



# Lecture 1: Introduction

# Welcome to CS231n



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Middle row, left to right

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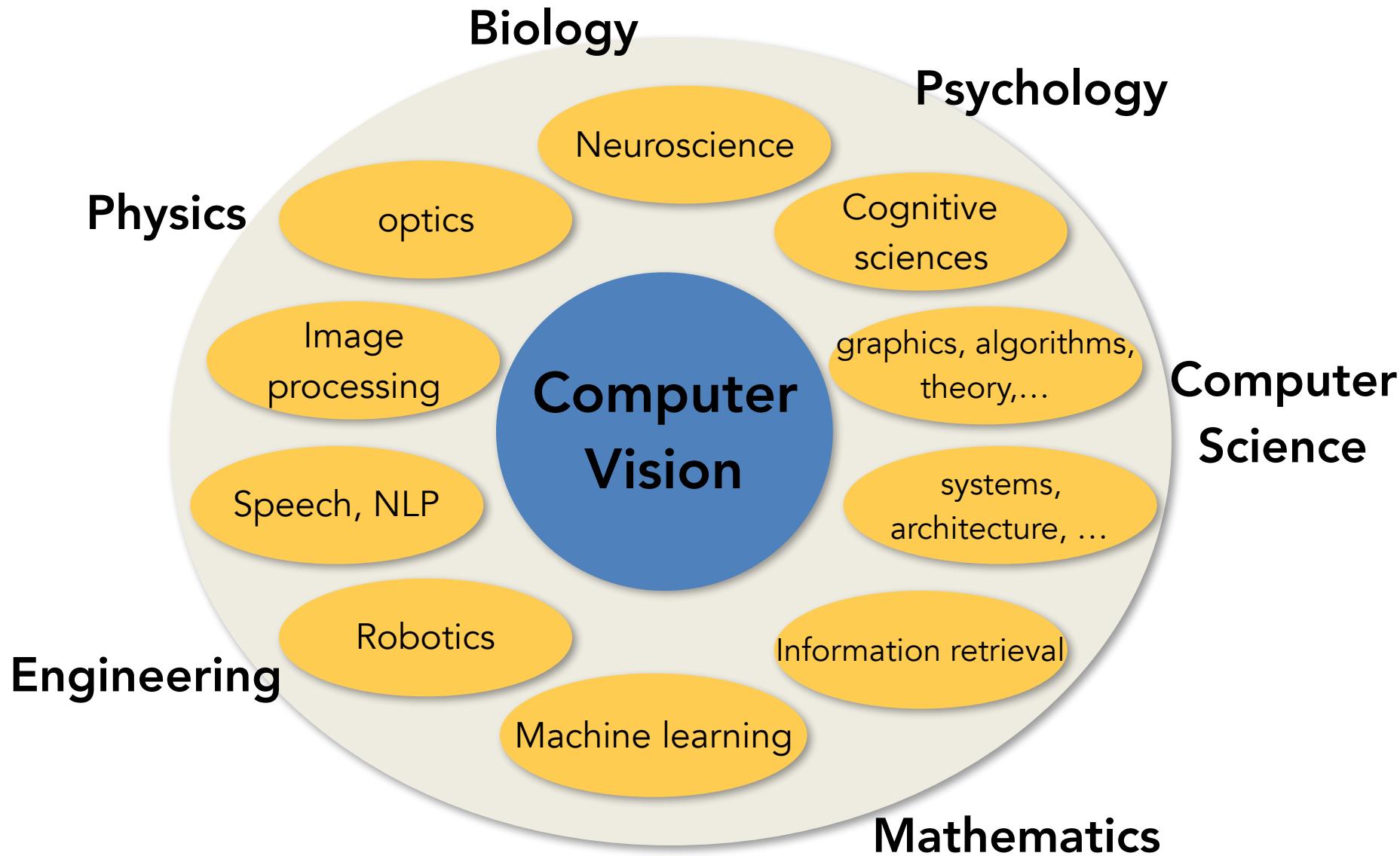
Bottom row, left to right

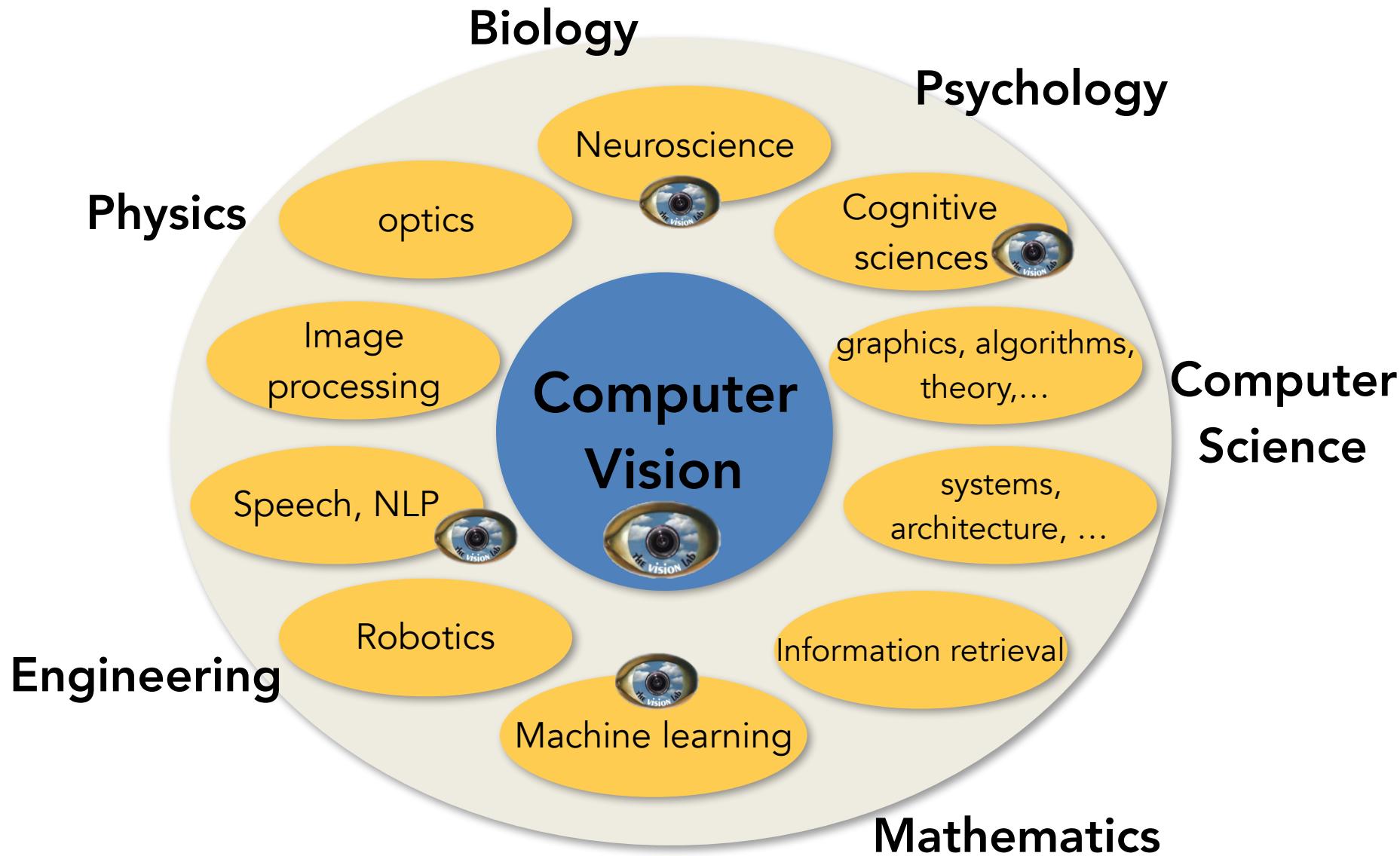
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# Related Courses @ Stanford

- CS131 (Fall 2016, Profs. Fei-Fei Li & Juan Carlos Niebles):
  - Undergraduate introductory class
- CS 224n (Winter 2017, Prof. Chris Manning and Richard Socher)
- CS231a (Spring 2017, Prof. Silvio Savarese)
  - Core computer vision class for seniors, masters, and PhDs
  - Topics include image processing, cameras, 3D reconstruction, segmentation, object recognition, scene understanding
- **CS231n (this term, Prof. Fei-Fei Li & Justin Johnson & Serena Yeung)**
  - **Neural network (aka “deep learning”) class on image classification**
- And an assortment of CS331 and CS431 for advanced topics in computer vision

