EECS 498-007 / 598-005
Deep Learning for Computer Vision

Lecture 1: Introduction

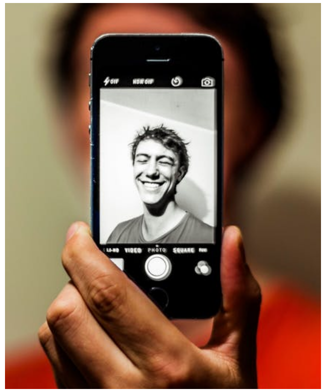
Deep Learning for Computer Vision

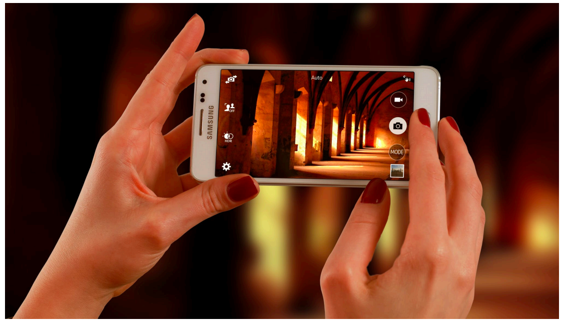
Deep Learning for Computer Vision

Building artificial systems that process, perceive, and reason about visual data

Computer Vision is everywhere!

