layers
19 layers
8 layers
8 layers
shallow
3.57
6.7
7.3
11.7
16.4
25.8
28.2
ILSVRC'15 ResNet
ILSVRC'14 GoogleNet
ILSVRC'14 VGG
ILSVRC'13
ILSVRC'12 AlexNet
ILSVRC'11
ILSVRC'10
ImageNet Classification top-5 error (%)

# Classic Deep Architectures

## ...introducing *Convolutional Layers*



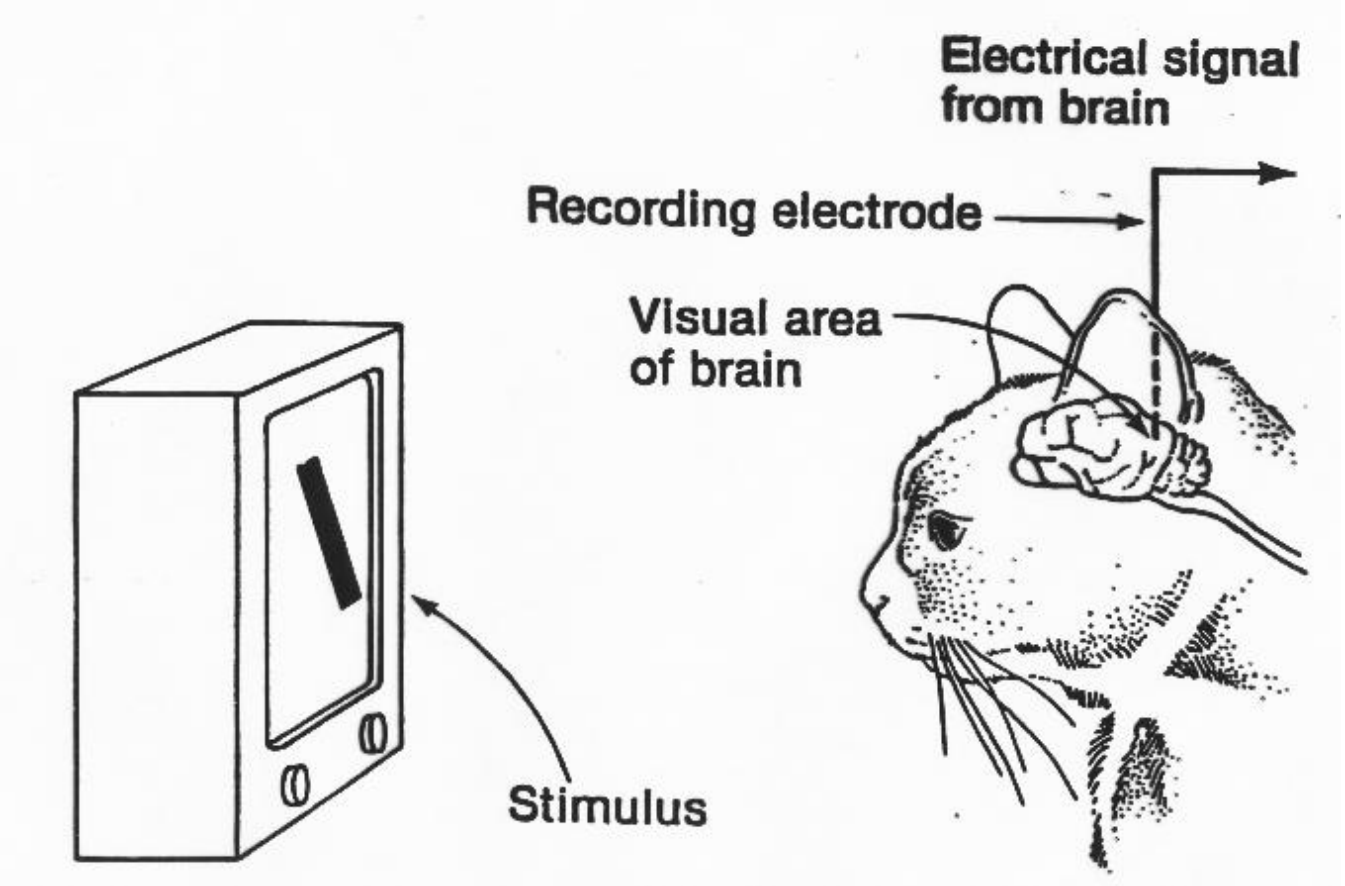
# Outline

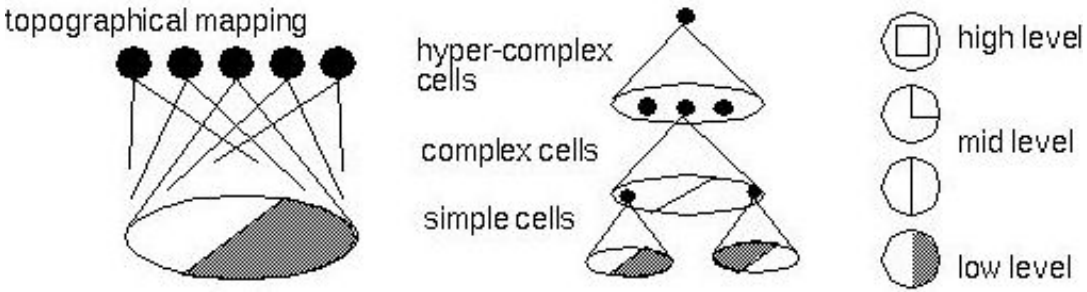
1 Antecedents
- Case Study: A History of Biological & Artificial Vision
- Building Blocks

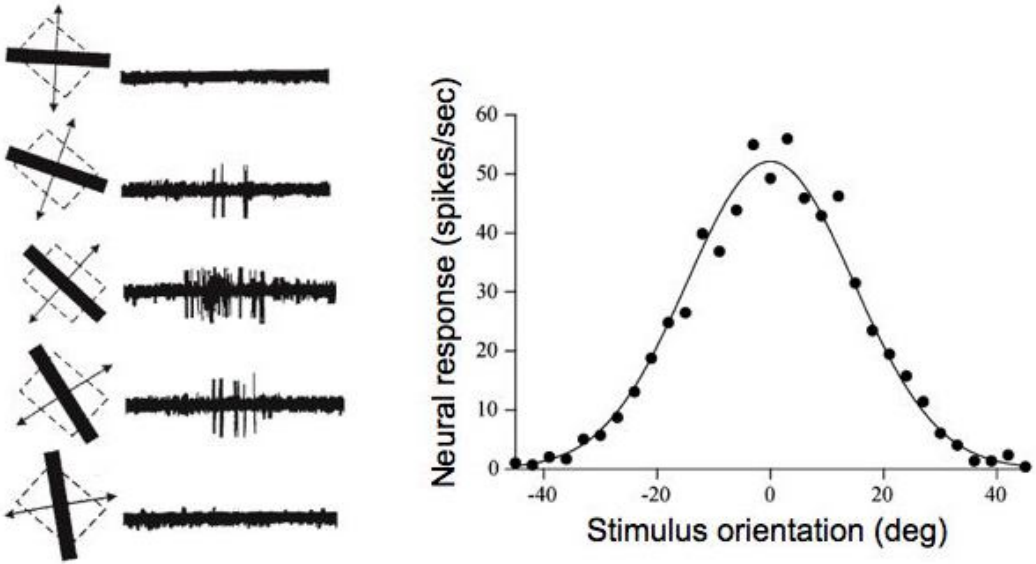
2 Theory
- Biological & Artificial Neurons
- Neural Networks
- Deep Neural Networks

3 Contemporary Applications
- Convolutional Neural Networks
- Long Short-Term Memory Recurrent Neural Networks
- Deep Learning at untapt
- Deep Reinforcement Learning

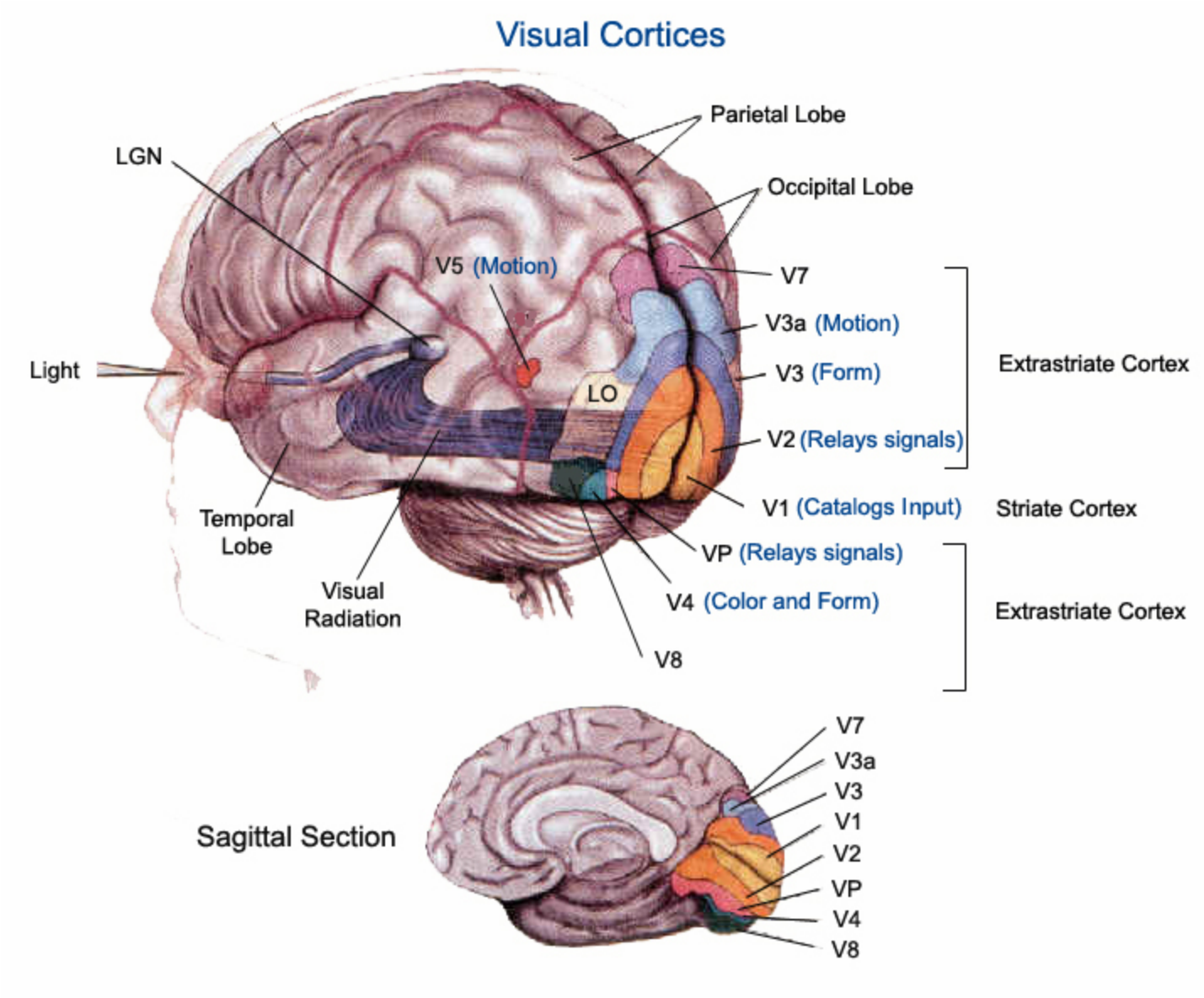
# Hubel & Wiesel (1959)