# Today's agenda

- A brief history of computer vision
- CS231n overview

# Evolution's Big Bang



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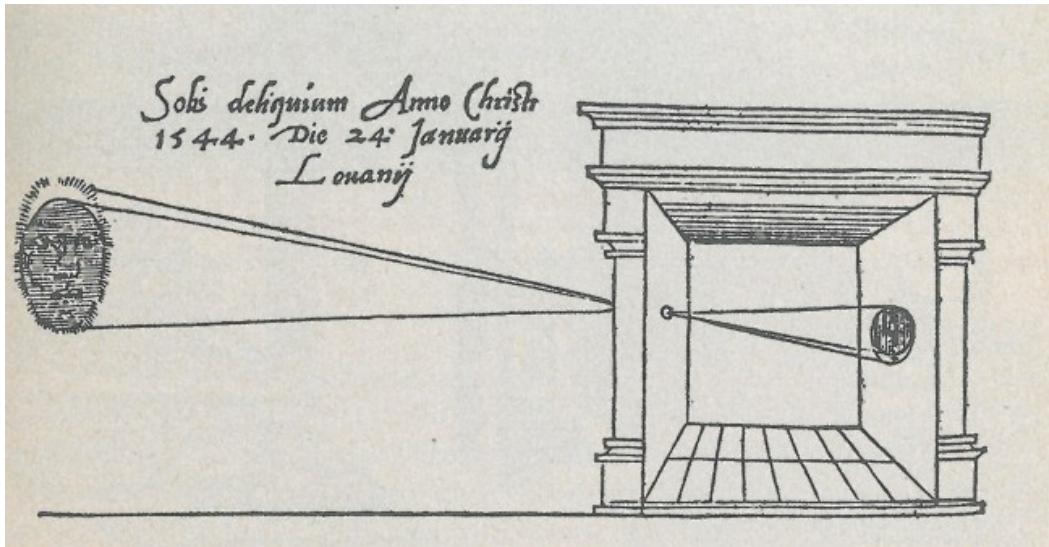


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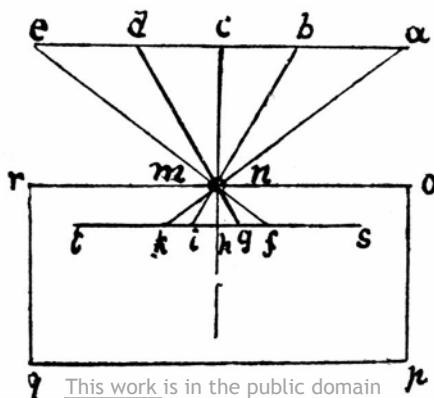
543million years, B.C.

# Camera Obscura

Gemma Frisius, 1545



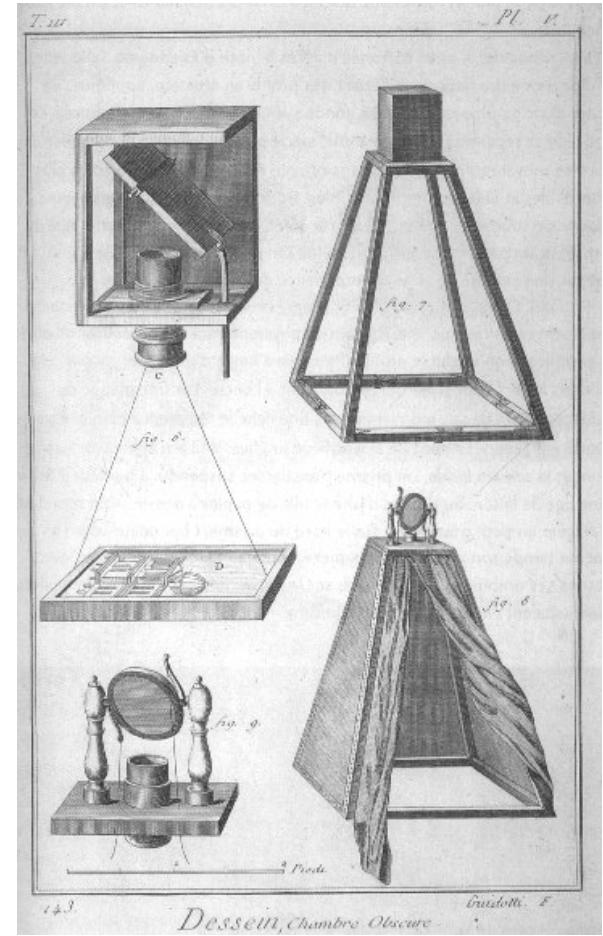
[This work is in the public domain](#)



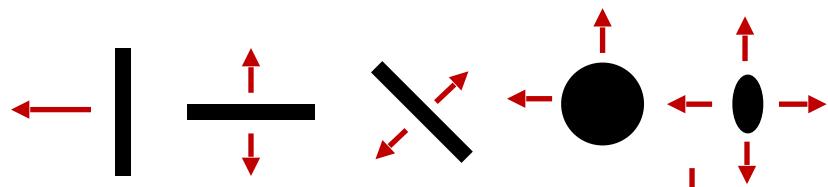
o Leonardo da Vinci,  
16<sup>th</sup> Century AD

[This work is in the public domain](#)

Encyclopedie, 18<sup>th</sup> Century



[This work is in the public domain](#)



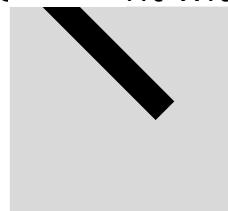
**Simple cells:**  
Response to light orientation

**Complex cells:**  
Response to light orientation and movement

**Hypercomplex cells:**  
Response to movement with end point

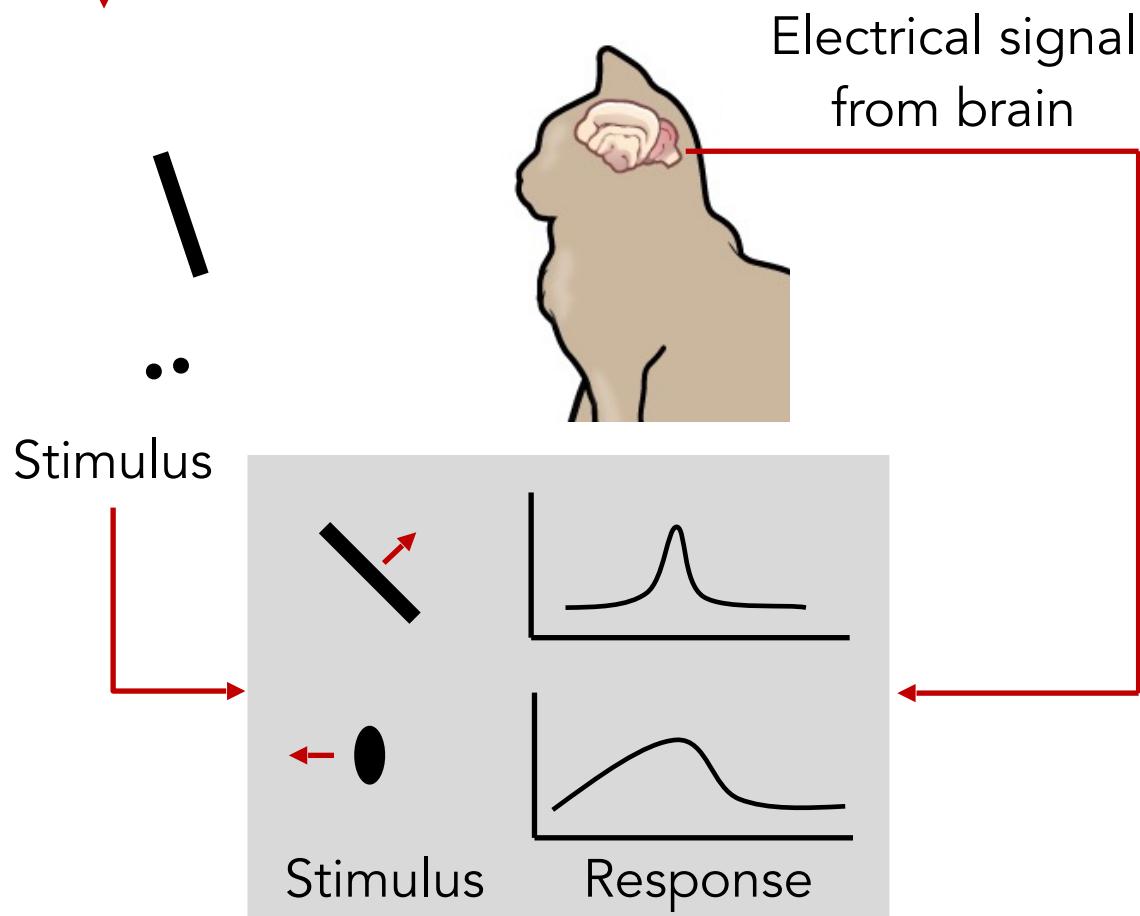


No response



Response  
(end point)