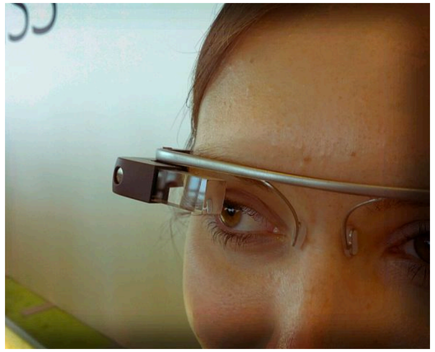








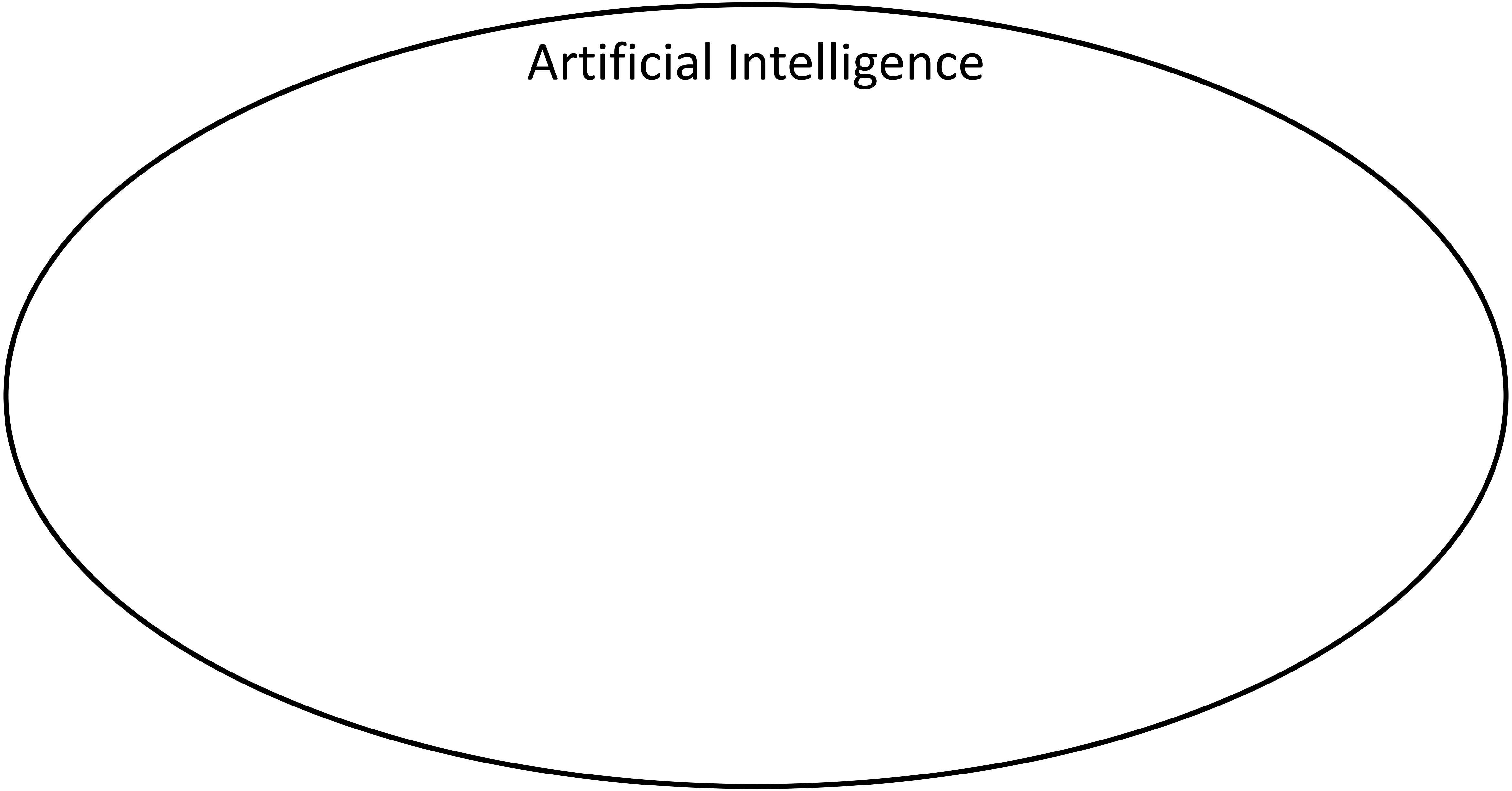


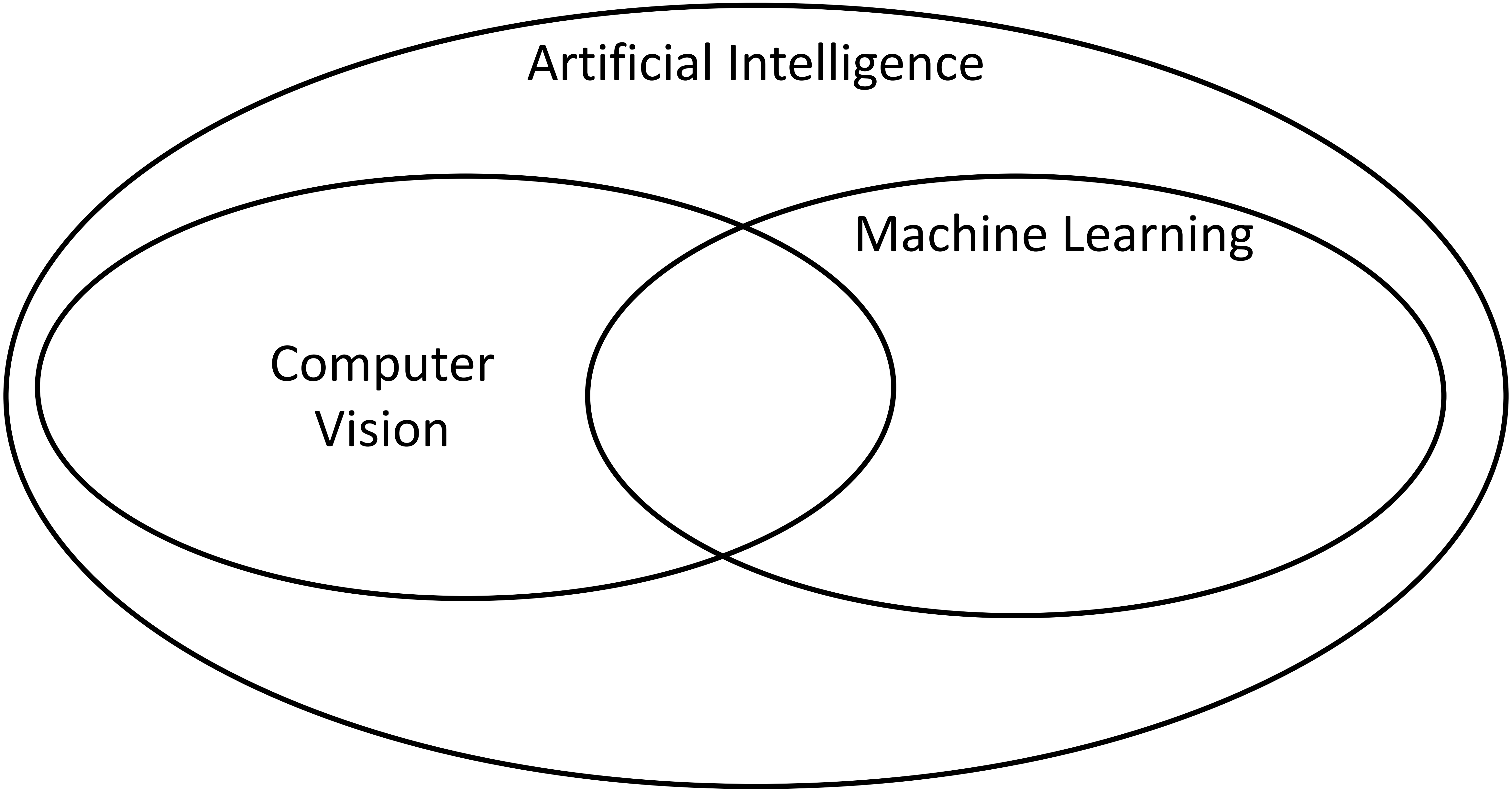
Deep Learning for Computer Vision

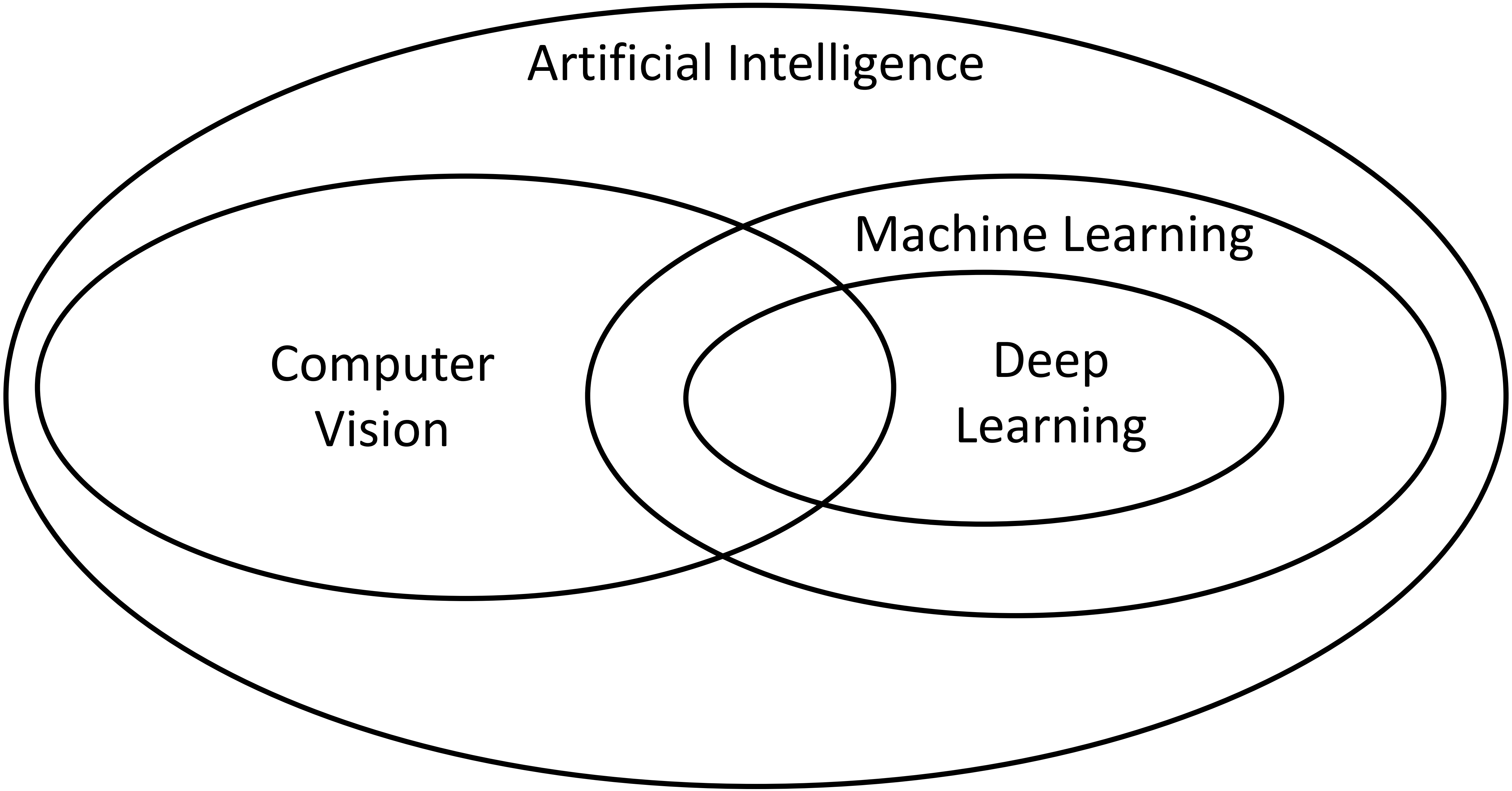
Building artificial systems that
learn from data and experience