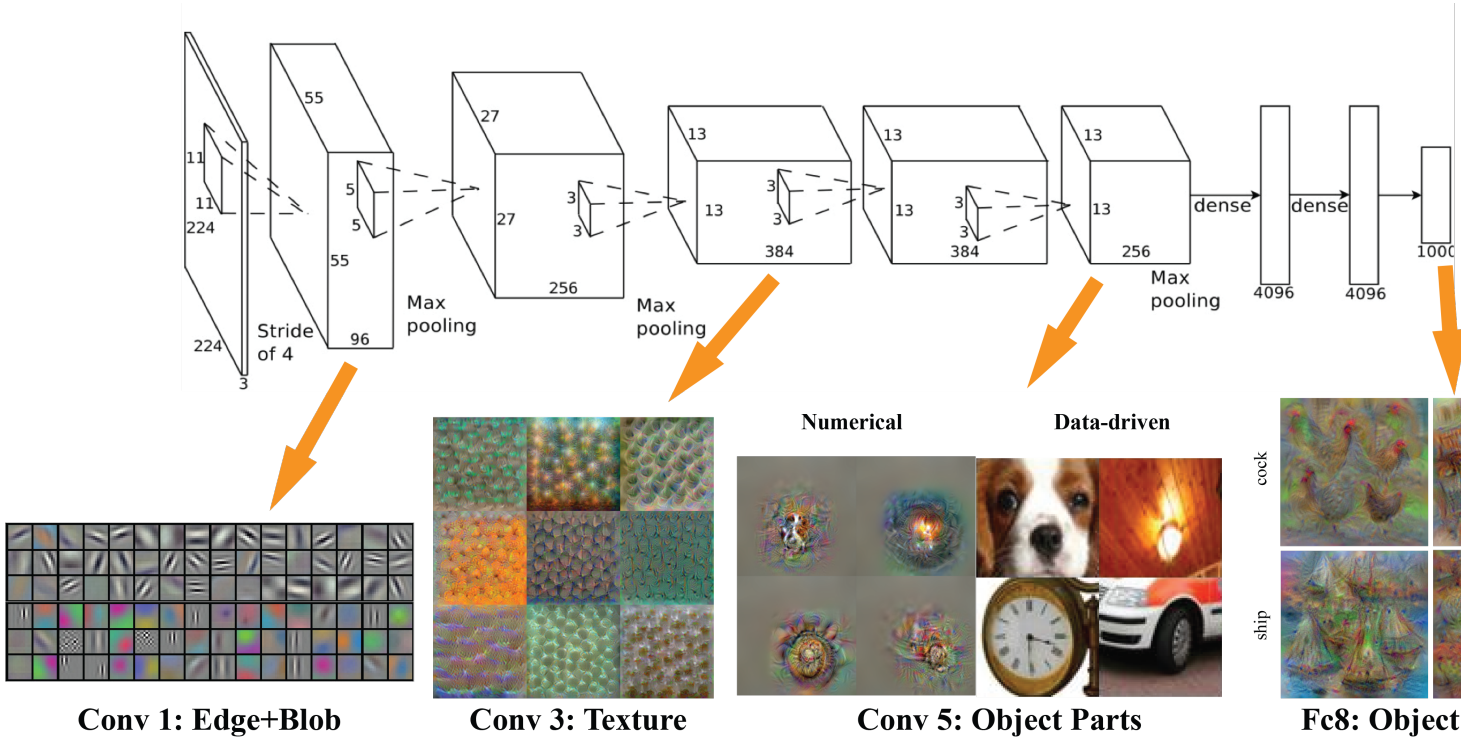



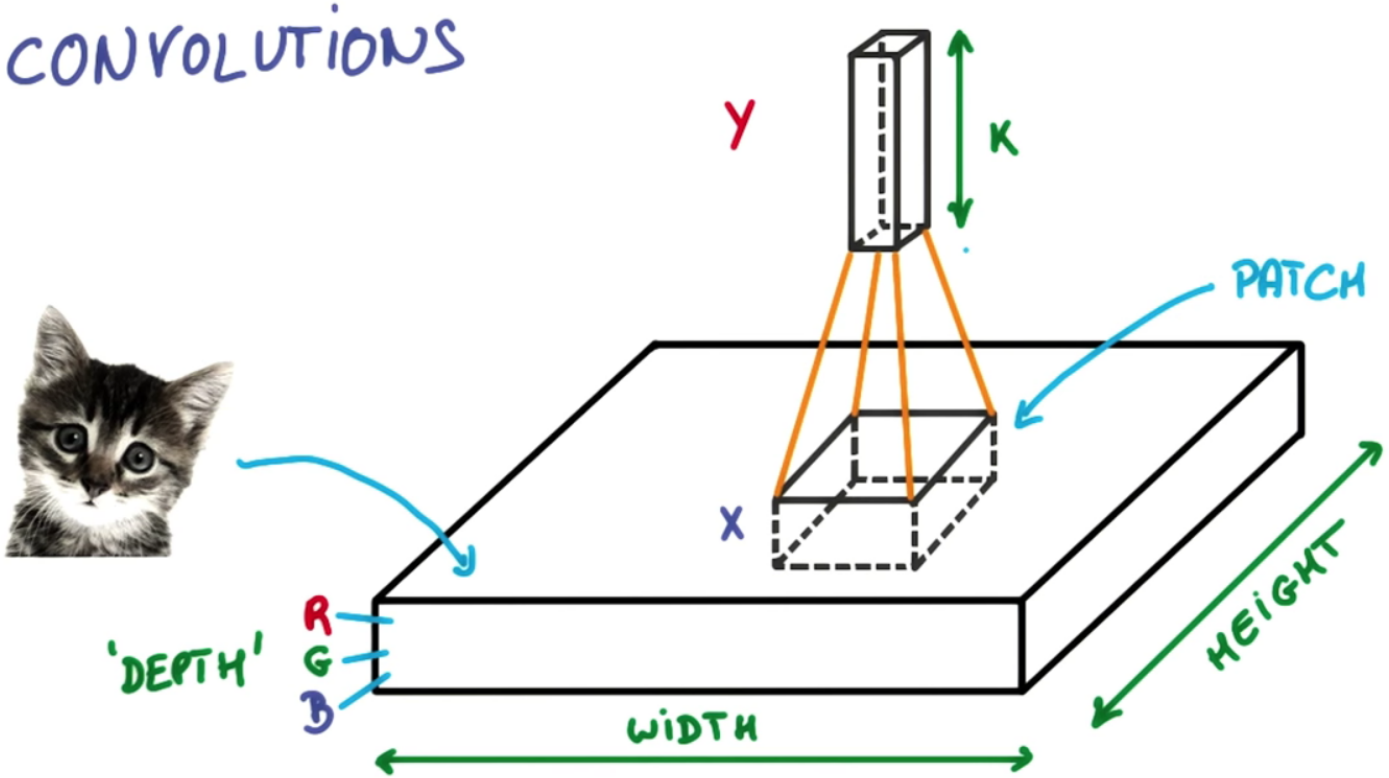

Hubel & Wiesel, 1968


Visual Cortices
Parietal Lobe
LGN
Occipital Lobe
V5 (Motion)
V7
V3a (Motion)
Light
V3 (Form)
LO
Extrastriate Cortex
V2 (Relays signals)
V1 (Catalogs Input)
Striate Cortex
Temporal Lobe
VP (Relays signals)
Visual Radiation
V4 (Color and Form)
Extrastriate Cortex
V8
Sagittal Section
V7
V3a
V3
V1
V2
VP
V4
V8

# AlexNet

## Krizhevsky, Sutskever & Hinton (2012)



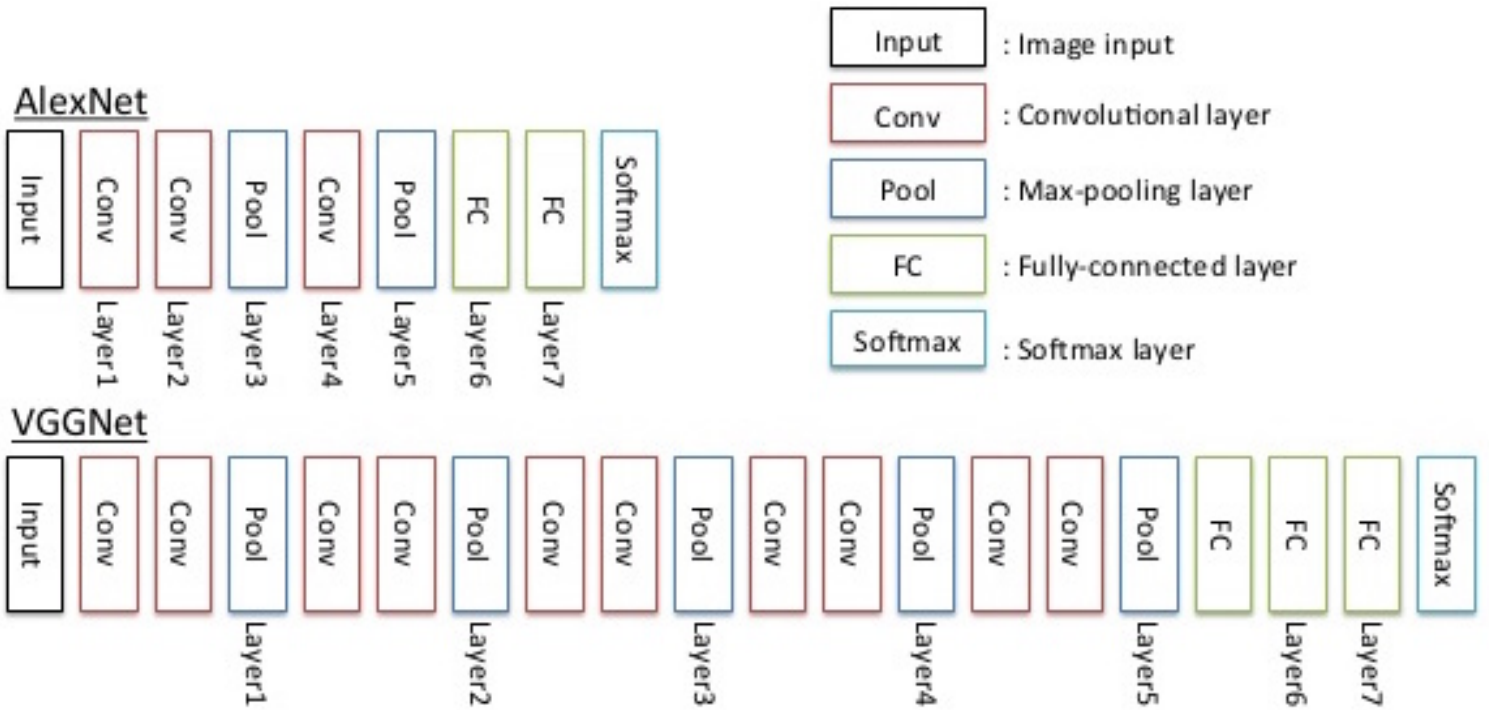

CONVOLUTIONS
Y
K
PATCH
X
'DEPTH'
R
G
B
WIDTH
HEIGHT

# ConvNet Visualisation

## Yosinski et al. (2015)

[video]

# Network Architectures



# AlexNet: ILSVRC '12 winner

Krizhevsky et al. (2012)

[TFLearn notebook]