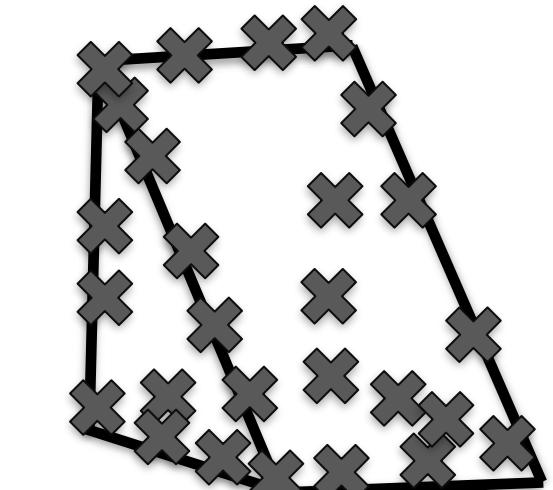
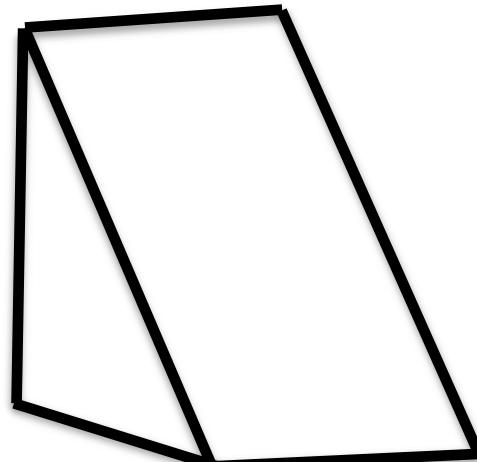
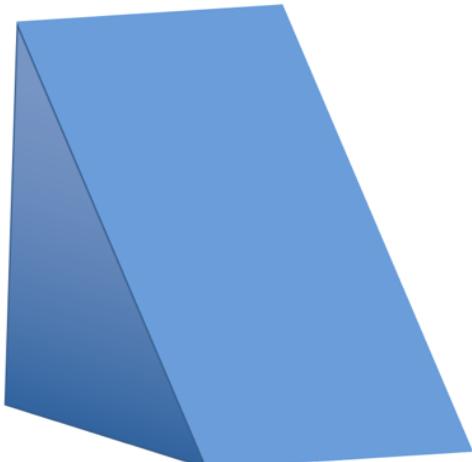
Hubel & Wiesel, 1959



Cat image by CNX OpenStax is licensed under CC BY 4.0; changes made

# Block world

Larry Roberts, 1963



MASSACHUSETTS INSTITUTE OF TECHNOLOGY

PROJECT MAC

Artificial Intelligence Group  
Vision Memo. No. 100.

July 7, 1966

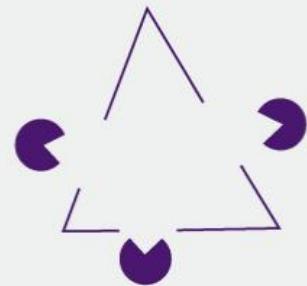
THE SUMMER VISION PROJECT

Seymour Papert

The summer vision project is an attempt to use our summer workers effectively in the construction of a significant part of a visual system. The particular task was chosen partly because it can be segmented into sub-problems which will allow individuals to work independently and yet participate in the construction of a system complex enough to be a real landmark in the development of "pattern recognition".

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# VISION



David Marr

FOREWORD BY  
Shimon Ullman

AFTERWORD BY  
Tomaso Poggio

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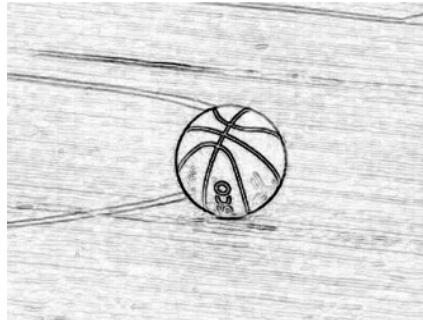
David Marr, 1970s

Input image

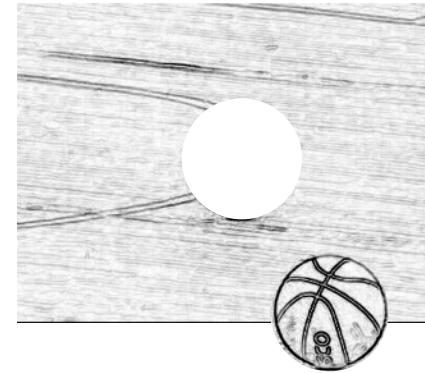


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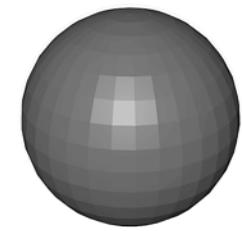
Edge image