Deep Learning for Computer Vision

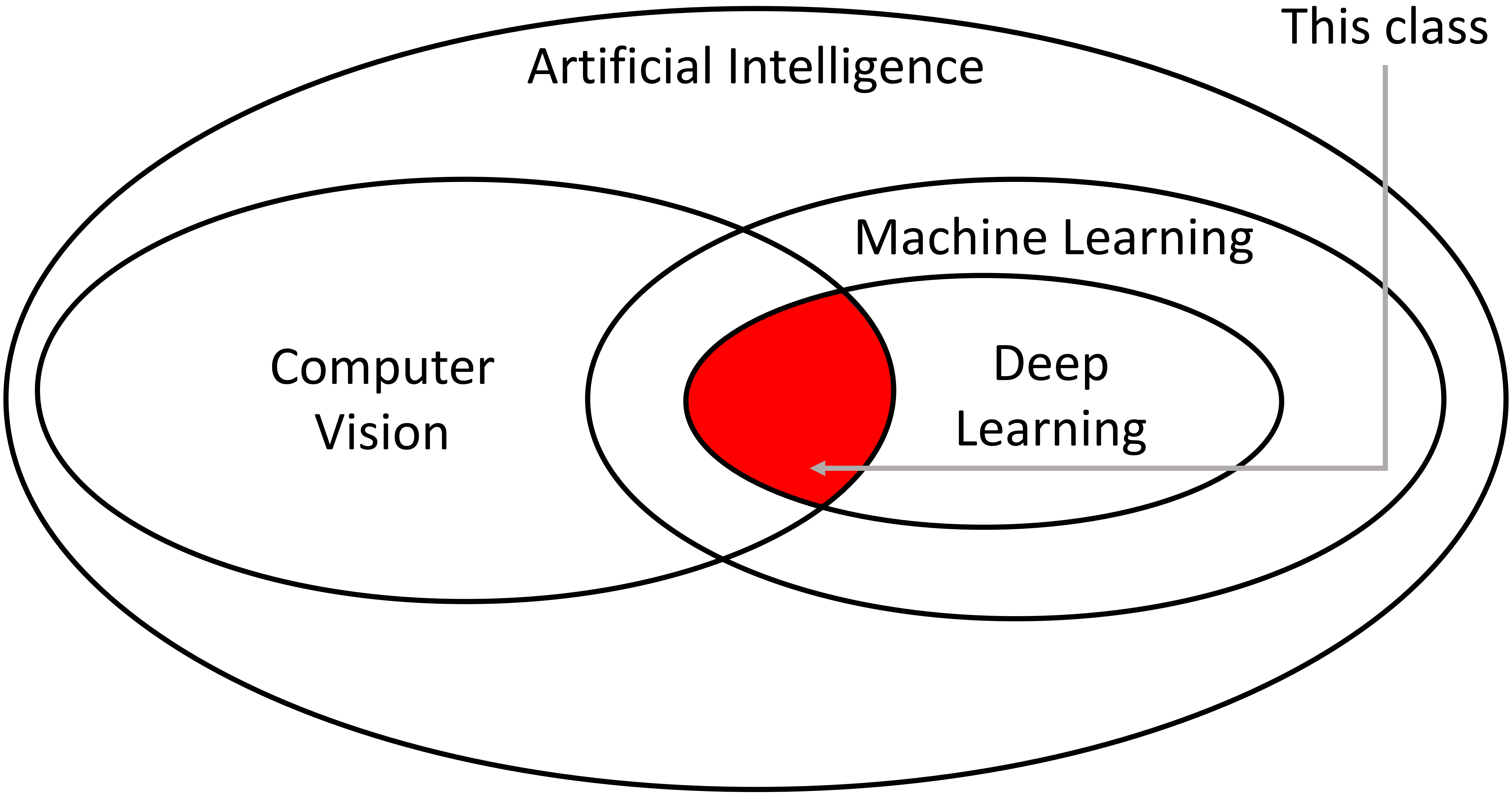
Hierarchical learning algorithms with many “layers”, (very) loosely inspired by the brain