# VGGNet: ILSVRC '14 runner-up

## Simonyan & Zisserman (2015)

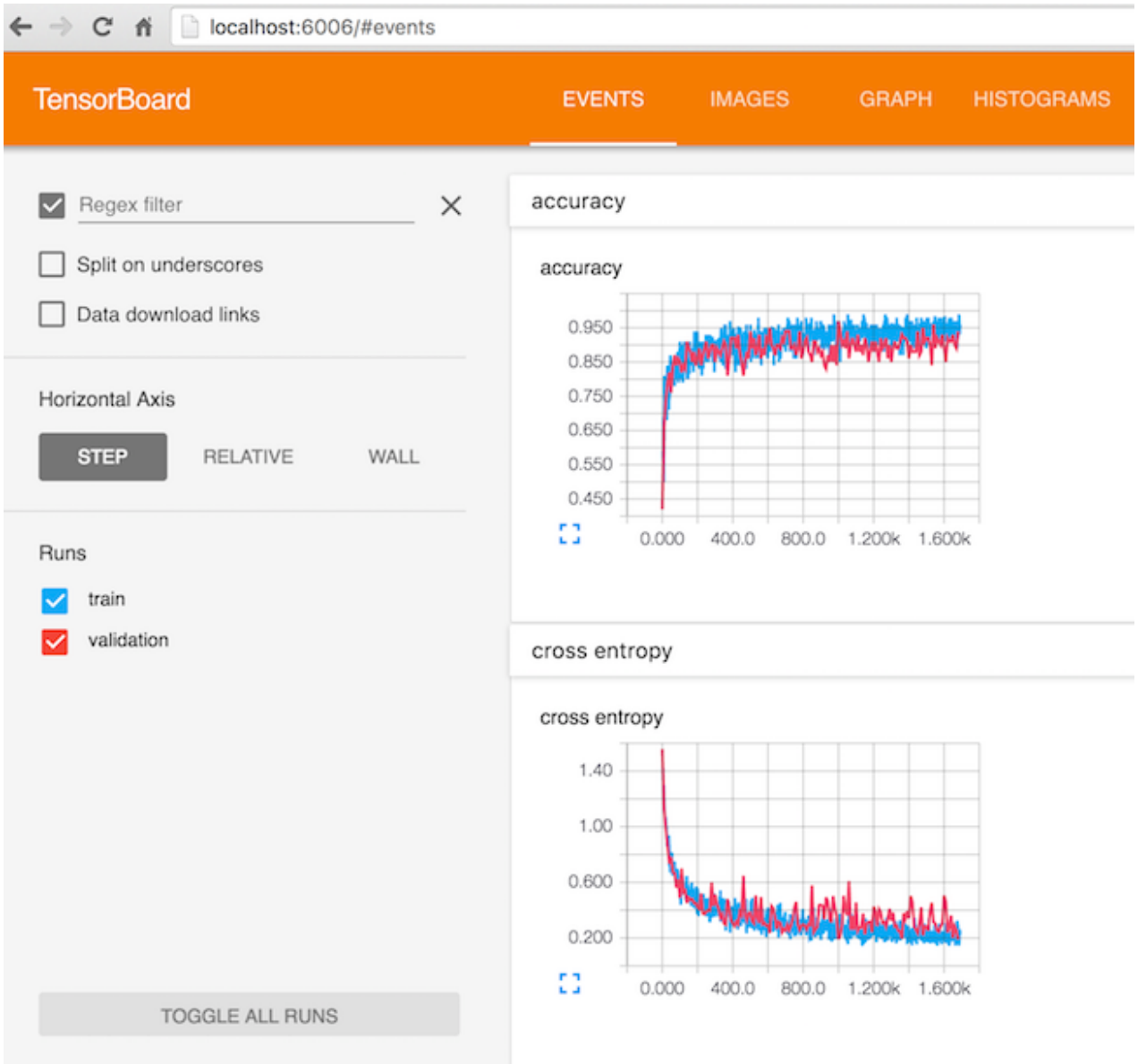
[TFLearn notebook]

# ConvNet in TensorFlow

| | **Caffe** | **Torch** | **Theano** | **TensorFlow** |
|---|---|---|---|---|
| *Language* | C++, Python | Lua | Python | Python |
| *Pretrained* | Yes++ | Yes++ | Yes (Lasagne) | Inception |
| *Parallel GPUs: Data* | Yes | Yes | Yes | Yes |
| *Parallel GPUs: Model* | No | Yes | Experimental | Yes (best) |
| *Readable Source Code* | Yes (C++) | Yes | No | No |
| *Good at RNN* | No | Mediocre | Yes | Yes (best) |
| *Higher-Level APIs* | No | No | Keras | Keras and TFLearn |

# ConvNet in TensorFlow

[notebook]


localhost:6006/#events
TensorBoard
EVENTS
IMAGES
GRAPH
HISTOGRAMS
Regex filter
Split on underscores
Data download links
Horizontal Axis
STEP
RELATIVE
WALL
Runs
train
validation
TOGGLE ALL RUNS
accuracy
accuracy
0.950
0.850
0.750
0.650
0.550
0.450
0.000
400.0
800.0
1.200k
1.600k
cross entropy
cross entropy
1.40
1.00
0.600
0.200
0.000
400.0
800.0
1.200k
1.600k

# ConvNet in Theano

| | **Caffe** | **Torch** | **Theano** | **TensorFlow** |
|---|---|---|---|---|
| *Language* | C++, Python | Lua | Python | Python |
| *Pretrained* | Yes++ | Yes++ | Yes (Lasagne) | Inception |
| *Parallel GPUs: Data* | Yes | Yes | Yes | Yes |
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# ConvNet in Theano

[demo]

# ConvNet in Keras

## calls TensorFlow or Theano

| | **Caffe** | **Torch** | **Theano** | **TensorFlow** |
|---|---|---|---|---|
| *Language* | C++, Python | Lua | Python | Python |
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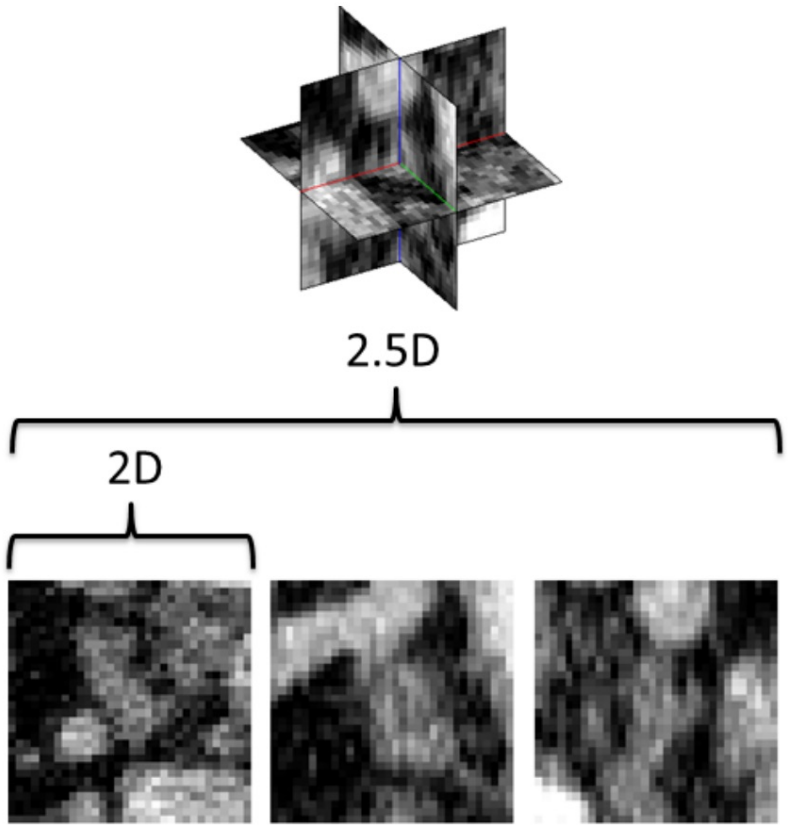
# ConvNet in Keras

## calls TensorFlow or Theano

[notebook]

# “2.5-dimension” CT Scans

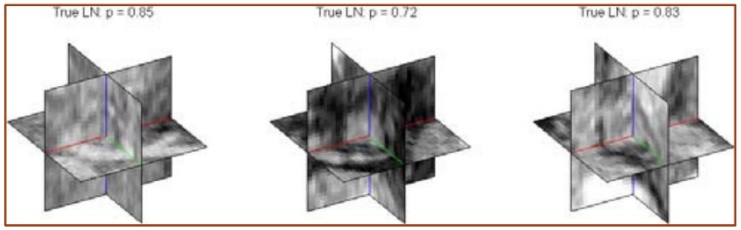
Roth et al. (2015)

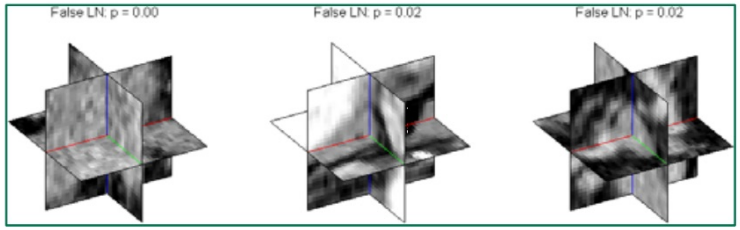


# Computer-Aided Detection

Shin et al. (2016); Roth et al. (2016)

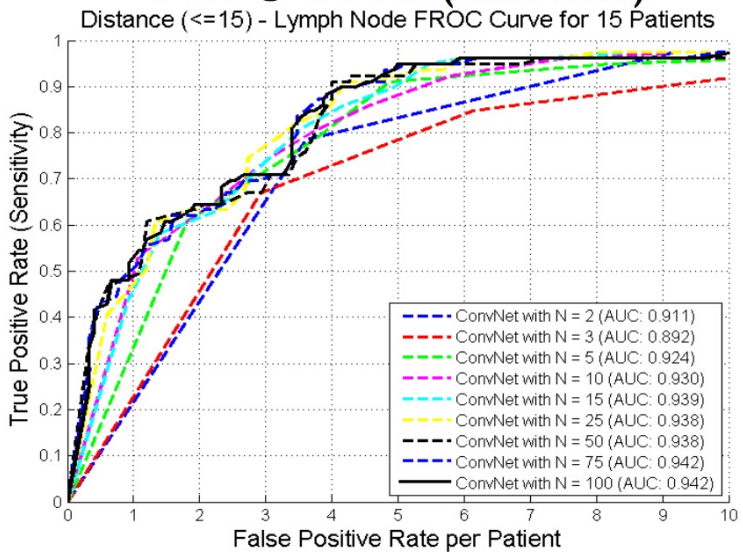
**Experimental Results** (~100% sensitivity but ~40 FPs/patient at candidate generation step; then 3-fold CV with data augmentation)