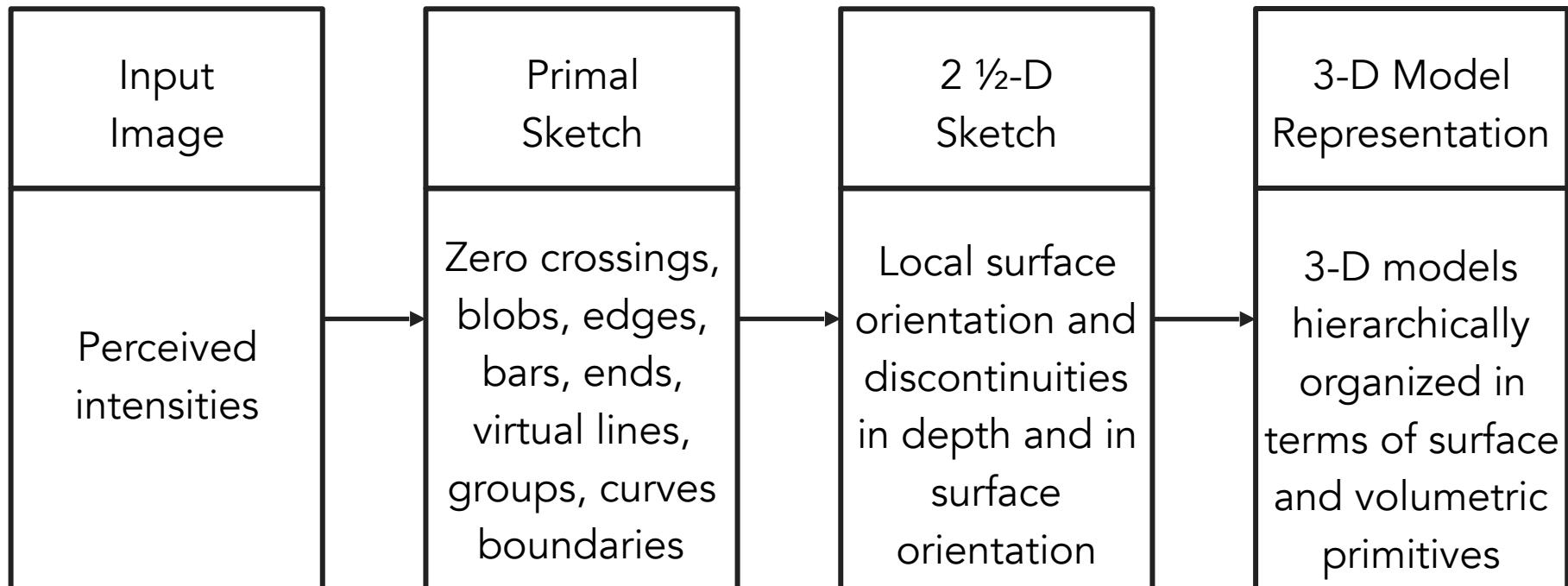
2 ½-D sketch



3-D model

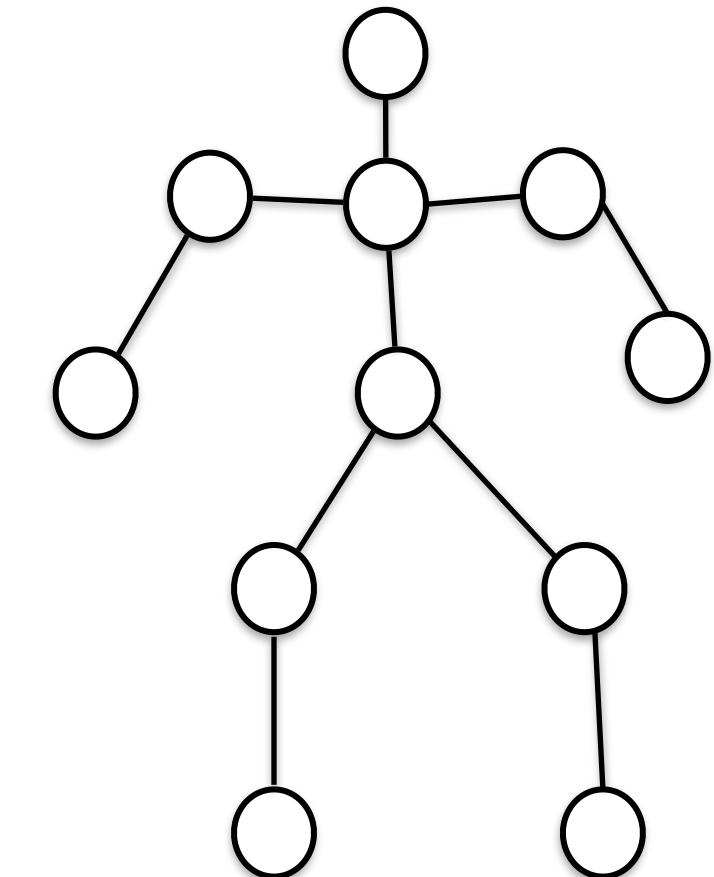
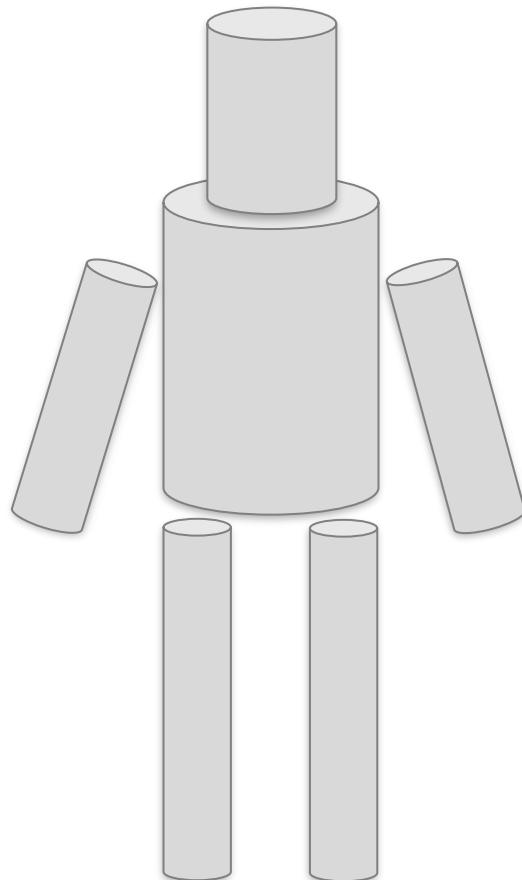


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Stages of Visual Representation, David Marr, 1970s

- Generalized Cylinder Brooks & Binford, 1979
- Pictorial Structure Fischler and Elschlager, 1973



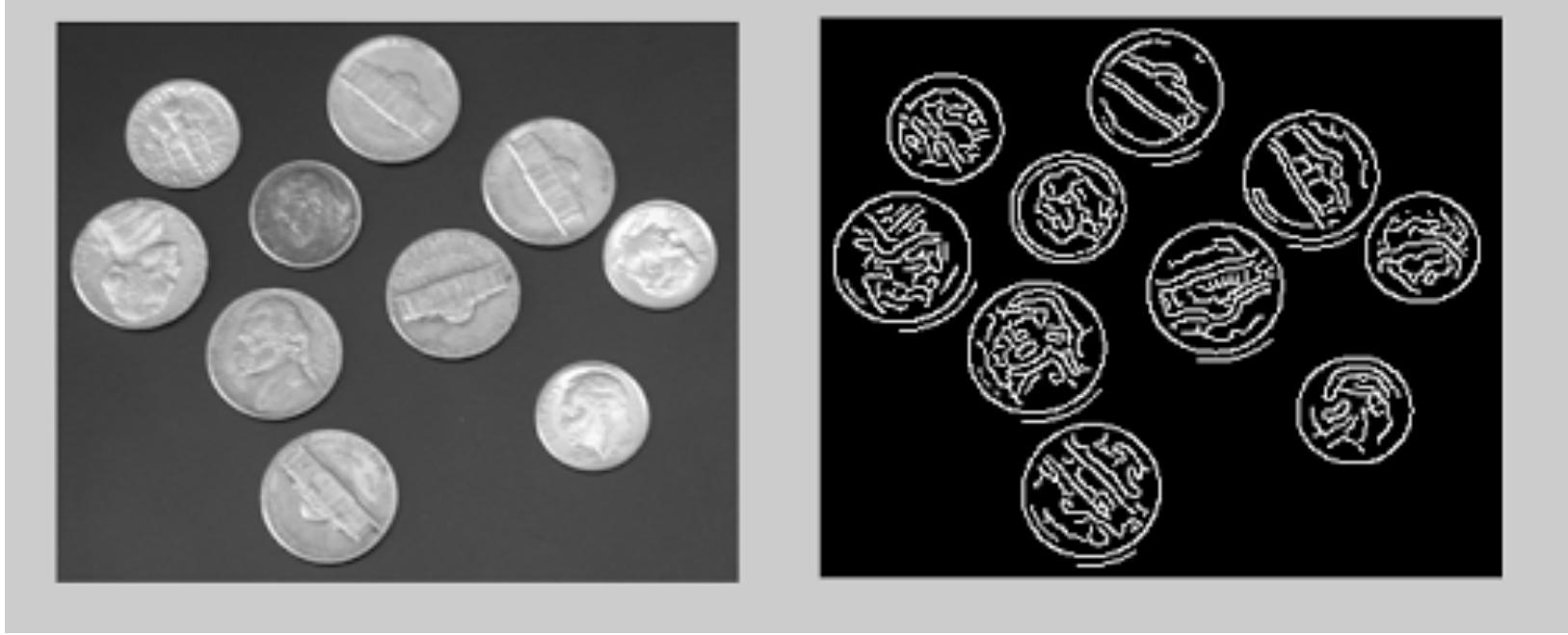


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David Lowe, 1987

# Normalized Cut (Shi & Malik, 1997)

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Face Detection, Viola & Jones,  
2001



Image is public  
domain



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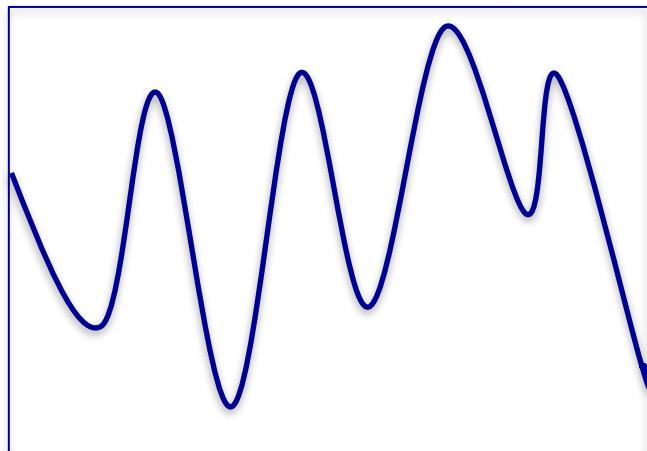


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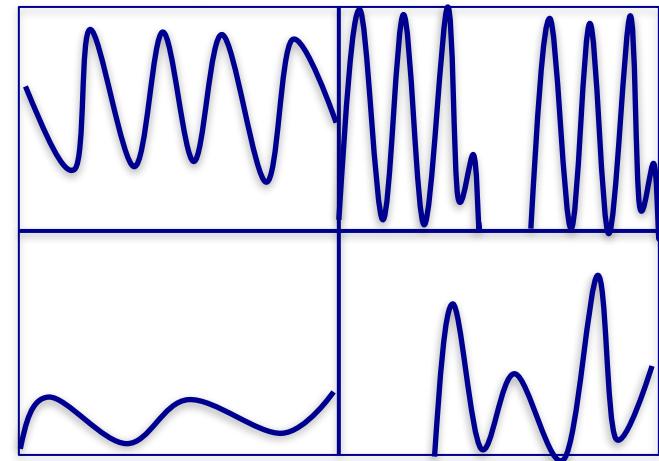
“SIFT” & Object Recognition, David Lowe, 1999