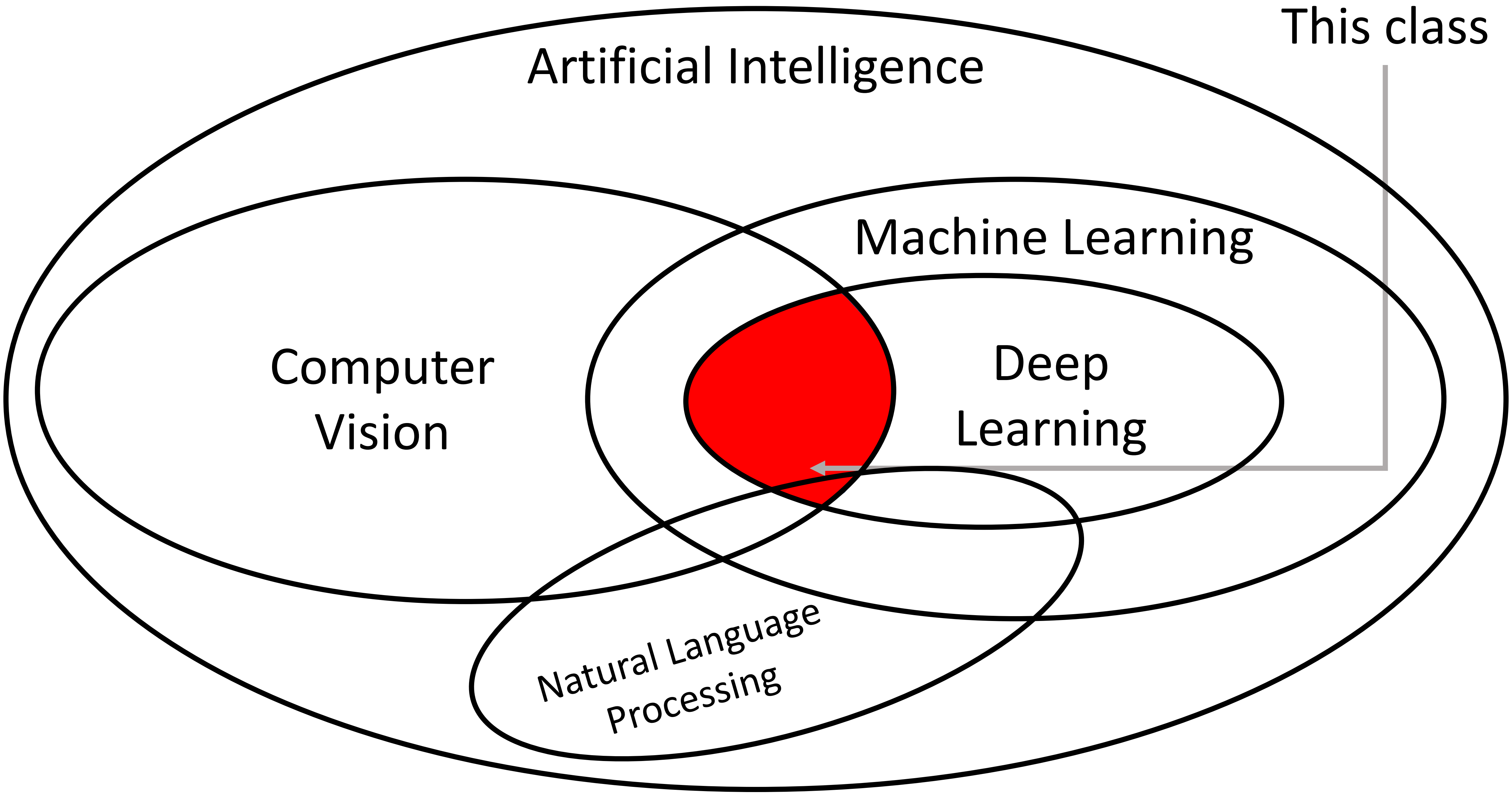

Artificial Intelligence

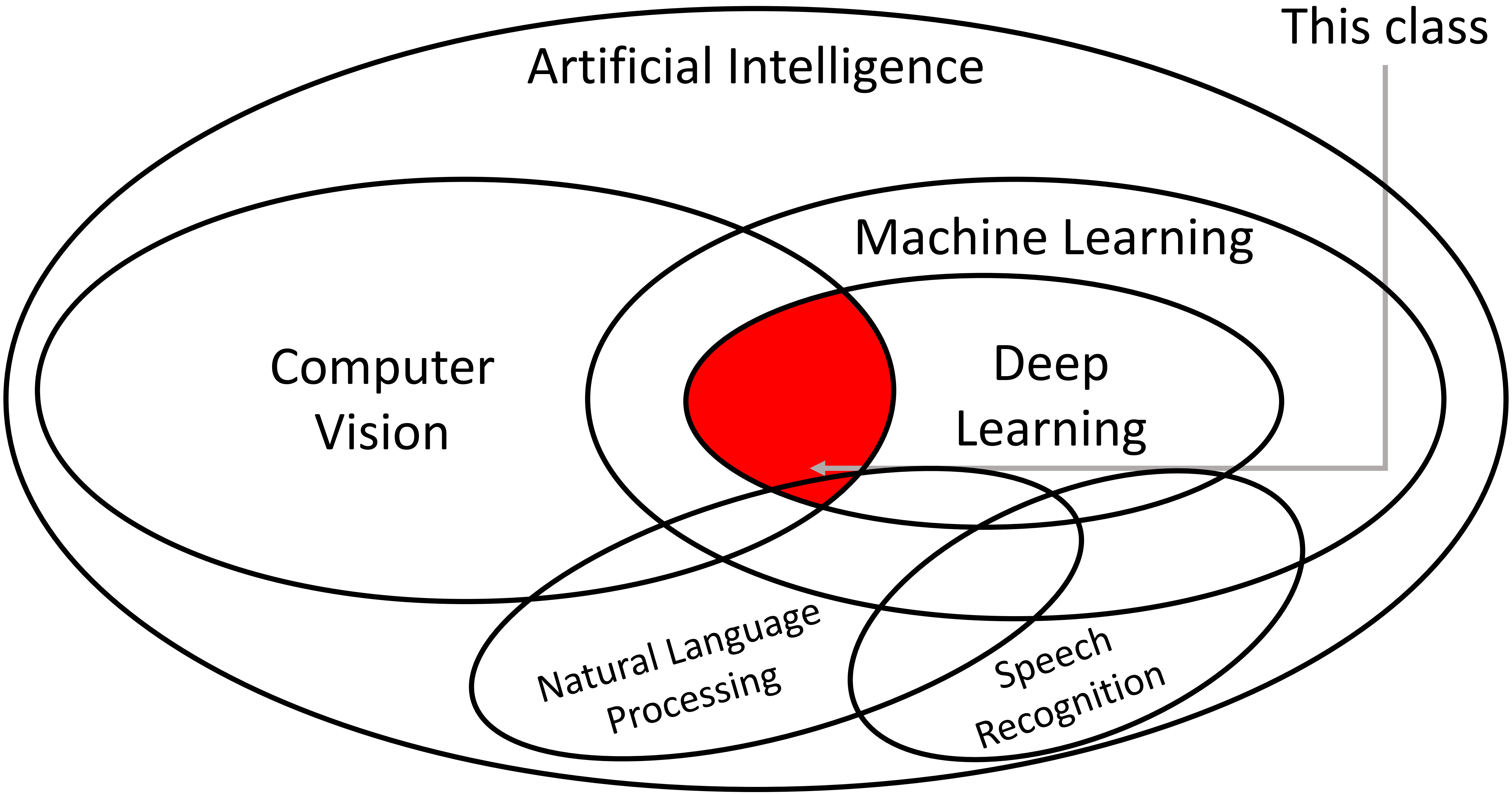

Artificial Intelligence
Machine Learning
Computer Vision

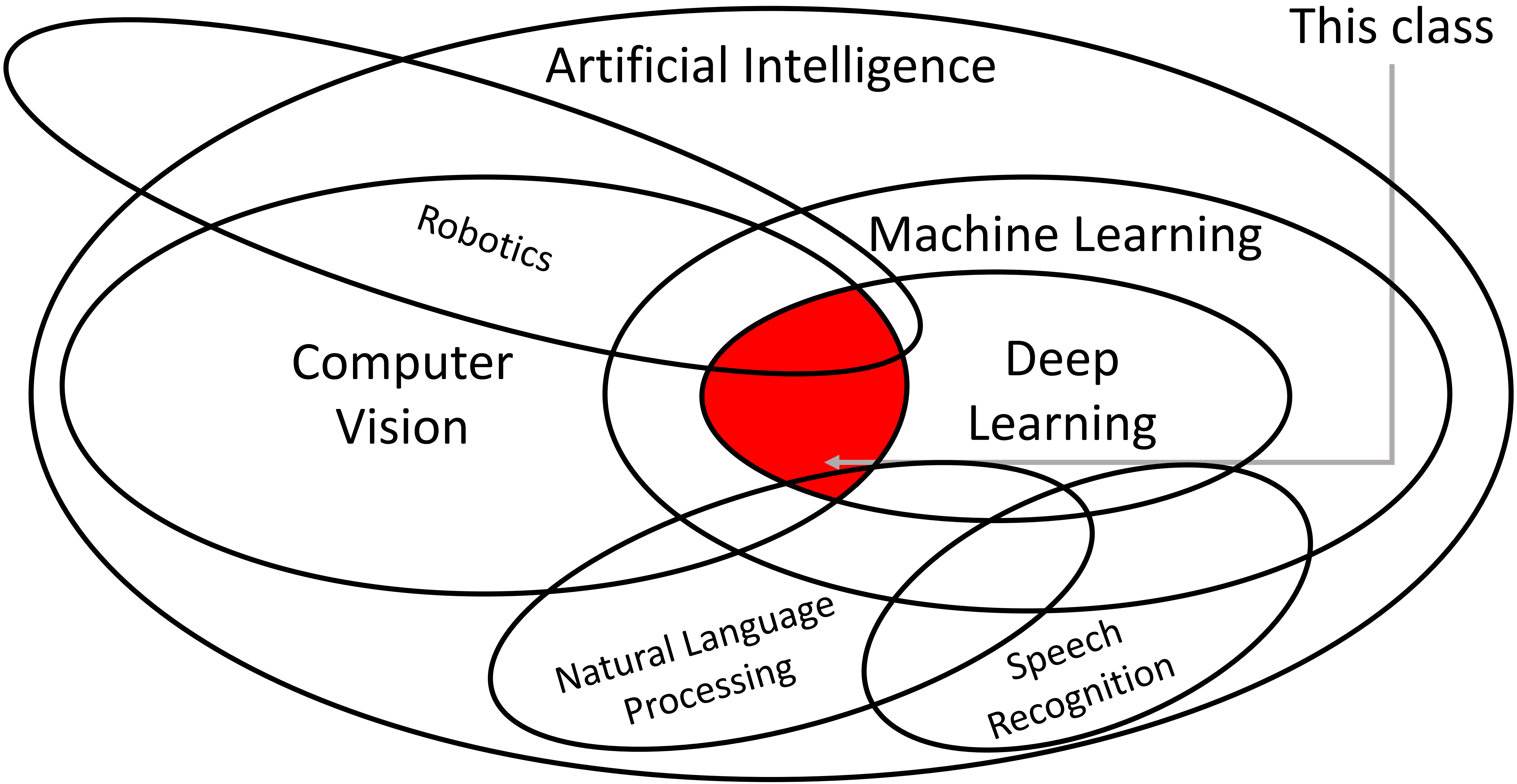


Artificial Intelligence
Machine Learning
Computer Vision
Deep Learning


This class
Artificial Intelligence
Machine Learning
Computer Vision
Deep Learning


This class
Artificial Intelligence
Machine Learning
Computer Vision
Deep Learning
Natural Language Processing


This class
Artificial Intelligence
Machine Learning
Computer Vision
Deep Learning
Natural Language Processing
Speech Recognition

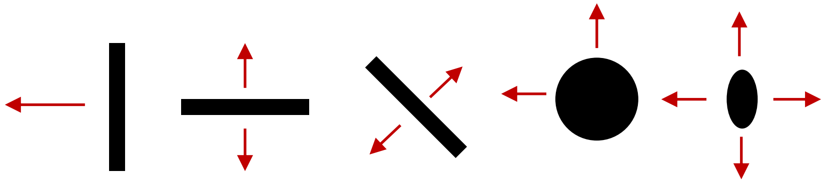

This class
Artificial Intelligence
Robotics
Machine Learning
Computer Vision
Deep Learning
Natural Language Processing
Speech Recognition