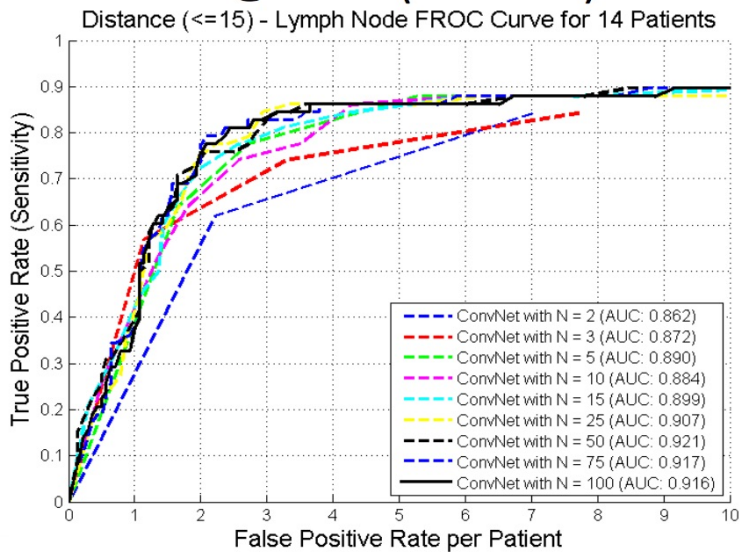

- Mediastinum

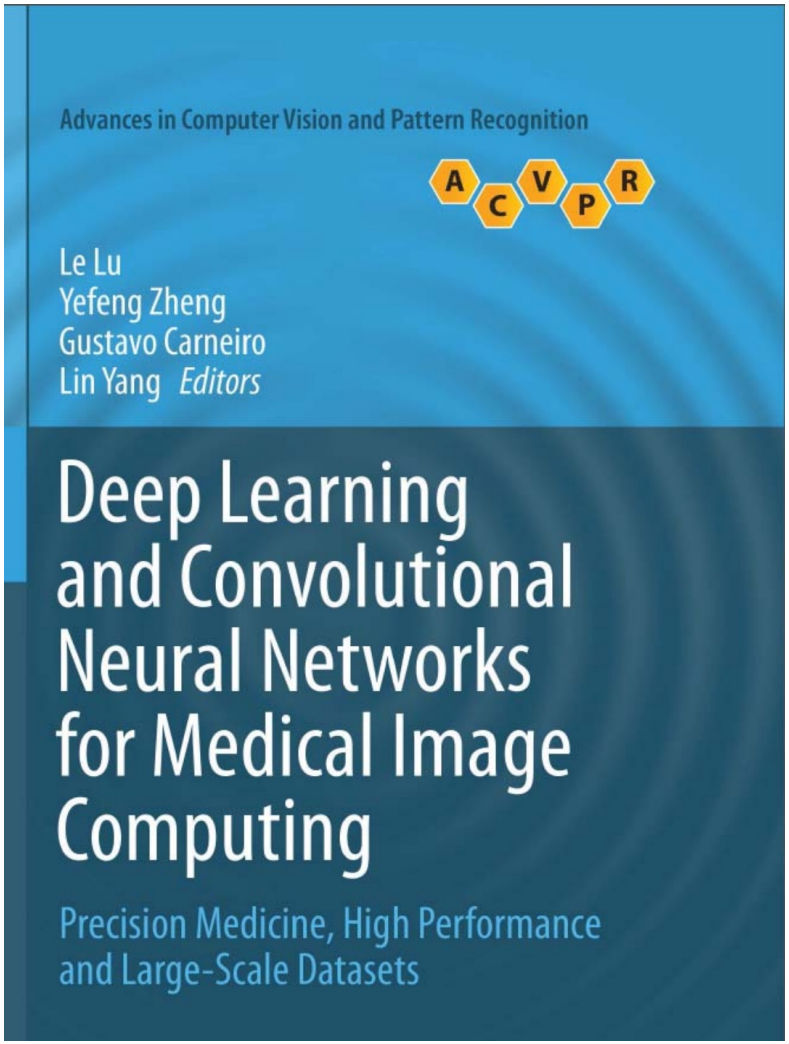
**71% @ 3 FPs** (was 55%)




- Abdomen

**83% @ 3 FPs** (was 30%)




Advances in Computer Vision and Pattern Recognition
A C V P R
Le Lu
Yefeng Zheng
Gustavo Carneiro
Lin Yang Editors
Deep Learning and Convolutional Neural Networks for Medical Image Computing
Precision Medicine, High Performance and Large-Scale Datasets

# Kaggle

## Data Science Bowl 2017

[link]

# Transfer Learning

## Caffe

| | **Caffe** | **Torch** | **Theano** | **TensorFlow** |
|---|---|---|---|---|
| *Language* | C++, Python | Lua | Python | Python |
| *Pretrained* | Yes++ | Yes++ | Yes (Lasagne) | Inception |
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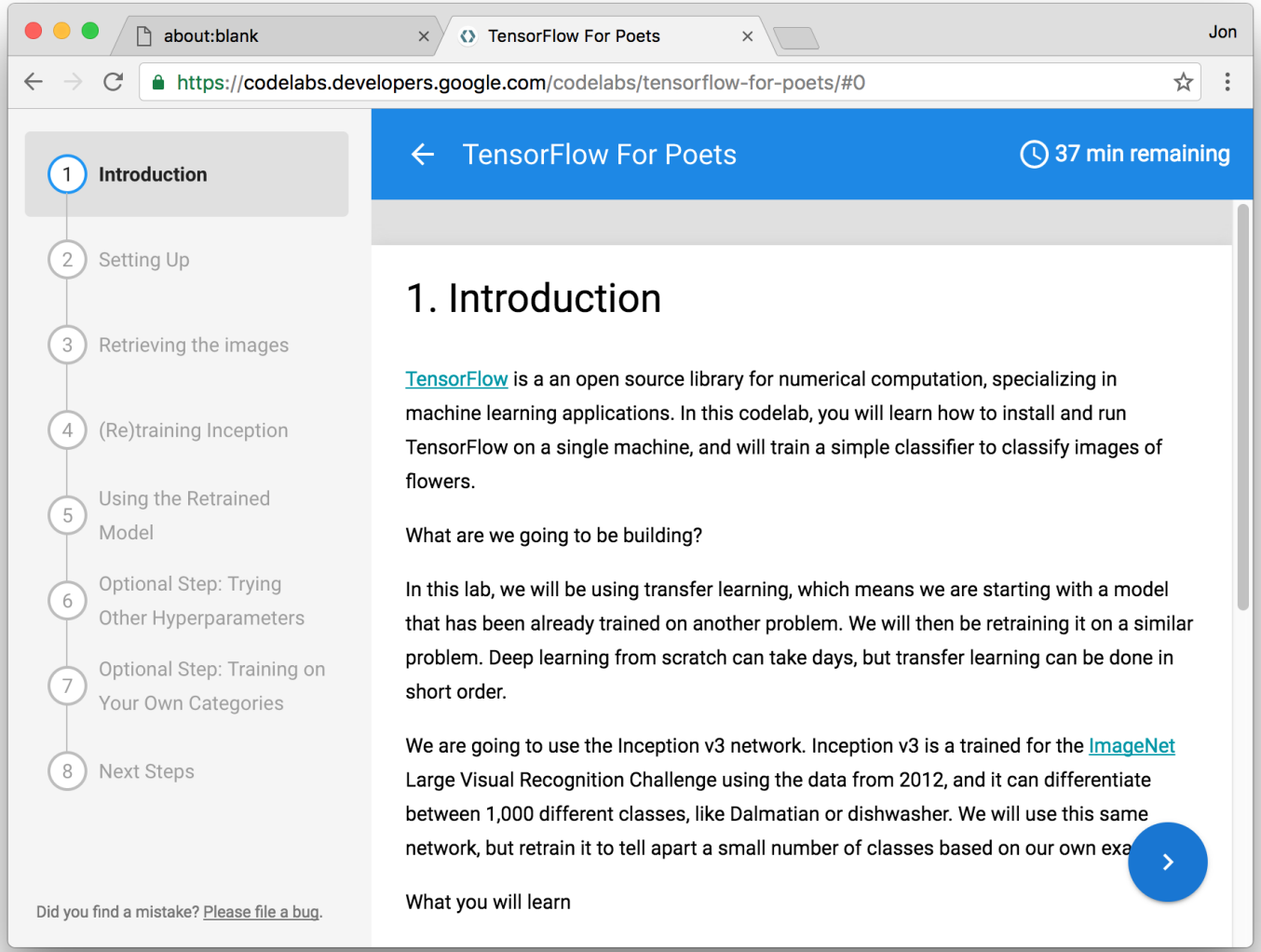
# Transfer Learning

## Caffe

[Model Zoo]

# Transfer Learning



# Video Classification

[video]

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- Deep Learning at untapt
- Deep Reinforcement Learning

# Sunspring

# Sunspring

INT. SHIP

We see H pull a book from a shelf, flip through it while speaking, and then put it back.

H
In a future with mass unemployment, young people are forced to sell blood. That's the first thing I can do.

H2
You should see the boys and shut up. I was the one who was going to be a hundred years old.

H
I saw him again. The way you were sent to me... that was a big honest idea. I am not a bright light.

C
Well, I have to go to the skull. I don't know.

He picks up a light screen and fights the security force of the particles of a transmission on his face.

H
(continuing)
What do you mean?

C
(smiles)
I don't know anything about any of this.

H
(to Hauk, taking his eyes from his mouth)
Then what?

H2
There's no answer.

C
(frowning)
We're going to see the money.

H
(reading)
"All right, you can't tell me that."

Steps back. Coffey is still going through.

C
I was coming to that thing because you were so pretty.

H
I don't know. I don't know what you're talking about.

C
That's right.

H
So what are you doing?

H2
I don't want to be honest with you.

He looks at him for a moment, then smiles at him.

H
You don't have to be a doctor.

H2
I am not sure. I don't know what you're talking about.

H
I want to see you too.

H2
What do you mean?

He starts to shake.

H
I'm sorry, but I'm sure you wouldn't even touch me.

H2
I don't know what you're talking about.

H
The principle is completely constructed for the same time.

H2
(smiling)
It was all about you to be true.

H
You didn't even see the movie with the rest of the base.

H2
I don't know.

H
I don't care.

H2
I know that it's a consequence. Whatever you want to know about the presence of the story, I'm a little bit of a boy on the floor.

H
I don't know. I just have to ask you to explain to me what you say.

H2
What do you mean?

H
Because I don't know what you're talking about.

H2
That was all the time.

H
I know that.

H2
I don't know.

H
(angry)
It would be a good time. I think I could have been my life.

H (CONT'D)
It may never be forgiven, but that is just too bad. I have to leave, but I'm not free of the world.

C
Yes. Perhaps I should take it from here. I'm not going to do something.

H
You can't afford to take this anywhere. It's not a dream. But I've got a good time to stay there.

C
Well, I think you can still be back on the table.

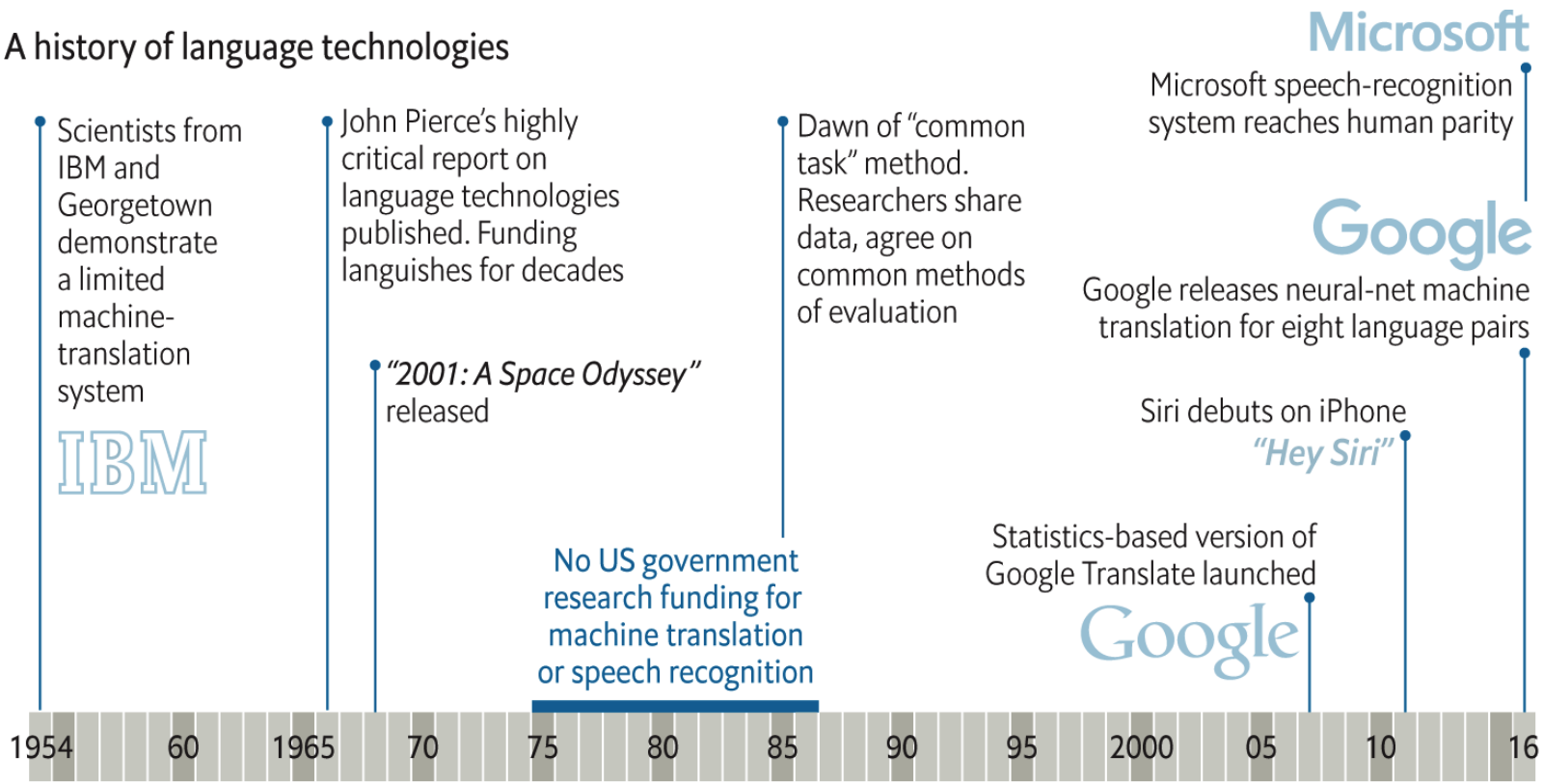
H
Mmm. It's a damn thing scared to say. Nothing is going to be a thing but I was the one that got on this rock with a child and then I left the other two.