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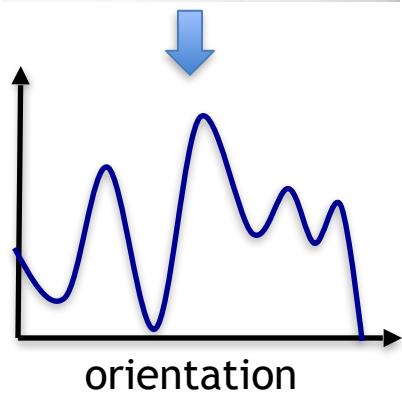


Level 0

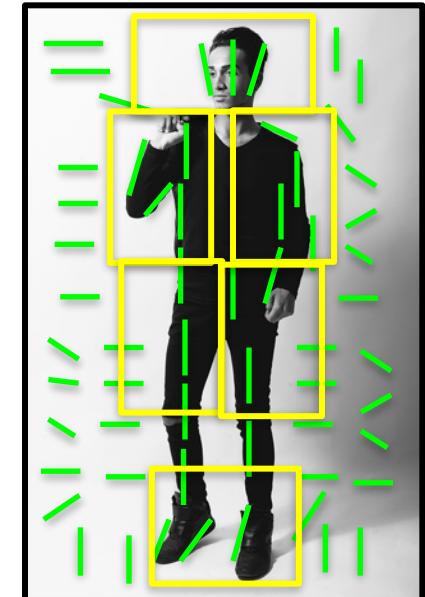


Level 1

Spatial Pyramid Matching, Lazebnik, Schmid & Ponce, 2006



Histogram of Gradients (HoG)  
Dalal & Triggs, 2005



Deformable Part Model  
Felzenswalb, McAllester, Ramanan, 2009

# PASCAL Visual Object Challenge (20 object categories)

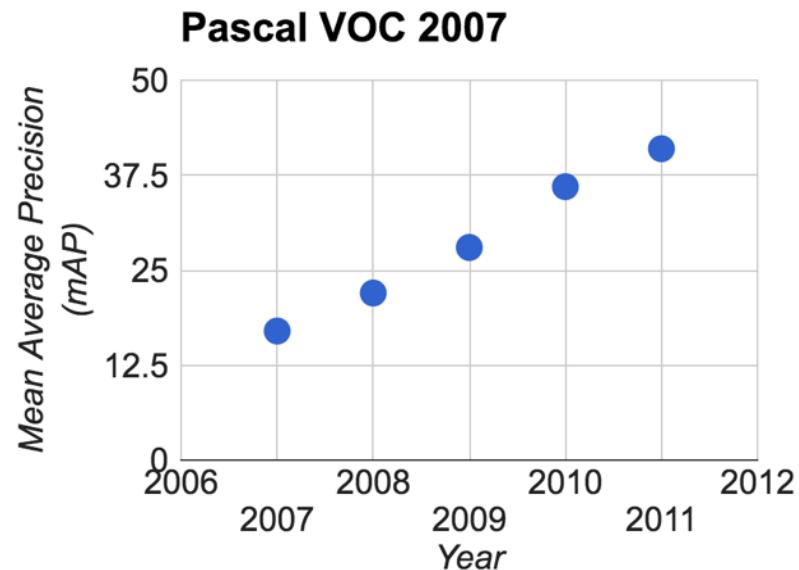
[Everingham et al. 2006-2012]

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[www.image-net.org](http://www.image-net.org)

**22K** categories and **14M** images

- Animals
  - Plants
  - Structures
  - Person
- Bird
- Fish
- Mammal
- Invertebrate
- Tree
- Flower
- Food
- Materials
- Artifact
- Tools
- Appliances
- Structures
- Scenes
- Indoor
- Geological Formations
- Sport Activities

Deng, Dong, Socher, Li, Li, & Fei-Fei, 2009

# IMAGENET Large Scale Visual Recognition Challenge

Steel drum

The Image Classification Challenge:

1,000 object classes

1,431,167 images



**Output:**  
Scale  
T-shirt  
Steel drum  
Drumstick  
Mud turtle



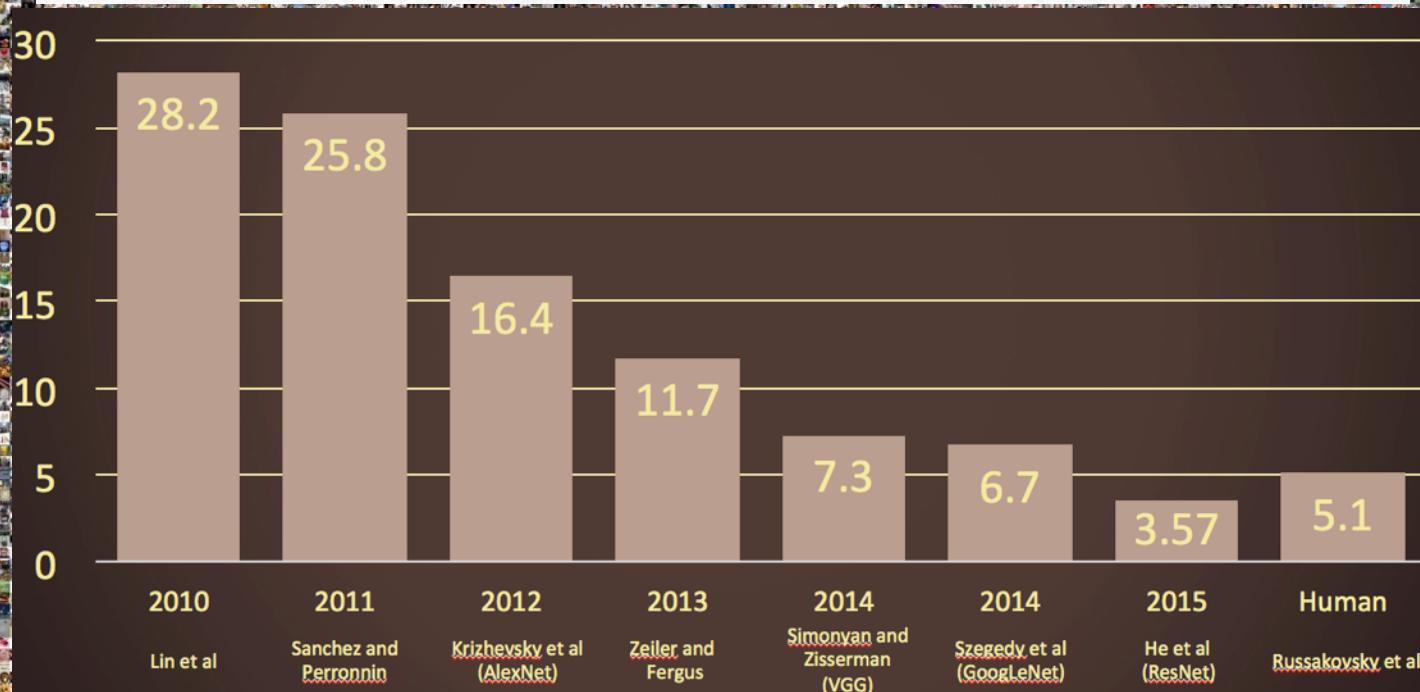
**Output:**  
Scale  
T-shirt  
Giant panda  
Drumstick  
Mud turtle



Russakovsky et al. arXiv, 2014

# IMAGENET Large Scale Visual Recognition Challenge

The Image Classification Challenge:  
1,000 object classes  
1,431,167 images



Russakovsky et al. arXiv, 2014

# Today's agenda

- A brief history of computer vision
- CS231n overview

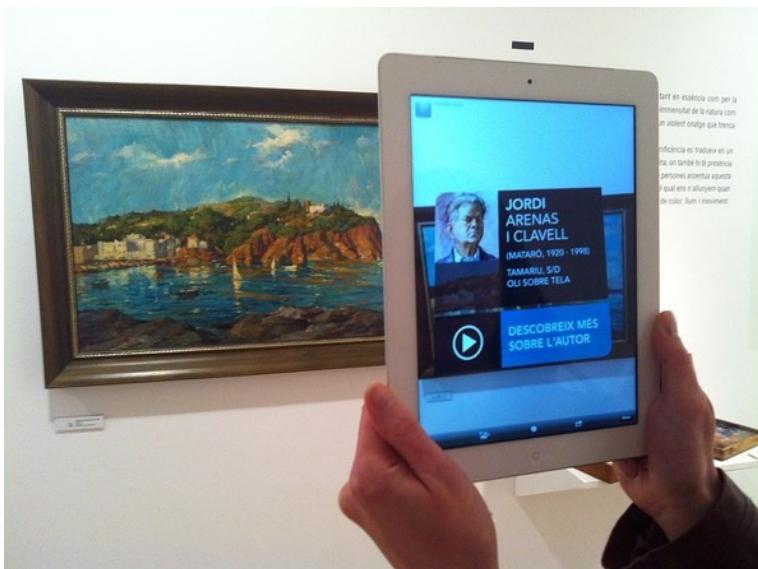
CS231n focuses on one of the most important  
problems of visual recognition –  
image classification