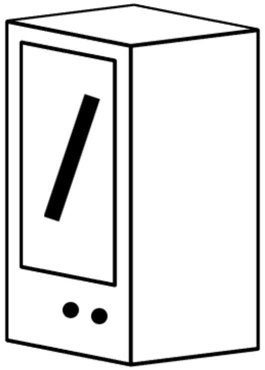
Today's Agenda

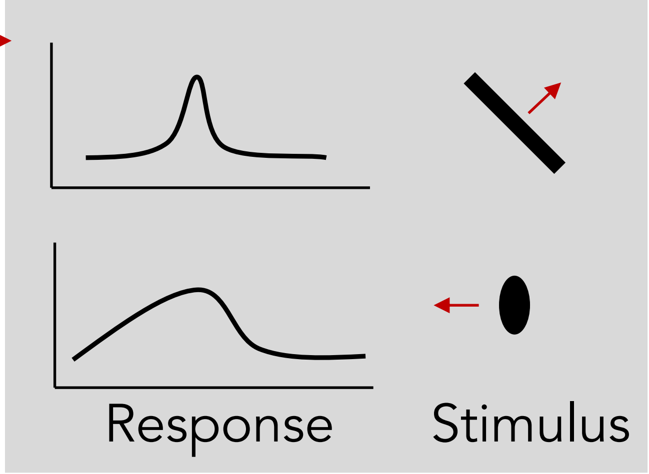
- A brief history of computer vision and deep learning
- Course overview and logistics

Hubel and Wiesel, 1959

Measure brain activity



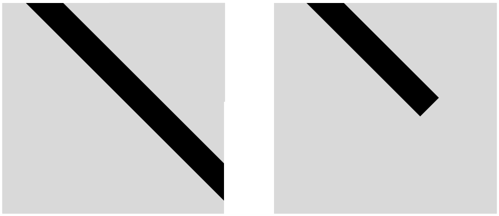




Simple cells:
Response to light orientation

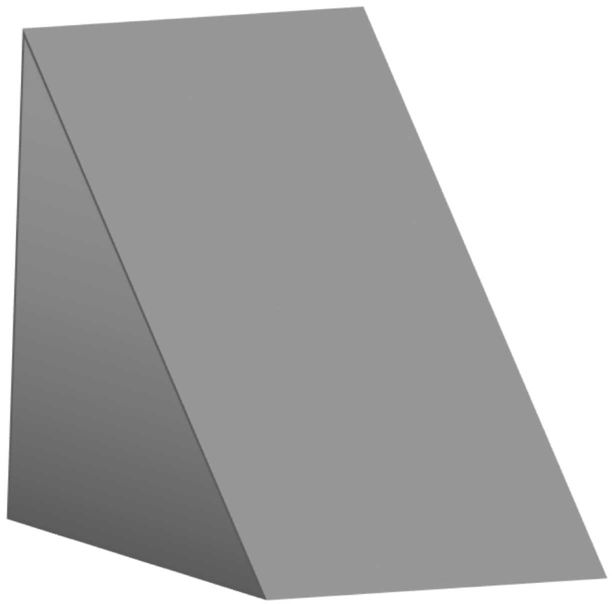
Complex cells:
Response to light orientation and movement

Hypercomplex cells:
response to movement with an end point

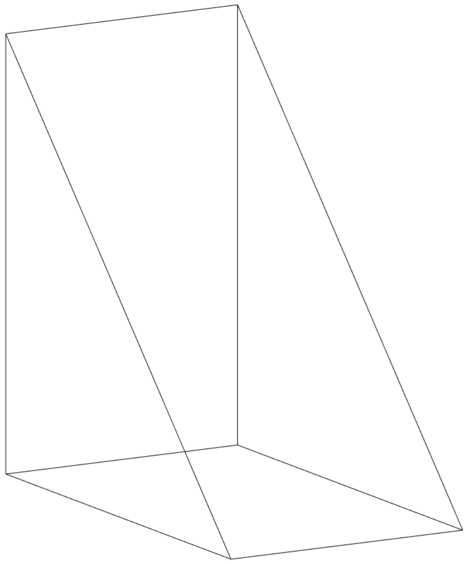


1959
Hubel & Wiesel

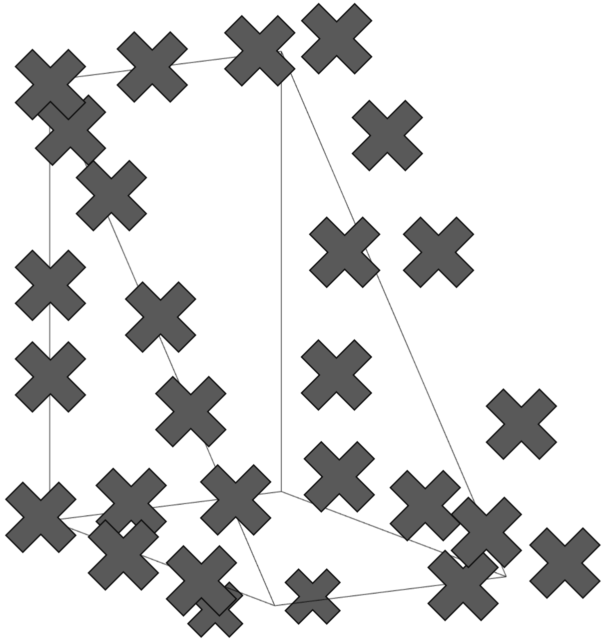
Larry Roberts, 1963



(a) Original picture



(b) Differentiated picture



(c) Feature points selected

1959
Hubel & Wiesel

1963
Roberts

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

PROJECT MAC

Artificial Intelligence Group July 7, 1966

Vision Memo. No. 100.

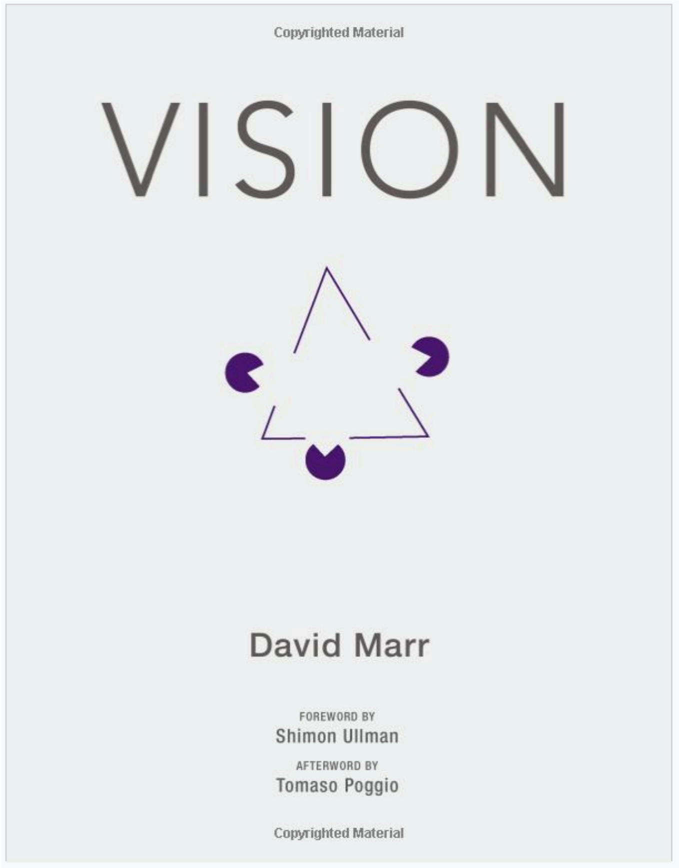
THE SUMMER VISION PROJECT

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".