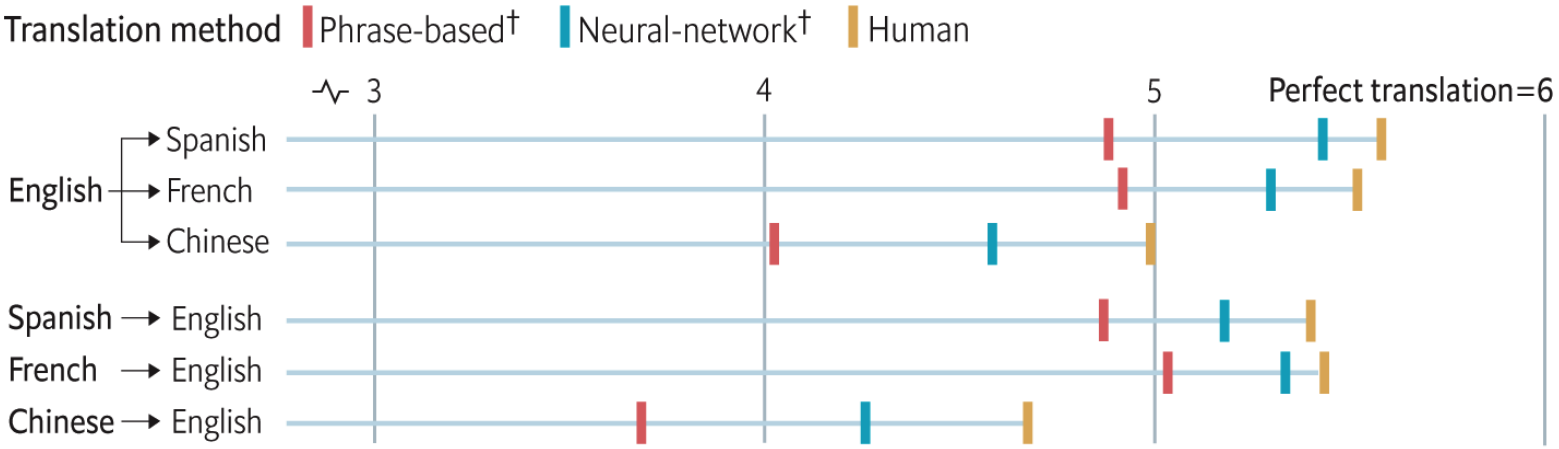
He is standing in the stars and sitting on the floor. He takes a seat on the counter and pulls the camera over to his back. He stares at it. He is on the phone. He cuts the shotgun from the edge of the room and puts it in his mouth. He sees a black hole in the floor leading to the man on the roof.

He comes up behind him to protect him. He is still standing next to him.

He looks through the door and the door closes. He looks at the bag from his backpack, and starts to cry.

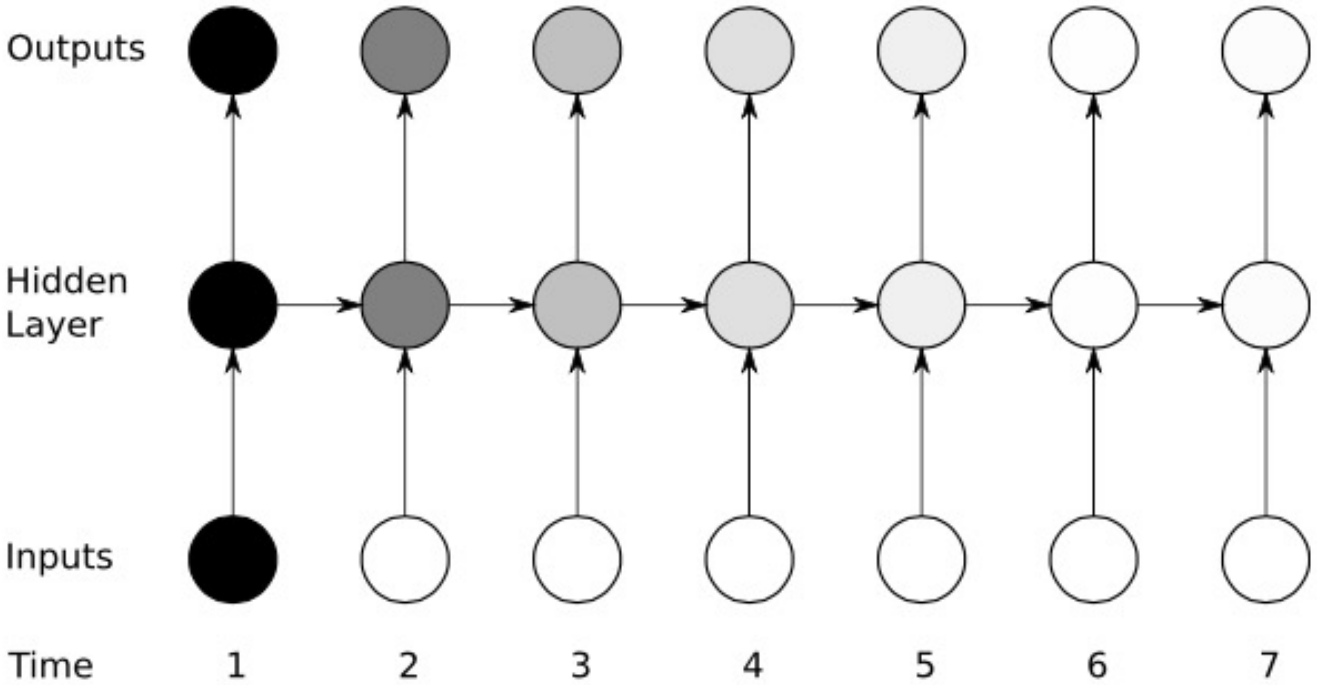
T
Well, there's the situation with me and the light on the ship. The guy was trying to stop me. He was like a baby and he was gone. I was worried about him. But even if he would have done it all. He couldn't come any more. I didn't mean to be a virgin. I mean, he was weak. And I thought I'd change my mind. He was crazy to take it out. It was a long time ago. He was a little late. I was going to be a moment. I just wanted to tell you that I was much better than he did. I had to stop him and I couldn't even tell. I didn't want to hurt him. I'm sorry. I know I don't like him. I can go home and be so bad and I love him. So I can get him all the way over here and find the square and go to the game with him and she won't show up. Then I'll check it out. But I'm going to see him when he gets to me. He looks at me and he throws me out of his eyes. Then he said he'd go to bed with me.


A history of language technologies
Scientists from IBM and Georgetown demonstrate a limited machine-translation system
IBM
John Pierce's highly critical report on language technologies published. Funding languishes for decades
"2001: A Space Odyssey" released
No US government research funding for machine translation or speech recognition
Dawn of "common task" method. Researchers share data, agree on common methods of evaluation
Statistics-based version of Google Translate launched
Google
Siri debuts on iPhone "Hey Siri"
Microsoft
Microsoft speech-recognition system reaches human parity
Google
Google releases neural-net machine translation for eight language pairs
1954
60
1965
70
75
80
85
90
95
2000
05
10
16


Translation method
Phrase-based†
Neural-network†
Human
3
4
5
Perfect translation=6
English
Spanish
French
Chinese
Spanish → English
French → English
Chinese → English

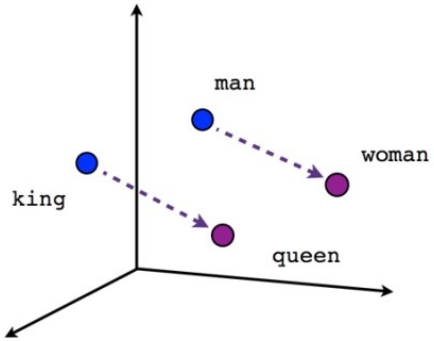
# RNNs; *LSTM* RNNs

## Hochreiter & Schmidhuber (1997)
## Graves, ... & Schmidhuber (2009)

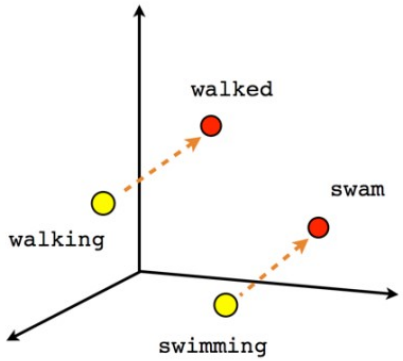


# Vector Space Embedding

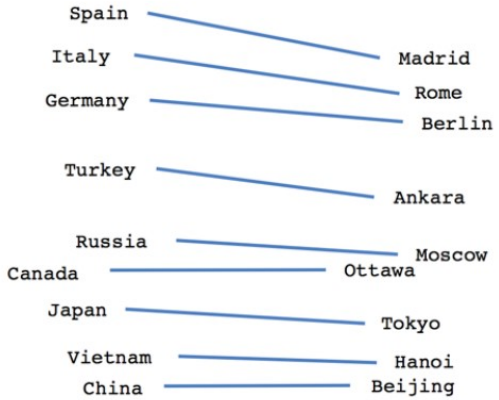
## Word2Vec: Mikolov, ... & Dean (2013)