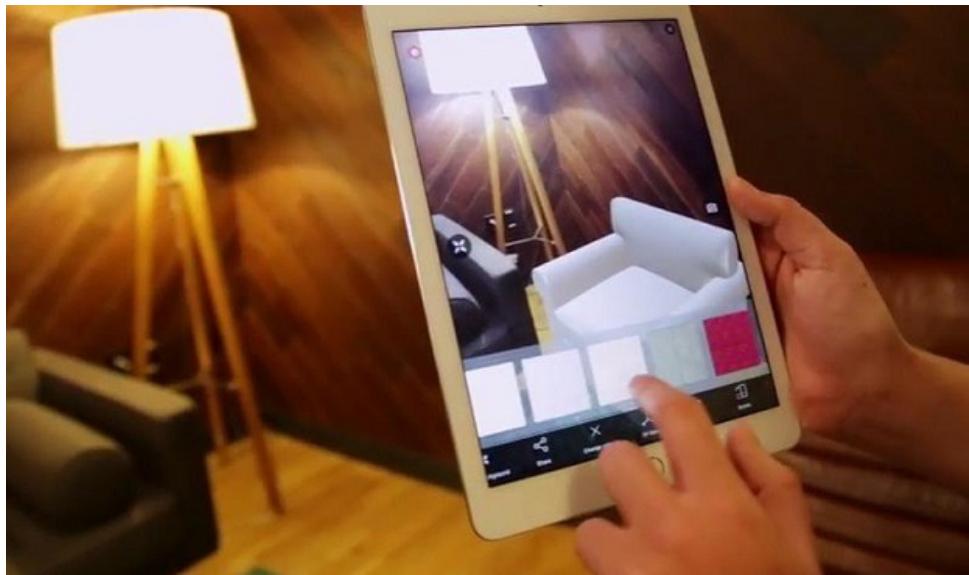
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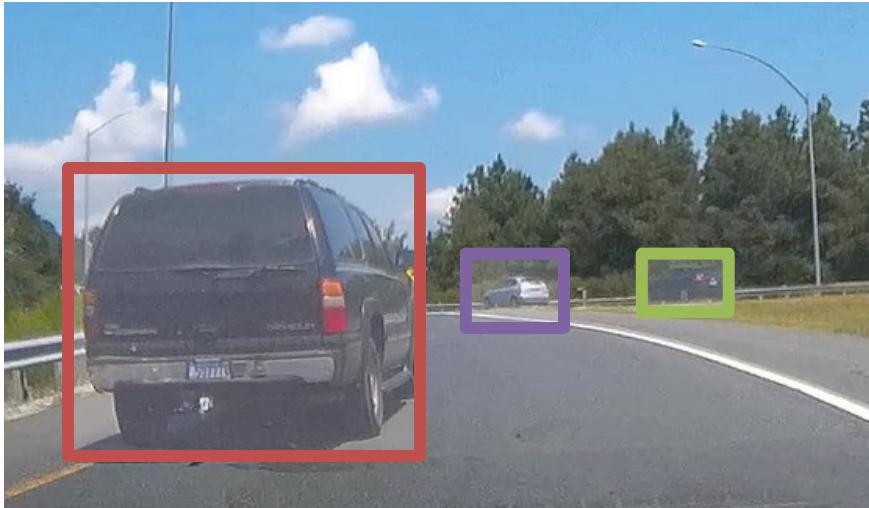


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There is a number of visual recognition problems that are related to image classification, such as object detection, image captioning



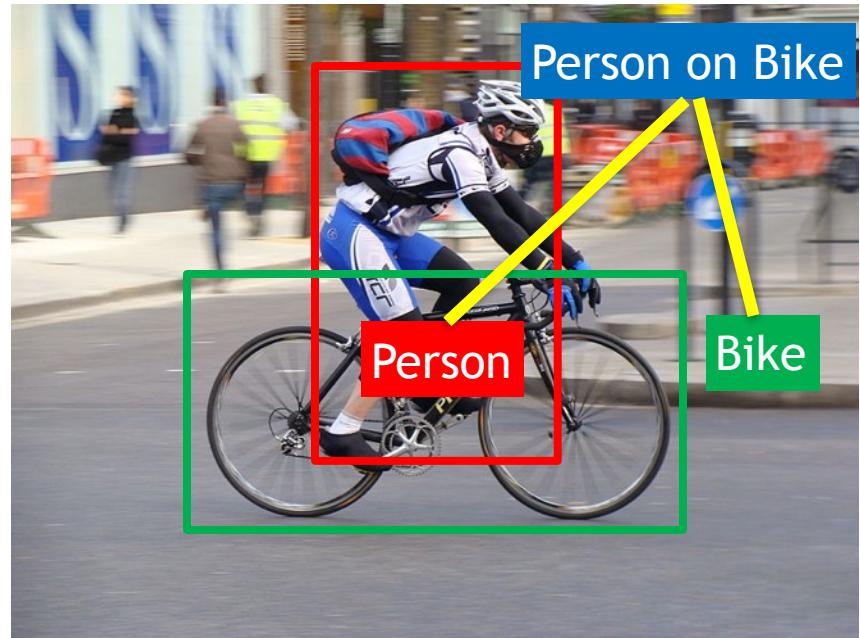
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Person  
Hammer

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- Object detection
- Action classification
- Image captioning
- ...



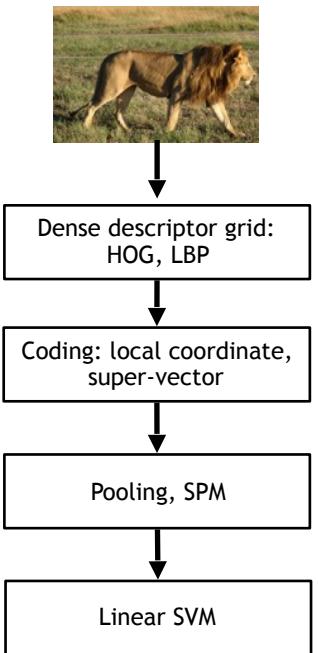
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Convolutional Neural Networks (CNN) have become an important tool for object recognition

# IMAGENET Large Scale Visual Recognition Challenge

## Year 2010

NEC-UIUC

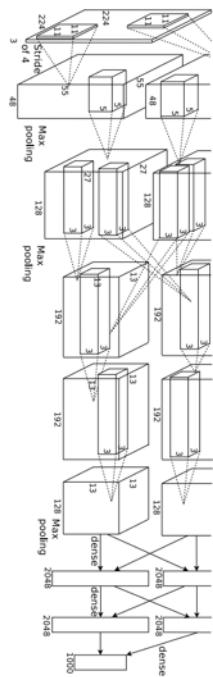


[Lin CVPR 2011]

Lion image by Swissfrog is licensed under CC BY 3.0

## Year 2012

SuperVision



[Krizhevsky NIPS 2012]

Figure copyright Alex Krizhevsky, Ilya Sutskever, and Geoffrey Hinton, 2012. Reproduced with permission.

## Year 2014

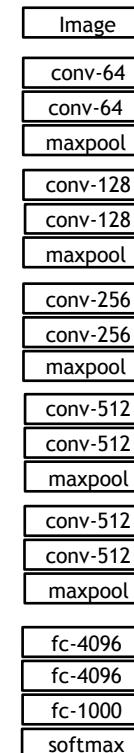
GoogLeNet

- Pooling
- Convolution
- Softmax
- Other



[Szegedy arxiv 2014]

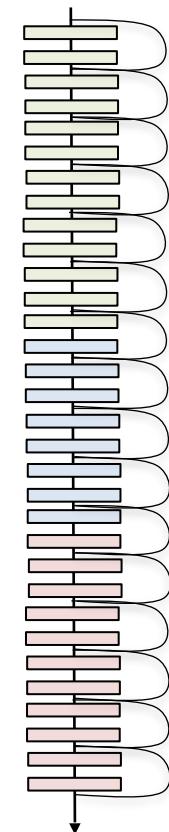
VGG



[Simonyan arxiv 2014]