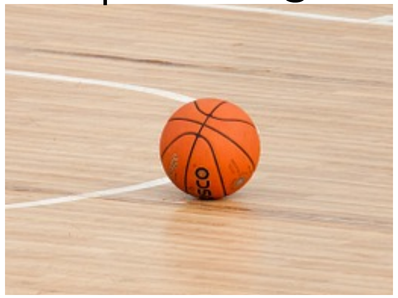
1959
Hubel & Wiesel

1963
Roberts



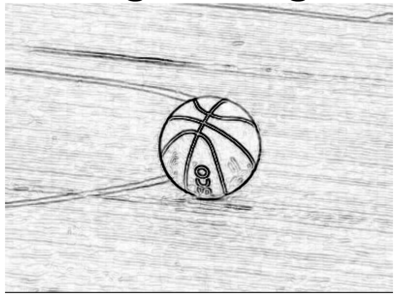
1959 Hubel & Wiesel	1963 Roberts	1970s David Marr

Input image

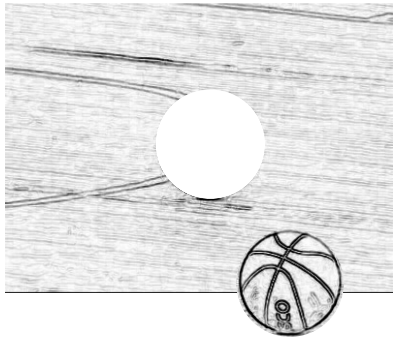


This image is CC0 1.0 public domain

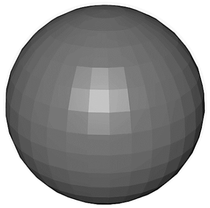
Edge image



2 ½-D sketch



3-D model

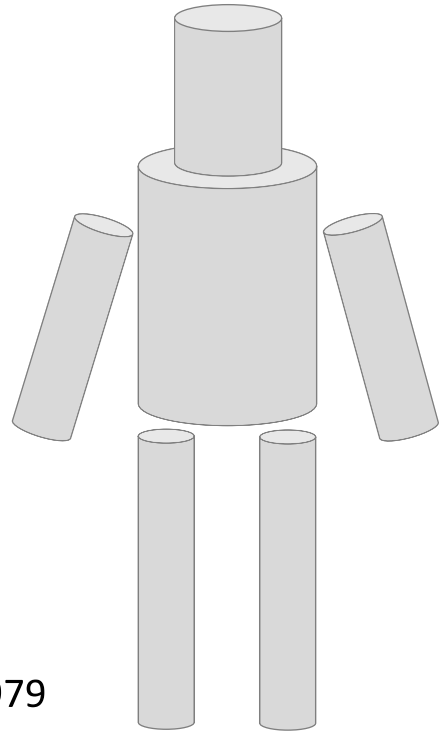


This image is CC0 1.0 public domain

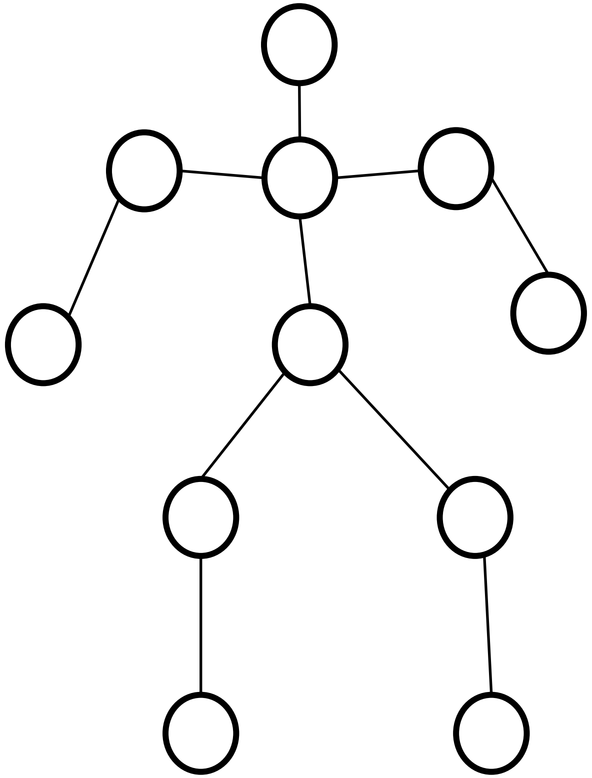
Input Image	Primal Sketch	2 ½-D Sketch	3-D Model Representation
Perceived intensities	Zero crossings, blobs, edges, bars, ends, virtual lines, groups, curves boundaries	Local surface orientation and discontinuities in depth and in surface orientation	3-D models hierarchically organized in terms of surface and volumetric primitives

Stages of Visual Representation, David Marr, 1970s

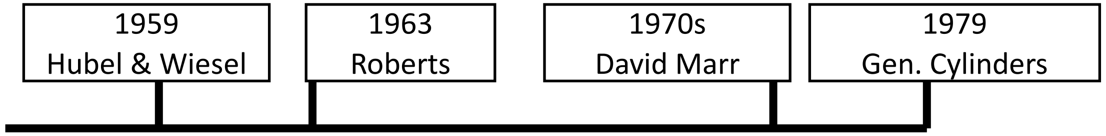
Recognition via Parts (1970s)



Generalized Cylinders,
Brooks and Binford, 1979



Pictorial Structures,
Fischler and Elshlager, 1973



Recognition via Edge Detection (1980s)

1959 Hubel & Wiesel	1963 Roberts	1970s David Marr	1979 Gen. Cylinders	1986 Canny

John Canny, 1986
David Lowe, 1987

Recognition via Grouping (1990s)

1959 Hubel & Wiesel | 1963 Roberts | 1970s David Marr | 1979 Gen. Cylinders | 1986 Canny | AI Winter | 1997 Norm. Cuts

Normalized Cuts, Shi and Malik, 1997

Recognition via Matching (2000s)

Image is public domain

Image is public domain

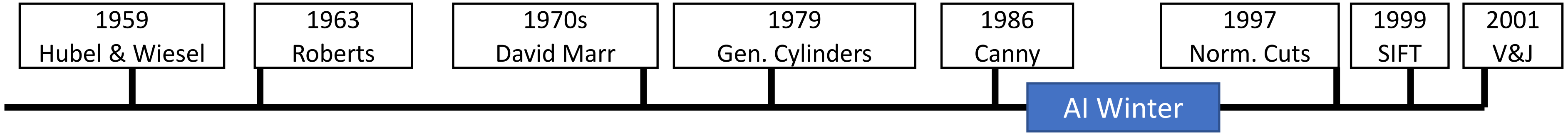
1959 Hubel & Wiesel | 1963 Roberts | 1970s David Marr | 1979 Gen. Cylinders | 1986 Canny | AI Winter | 1997 Norm. Cuts | 1999 SIFT

SIFT, David Lowe, 1999

Face Detection

Viola and Jones, 2001

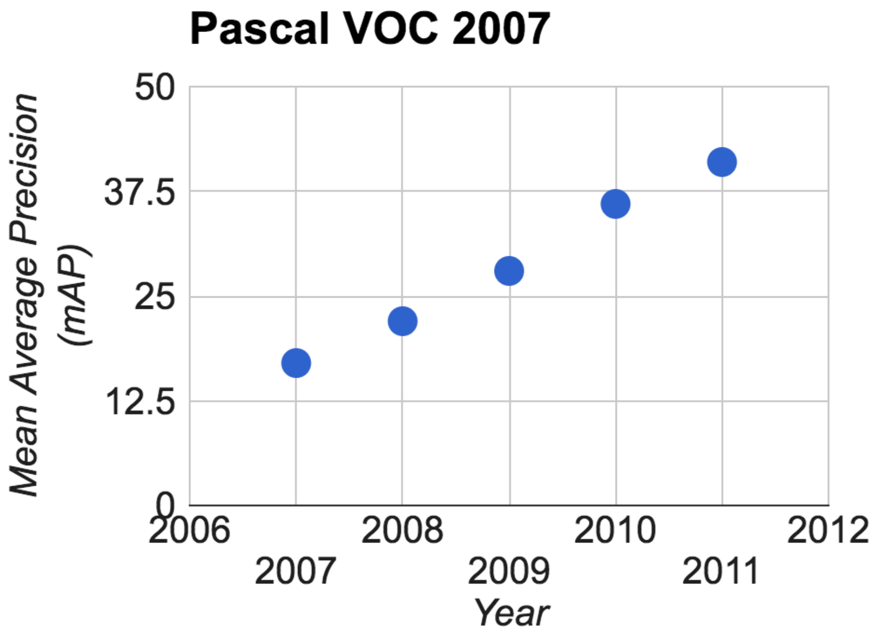
One of the first successful applications of machine learning to vision