Male-Female



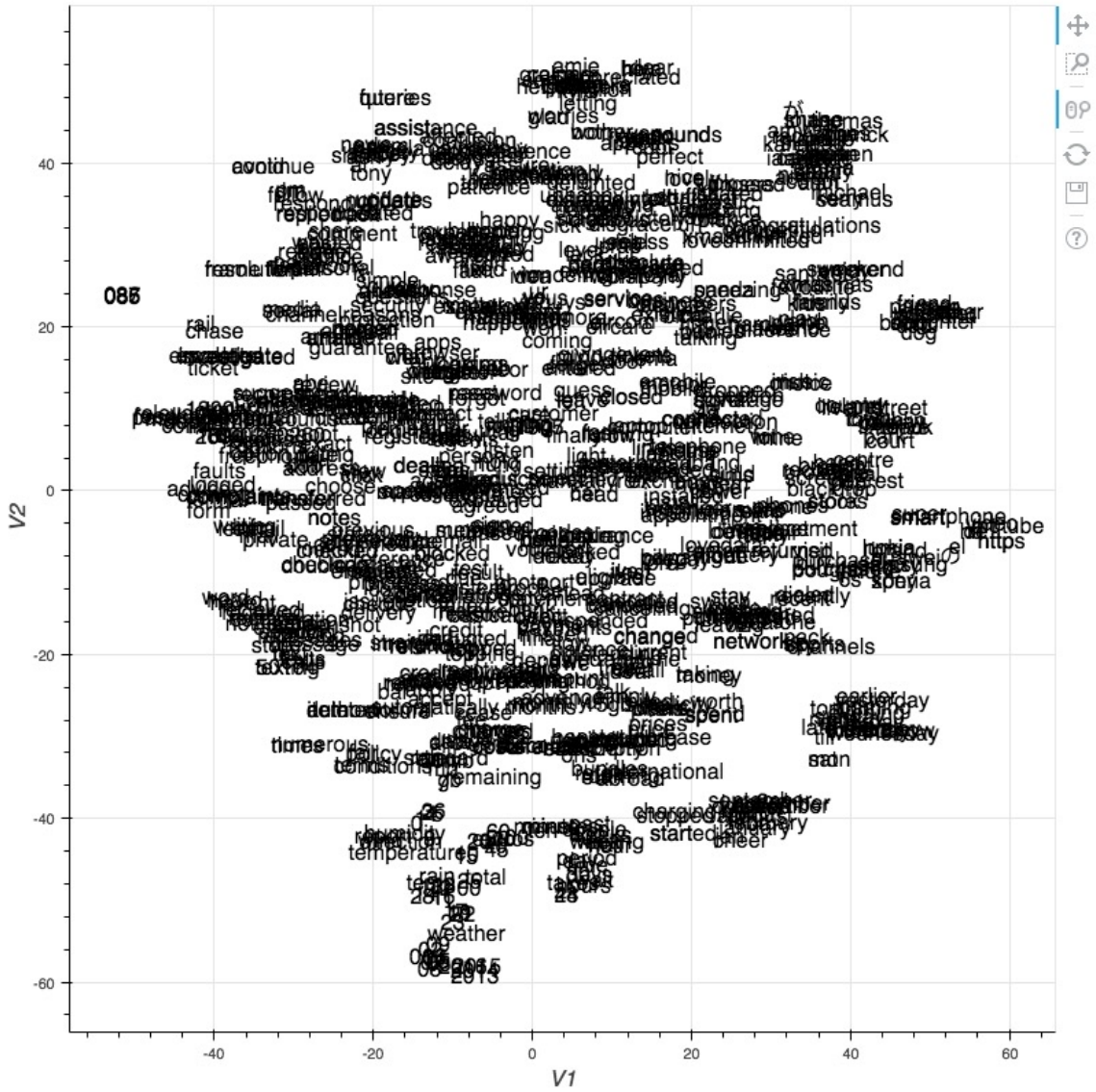

Verb tense



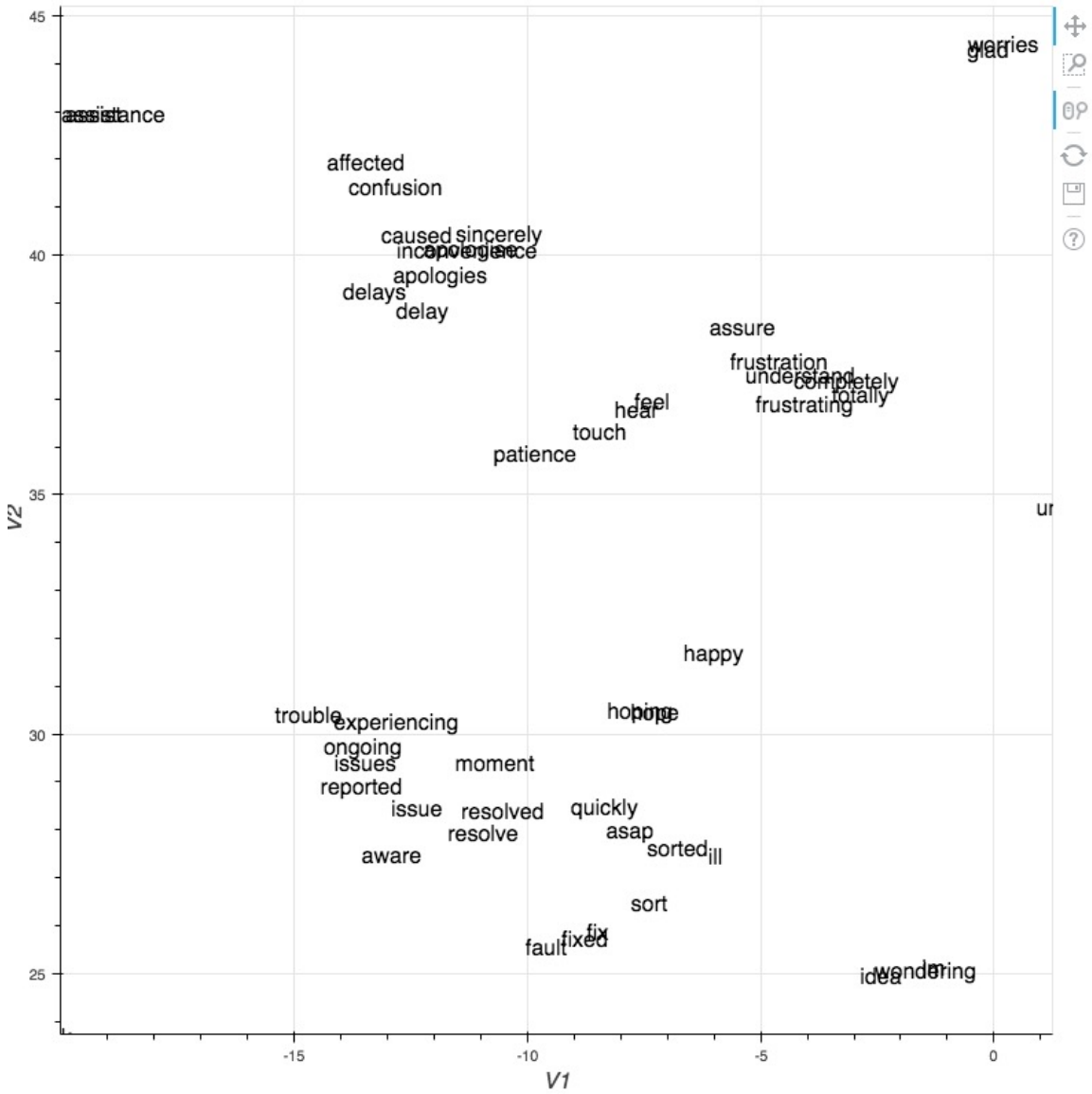

Country-Capital

# t-SNE

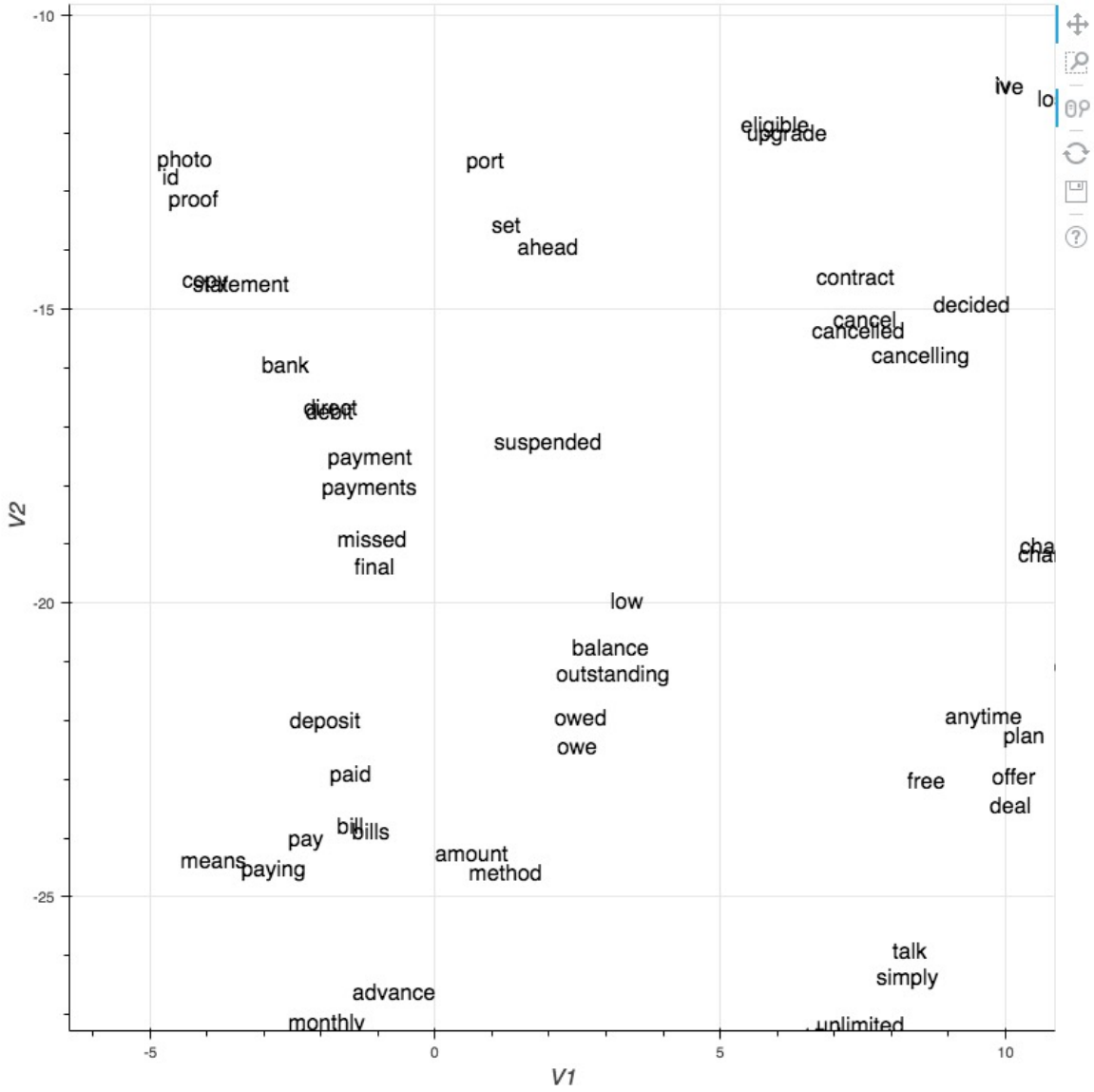
## Hinton & van der Maaten (2008)



# Word2Vec + t-SNE



# Word2Vec + t-SNE



# ‘Understand’ Language

## with Word2Vec features in your model

```
model.most_similar(positive=['angular'])
```

```
[('angularjs', 0.9534549117088318),
 ('backbonejs', 0.9315043687820435),
 ('ember', 0.905410647392273),
 ('emberjs', 0.9029799103736877),
 ('reactjs', 0.896049439907074),
 ('requirejs', 0.8759748339653015),
 ('coffeescript', 0.8645504713058472),
 ('bootstrap', 0.8554328083992004),
 ('nodejs', 0.8515532612800598),
 ('backbone', 0.8443130254745483)]
```

```
model.most_similar(positive=['managed'])
```

```
[('oversaw', 0.8659406900405884),
 ('directed', 0.8491166234016418),
 ('supervised', 0.8058902621269226),
 ('coordinated', 0.7858685851097107),
 ('led', 0.7539615035057068),
 ('orchestrated', 0.7211644649505615),
 ('supported', 0.7198437452316284),
 ('comanaged', 0.6774874925613403),
 ('encompassing', 0.6726169586181641),
 ('administered', 0.6706464886665344)]
```

[even with small corpora]

# Quick, Draw!

## ConvNet + LSTM

[link]