## Year 2015

MSRA

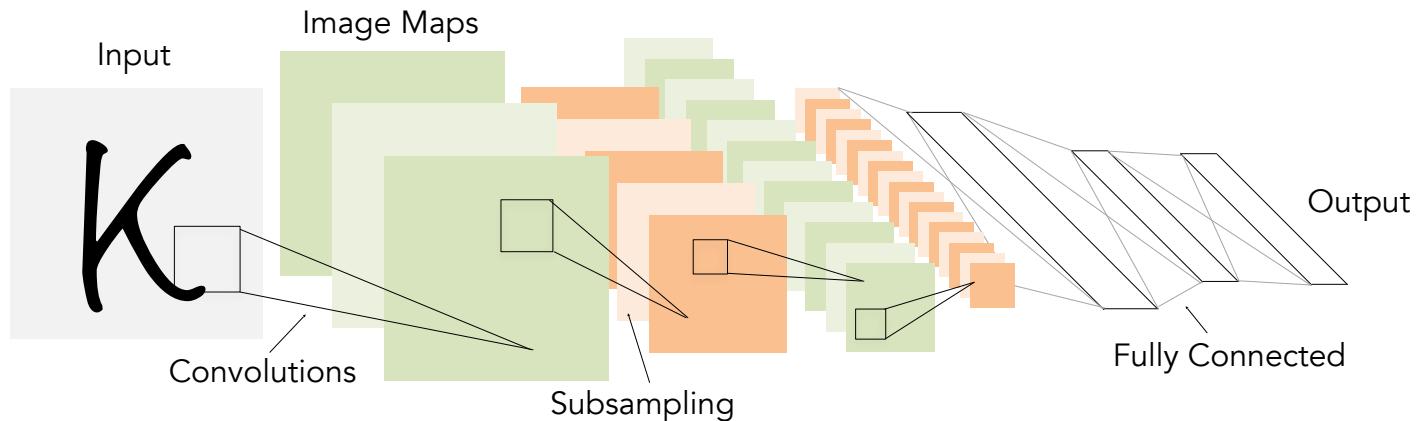


[He ICCV 2015]

Convolutional Neural Networks (CNN)  
were not invented overnight

# 1998

LeCun et al.



# of transistors



$10^6$

pentium® II

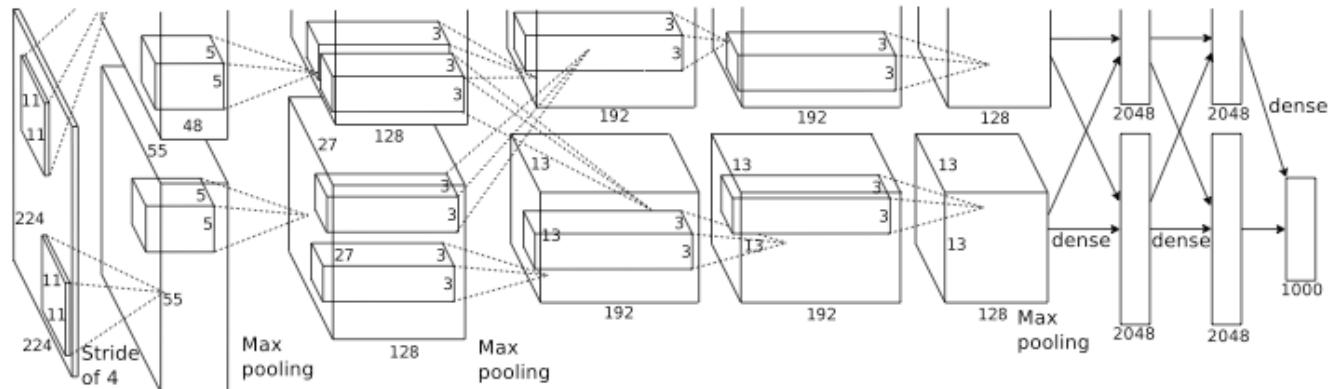
# of pixels used in training

$10^7$



# 2012

Krizhevsky et al.



# of transistors



$10^9$

GPUs



# of pixels used in training

$10^{14}$



Figure copyright Alex Krizhevsky, Ilya Sutskever, and Geoffrey Hinton, 2012.  
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The quest for visual intelligence  
goes far beyond object recognition...

Wall

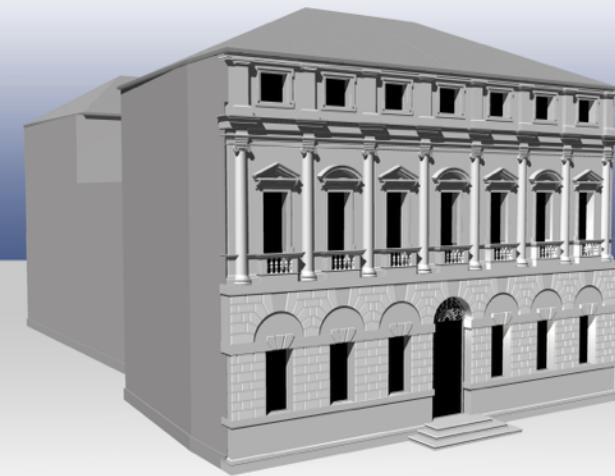
Laptop

Glass

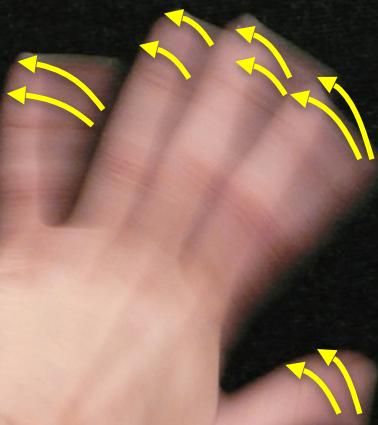
Wire

Desk

[Image](#) is GFDL



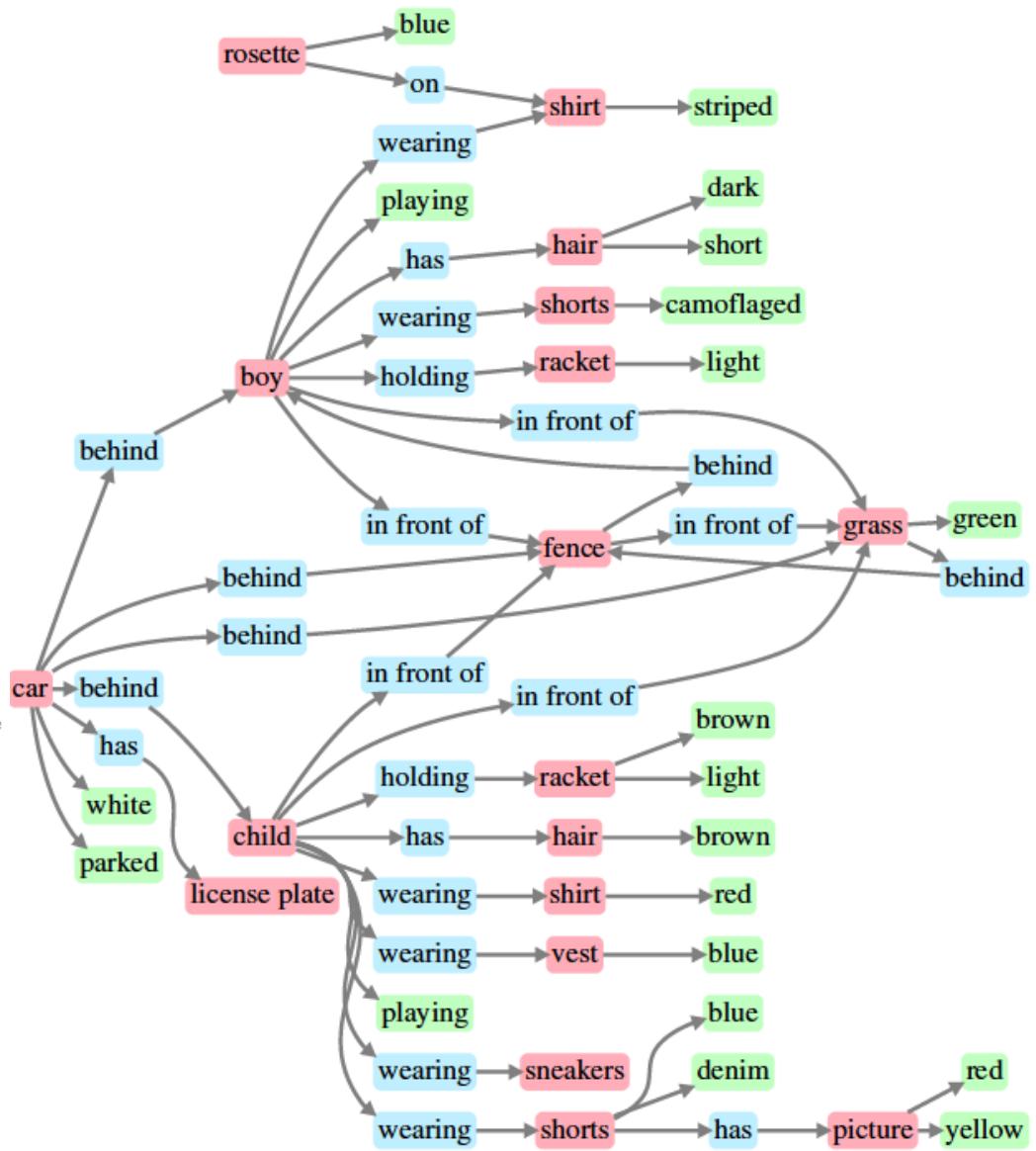
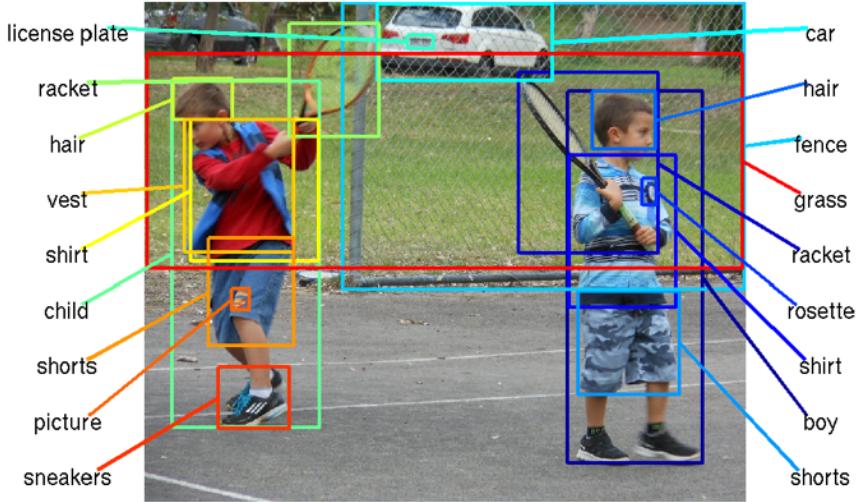
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Waving