PASCAL Visual Object Challenge

Image is CC0 1.0 public domain

Image is CC0 1.0 public domain



1959 Hubel & Wiesel	1963 Roberts	1970s David Marr	1979 Gen. Cylinders	1986 Canny	1997 Norm. Cuts	1999 SIFT	2001 V&J	2001 PASCAL

AI Winter

IMAGENET Large Scale Visual Recognition Challenge

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

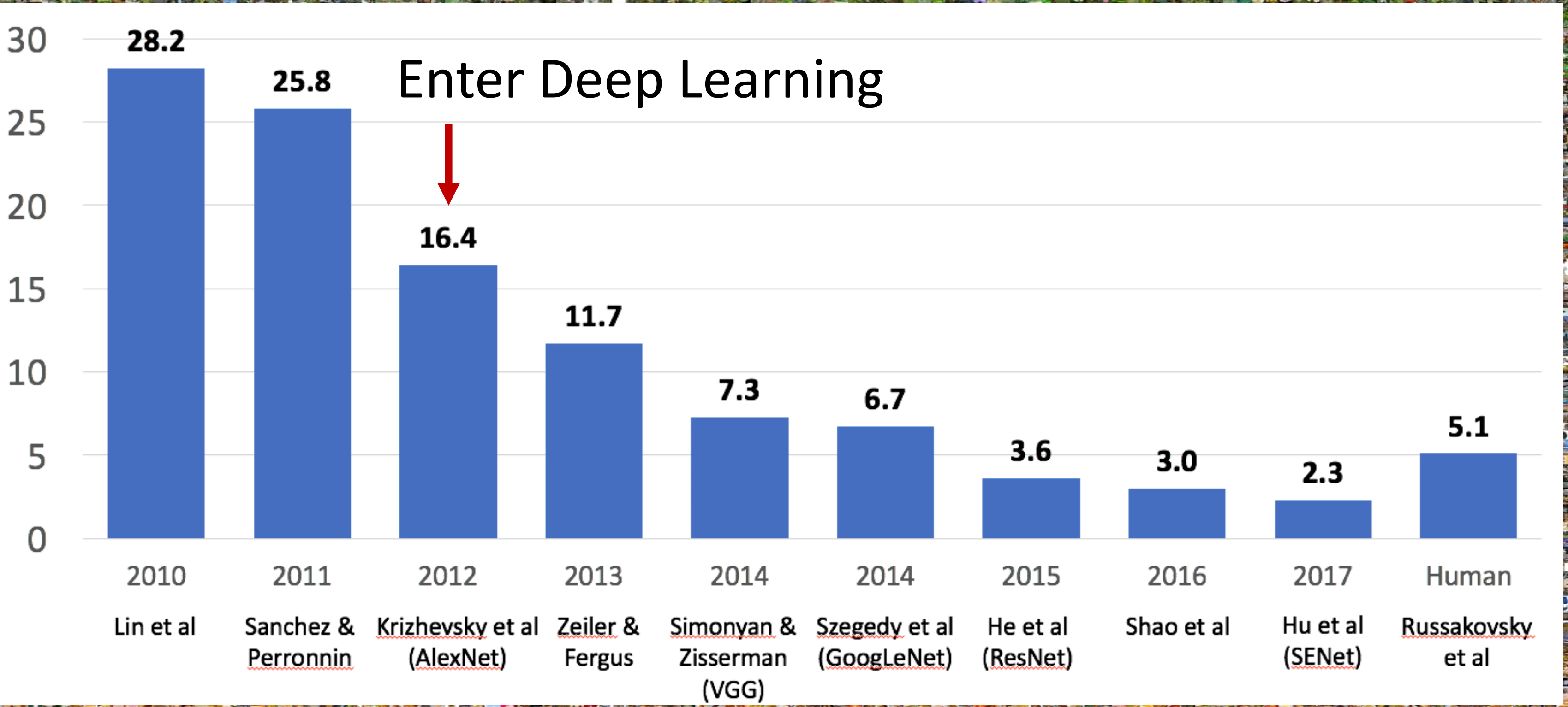
Output:
Scale
T-shirt
<u>Steel drum</u>
Drumstick
Mud turtle

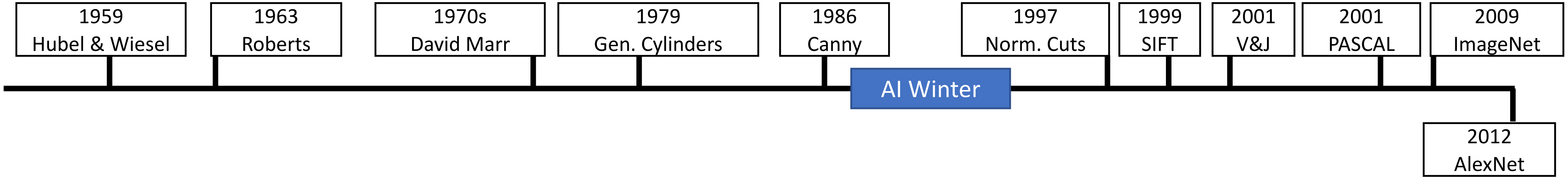
Deng et al, 2009
Russakovsky et al. IJCV 2015

1959	1963	1970s	1979	1986	1997	1999	2001	2001	2009
Hubel & Wiesel	Roberts	David Marr	Gen. Cylinders	Canny	Norm. Cuts	SIFT	V&J	PASCAL	ImageNet