# Outline

1 Antecedents
- Case Study: A History of Biological & Artificial Vision
- Building Blocks

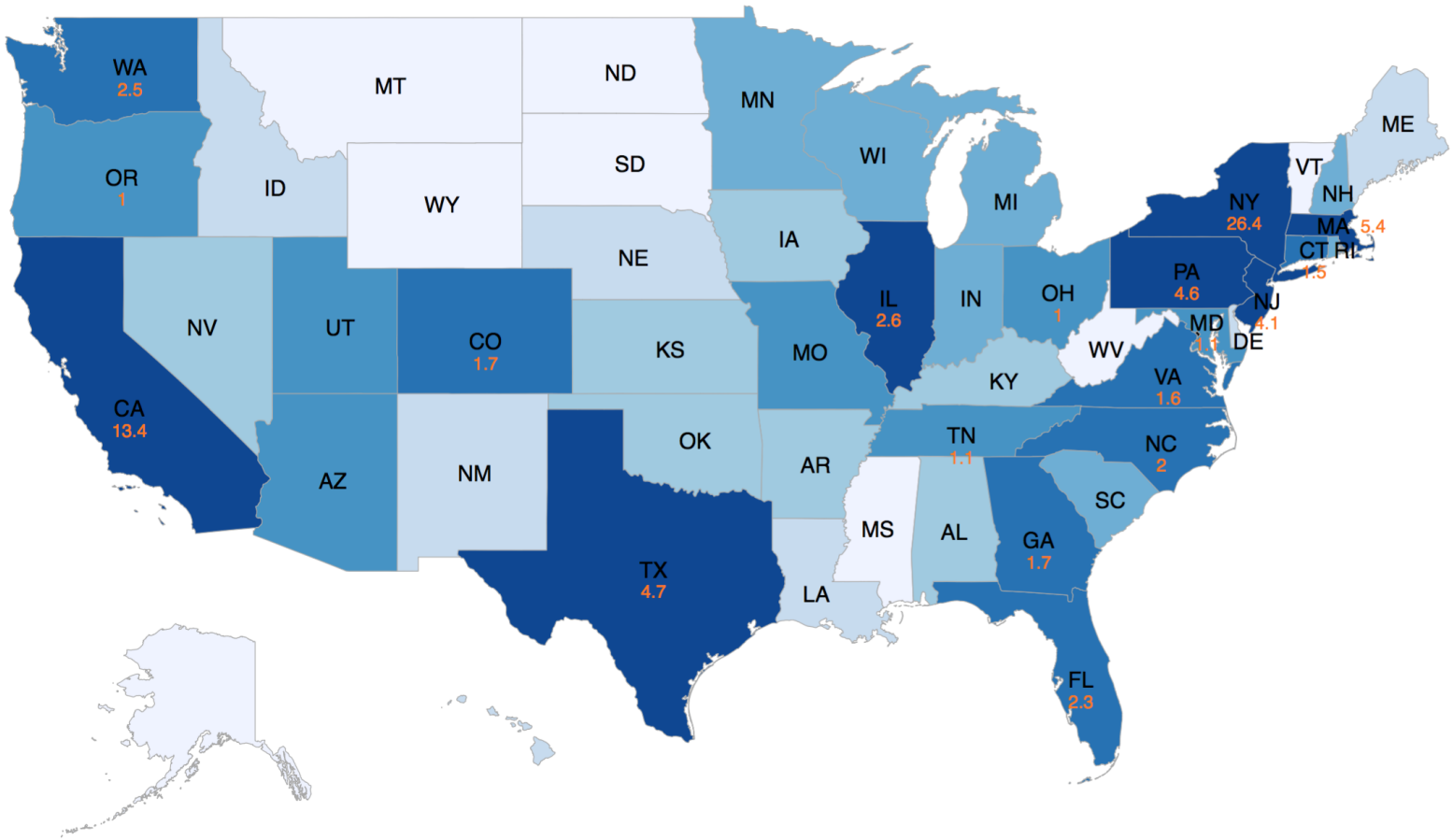
2 Theory
- Biological & Artificial Neurons
- Neural Networks
- Deep Neural Networks

3 Contemporary Applications
- Convolutional Neural Networks
- Long Short-Term Memory Recurrent Neural Networks
- Deep Learning at untapt
- Deep Reinforcement Learning

# untapt

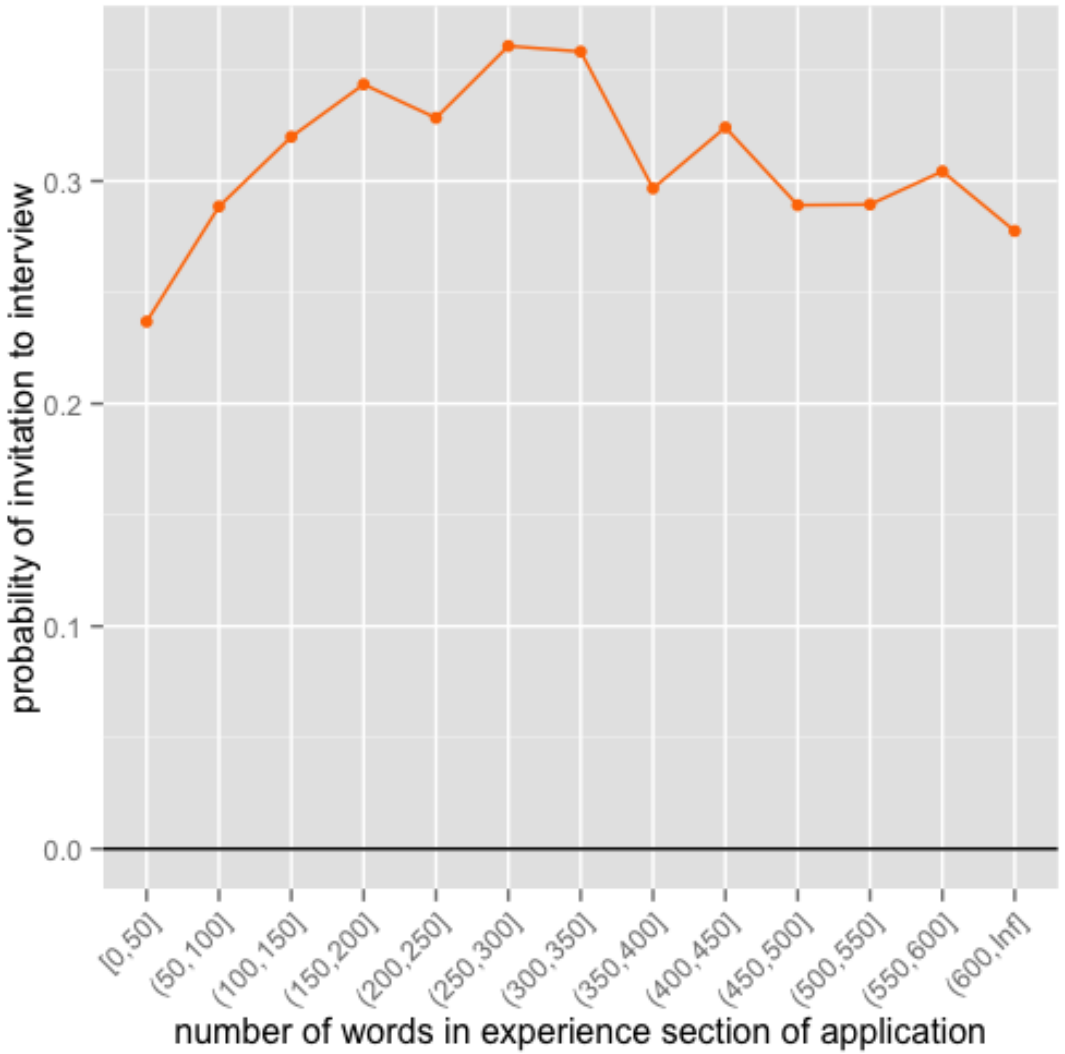
## Digital Recruitment Platform

# untapt


WA
2.5
OR
1
CA
13.4
NV
ID
MT
WY
UT
AZ
CO
1.7
NM
ND
SD
NE
KS
OK
TX
4.7
MN
IA
MO
AR
LA
WI
IL
2.6
MI
IN
OH
1
KY
TN
1.1
MS
AL
GA
1.7
FL
2.3
SC
NC
2
VA
1.6
WV
PA
4.6
NY
26.4
MD
1.1
DE
NJ
4.1
CT
1.5
RI
MA
5.4
VT
NH
ME