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Johnson *et al.*, “Image Retrieval using Scene Graphs”, CVPR 2015

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## **PT = 500ms**



Some kind of game or fight. Two groups of two men? The man on the left is throwing something. Outdoors seemed like because i have an impression of grass and maybe lines on the grass? That would be why I think perhaps a game, rough game though, more like rugby than football because they pairs weren't in pads and helmets, though I did get the impression of similar clothing. maybe some trees? in the background. (Subject: SM)

Fei-Fei, Iyer, Koch, Perona, JoV, 2007

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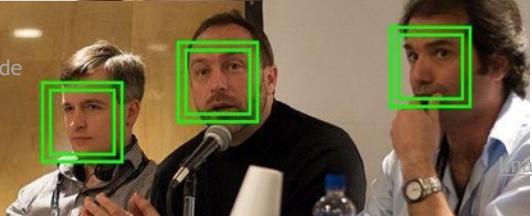


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Example credit: [Andrej Karpathy](#)



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# Who we are

## Instructors



Fei-Fei Li



Justin Johnson



Serena Yeung

## Emeritus



Andrej Karpathy

## Teaching Assistants



Albert Haque



Rishi Bedi



Shyamal Buch



Zhao (Joe) Chen



Timnit Gebru



Agrim Gupta



De-An Huang



Russell Kaplan



Leo Keselman



Nishith  
Khandwala



Shayne Longpre



Zelun Luo



Lane McIntosh



Oliver Moindrot



Amani Peddada



Emma Peng



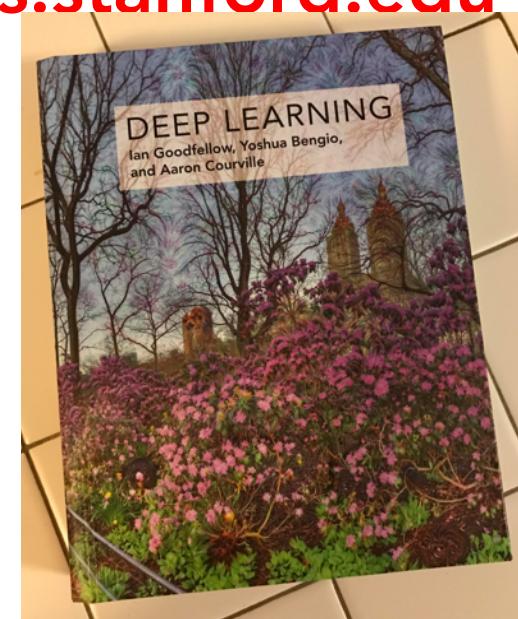
Ben Poole



Luda Zhao

# Course Logistics

- Keeping in touch:
  - Piazza
  - **[cs231n-spring1617-staff@lists.stanford.edu](mailto:cs231n-spring1617-staff@lists.stanford.edu)**
- Optional textbook:
  - *Deep Learning* by Goodfellow, Bengio, and Courville
  - Free online

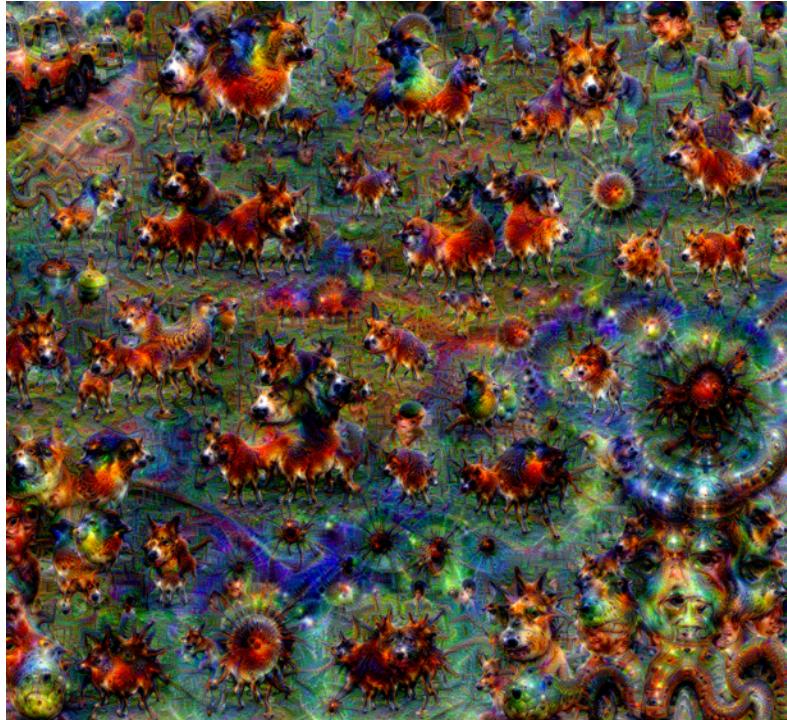


# Our philosophy

- Thorough and Detailed.
  - Understand how to write from scratch, debug and train convolutional neural networks.
- Practical.
  - Focus on practical techniques for training these networks at scale, and on GPUs (e.g. will touch on distributed optimization, differences between CPU vs. GPU, etc.) Also look at state of the art software tools such as Caffe, TensorFlow, and (Py)Torch
- State of the art.
  - Most materials are new from research world in the past 1-3 years. Very exciting stuff!
- Fun.
  - Some fun topics such as Image Captioning (using RNN)
  - Also DeepDream, NeuralStyle, etc.

# Our philosophy (cont'd)

- Fun.
  - Some fun topics such as Image Captioning (using RNN)
  - Also DeepDream, NeuralStyle, etc.



# Grading policy

- 3 Problem Sets: 15%  $\times$  3 = 45%
- Midterm Exam: 15%
- Final Course Project: 40%
  - Milestone: 5%
  - Final write-up: 35%
  - Bonus points for exceptional poster presentation
- Late policy
  - 7 free late days – use them in your ways
  - Afterwards, 25% off per day late
  - Not accepted after 3 late days per PS
  - Does not apply to Final Course Project
- Collaboration policy
  - Read the student code book, understand what is 'collaboration' and what is 'academic infraction'

# Pre-requisite

- Proficiency in Python, some high-level familiarity with C/C++
  - All class assignments will be in Python (and use numpy), but some of the deep learning libraries we may look at later in the class are written in C++.
  - A Python tutorial available on course website
- College Calculus, Linear Algebra
- Equivalent knowledge of CS229 (Machine Learning)
  - We will be formulating cost functions, taking derivatives and performing optimization with gradient descent.

# Syllabus

- Go to website...

<http://cs231n.stanford.edu/>

# References

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