# untapt

## Candidate-Side Feedback

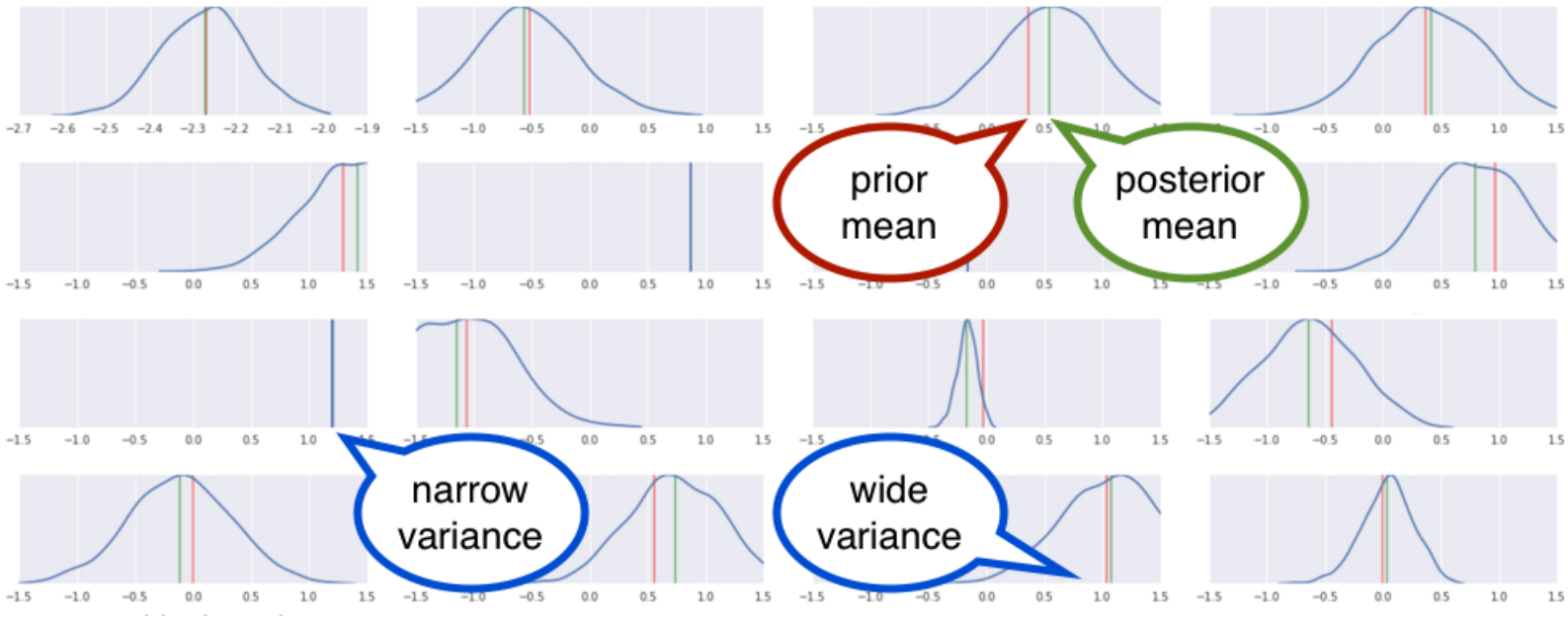


# untapt

## Client-Side Feedback

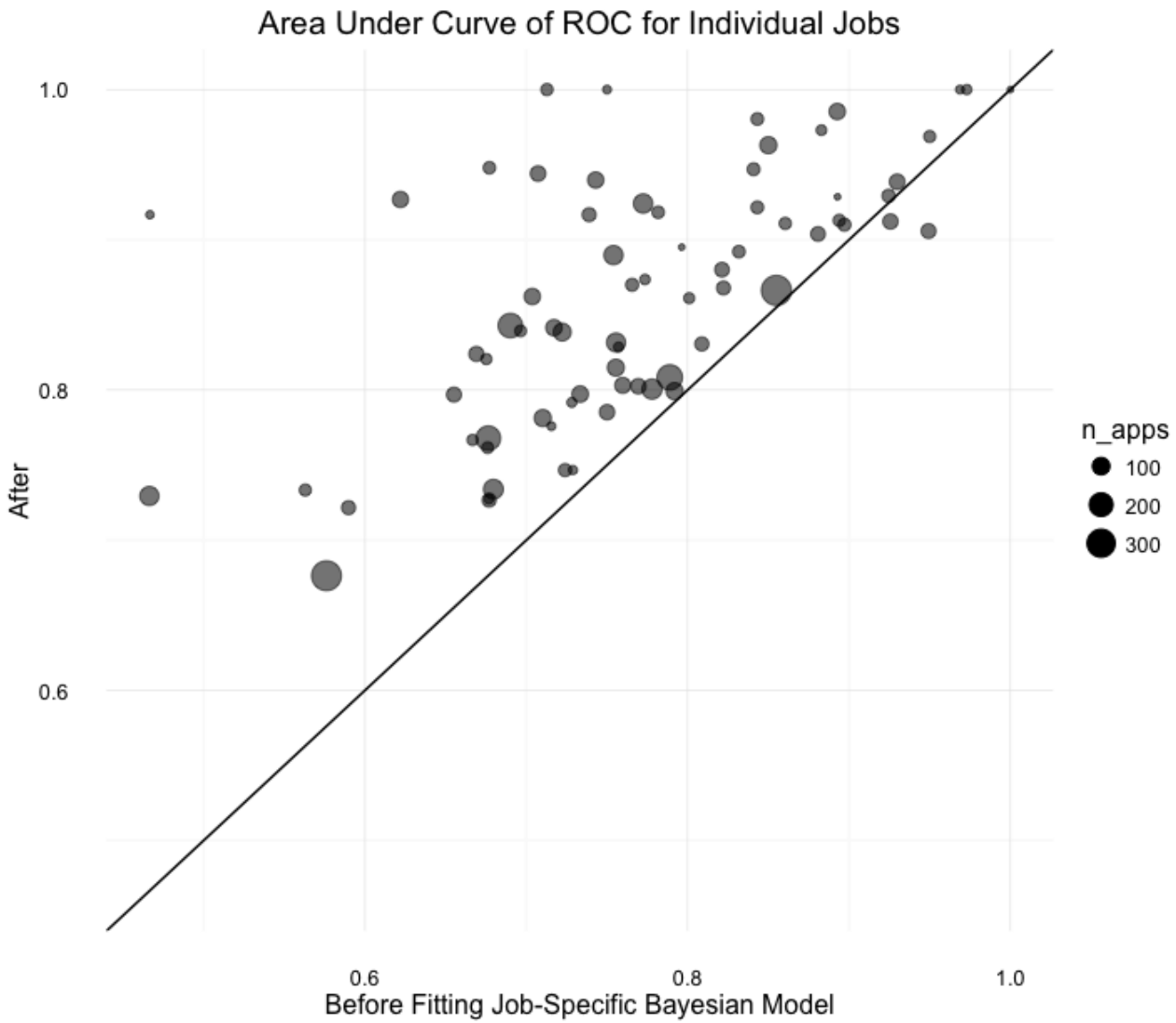
# untapt

## Multi-Stage Bayesian Regression with PyMC3




Krohn, Rives-Corbett & Donner (2016)

# untapt




Krohn, Rives-Corbett & Donner (2016)

# untapt

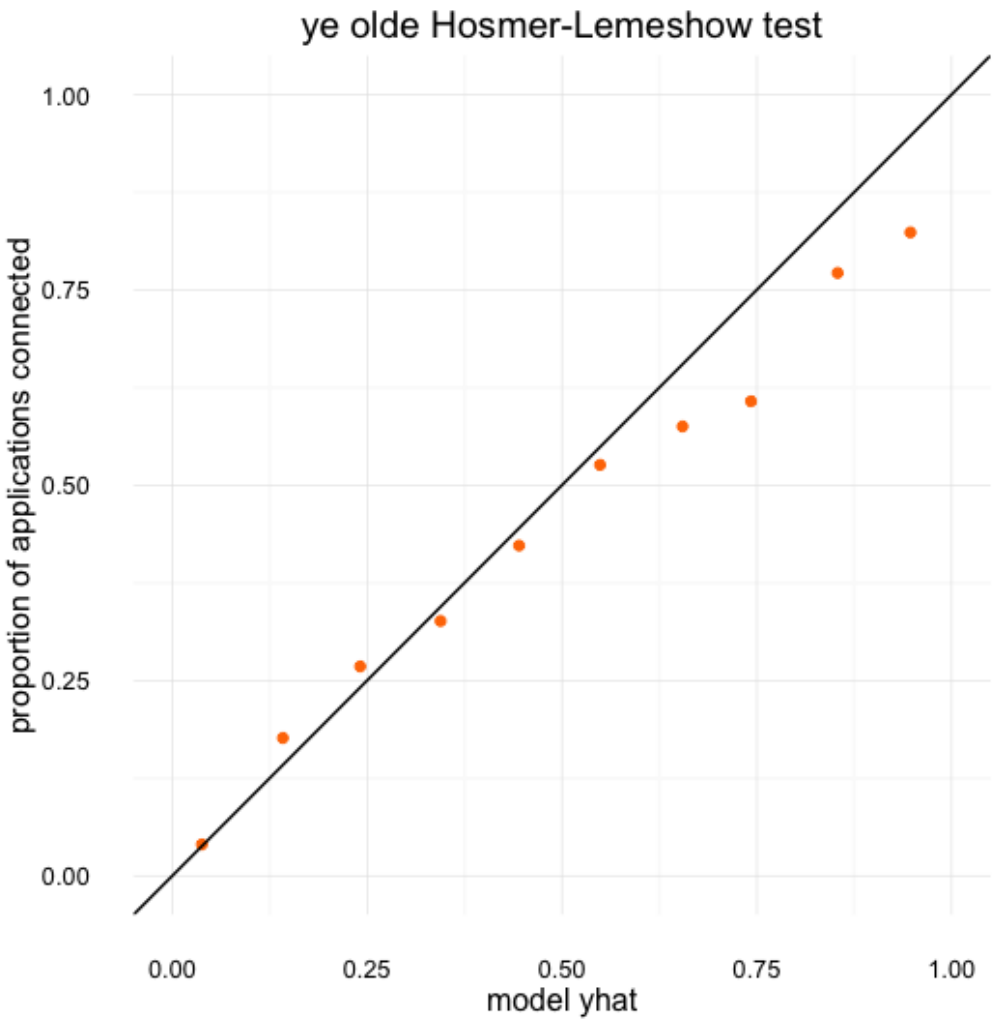
## Ensemble with Deep Neural Net

```
Give me one bullet-point from your resume:
>> • Sat around all day checking my Facebook feed
I predict a 0.0% chance of interview
```

```
Give me one bullet-point from your resume:
>> • Developed trading applications in Python
I predict a 24.6% chance of interview
```

```
Give me one bullet-point from your resume:
>> • Developed python solution for Monte Carlo risk calculation using numpy,
 scipy and pandas, with a Javascript frontend in AngularJS and React
I predict a 98.1% chance of interview
```

deep-orange.untapt.com


ye olde Hosmer-Lemeshow test
proportion of applications connected
1.00
0.75
0.50
0.25
0.00
0.00
0.25
0.50
0.75
1.00
model yhat

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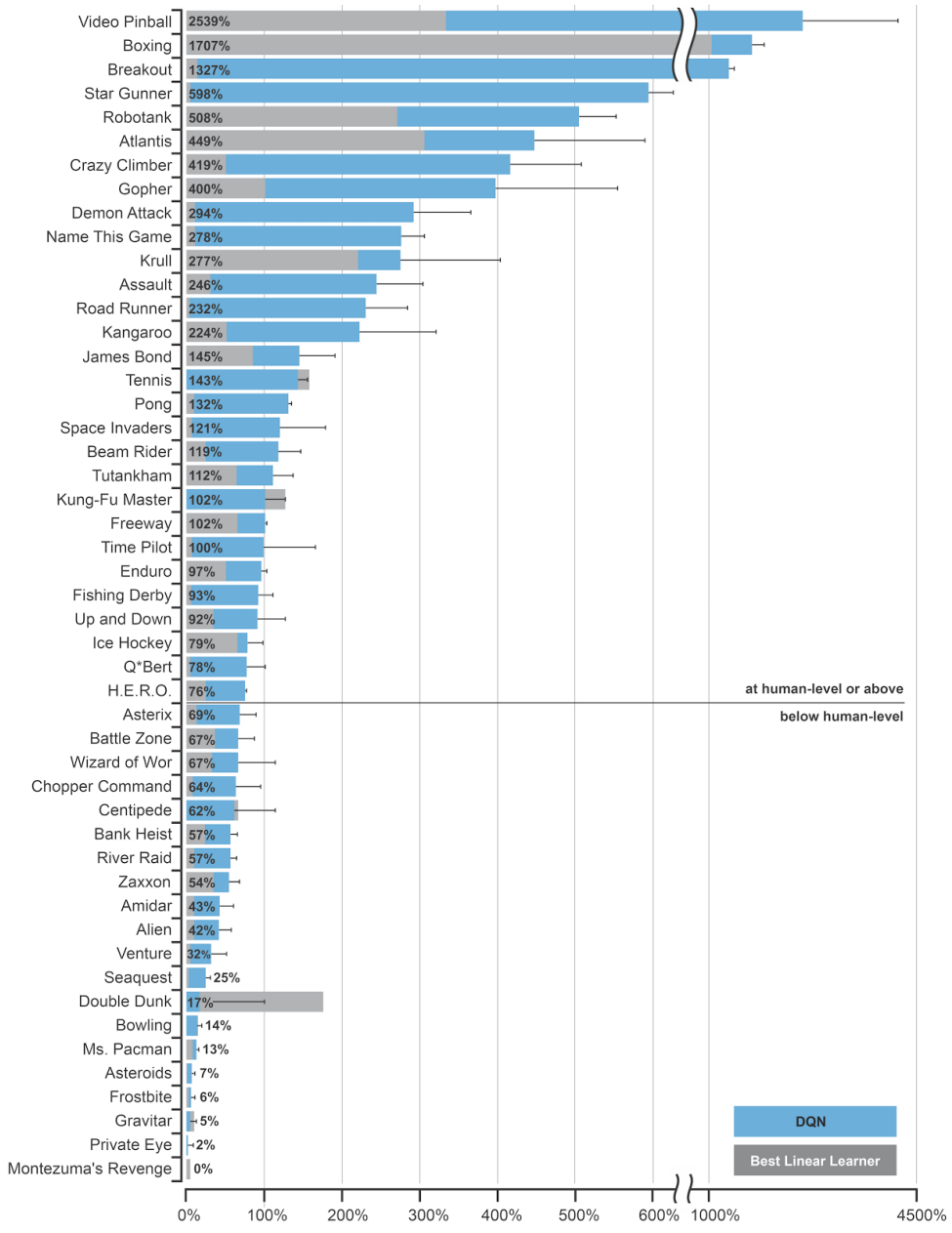
# AlphaGO

## Silver et al. (2016)

# Deep Q-Learning

## Mnih et al. (2015)




[Atari Games]

[OpenAI Universe]

[Google DeepMind Lab]

| | |
|---|---|
| Software Engineering | Full Stack Developer<br>New York City · Full Time · $80K – $120K · 0.1% – 0.25% |
| Operations | Junior Talent Strategist<br>New York City · Full Time · $40K – $50K · 0.1% – 0.2% |
| Sales | Software Sales Professional<br>New York City, Boston · Full Time · $60K – $90K · 0.25% – 0.75% |

[Details at `angel.co/untapt`]


CHEERS