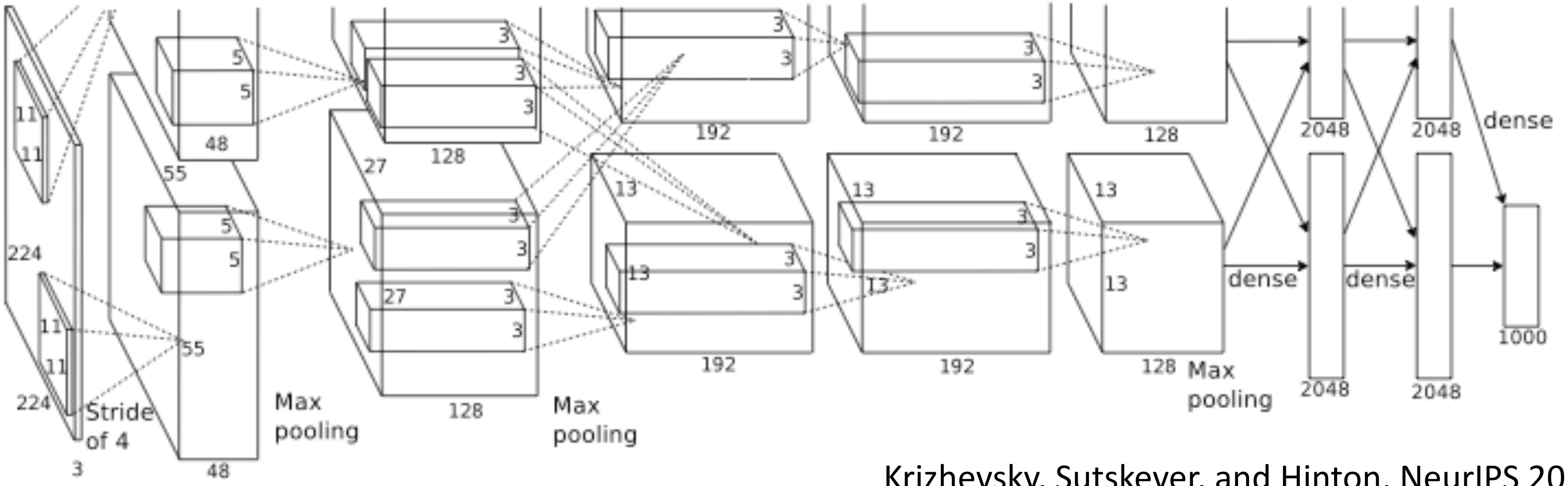
AI Winter

IMAGENET Large Scale Visual Recognition Challenge

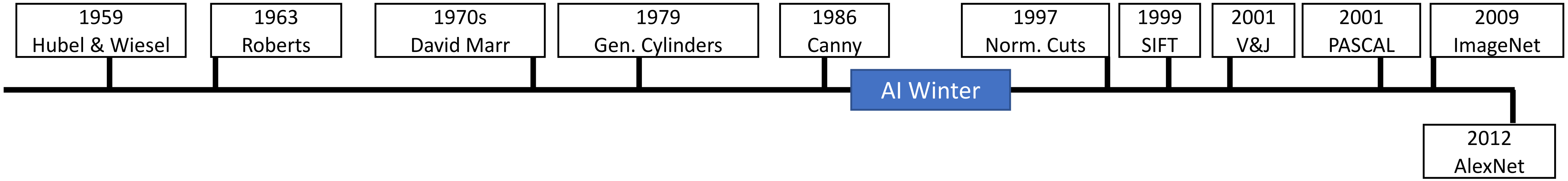




AlexNet: Deep Learning Goes Mainstream



Krizhevsky, Sutskever, and Hinton, NeurIPS 2012



Perceptron

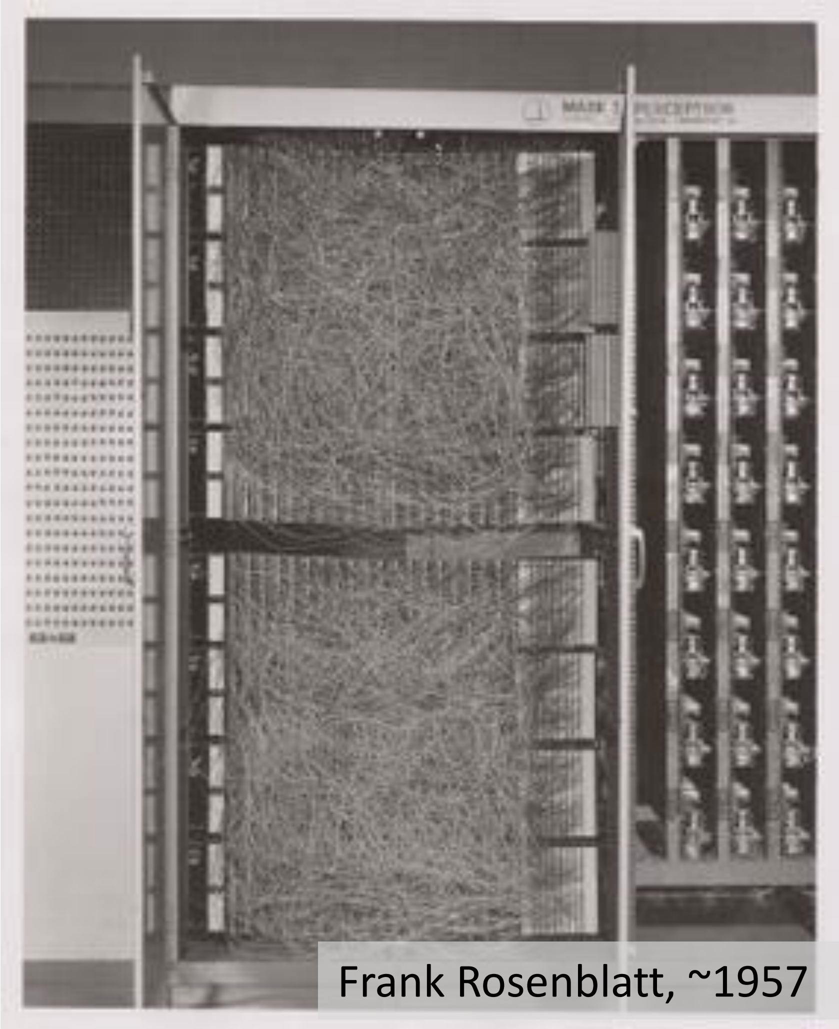
One of the earliest algorithms that could learn from data

Implemented in hardware! Weights stored in potentiometers, updated with electric motors during learning

Connected to a camera that used 20x20 cadmium sulfide photocells to make a 400-pixel image

Could learn to recognize letters of the alphabet

Today we would recognize it as a **linear classifier**

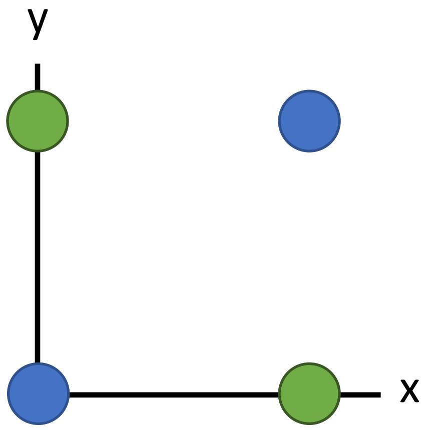


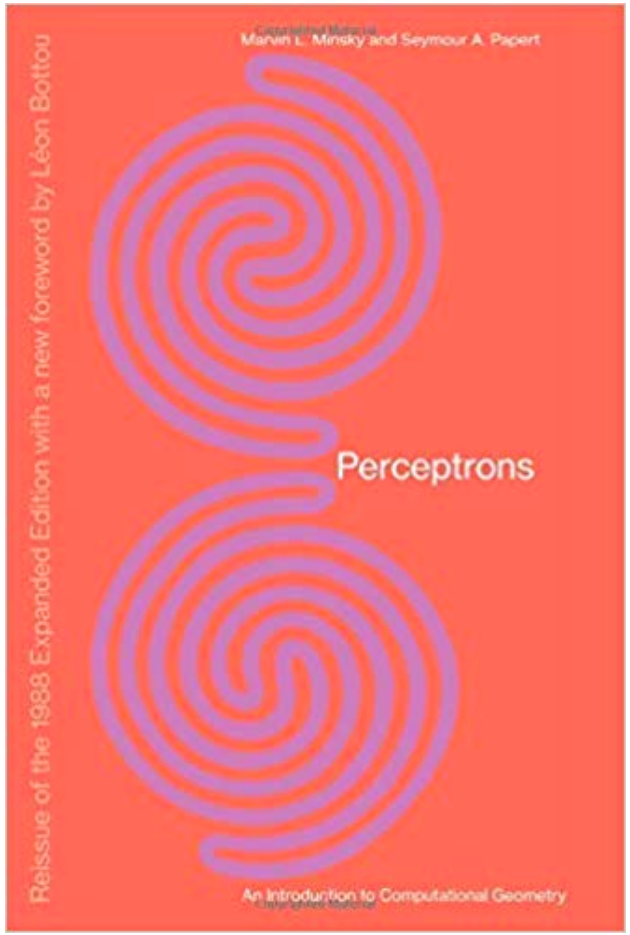
Frank Rosenblatt, ~1957

1959 Hubel & Wiesel
1963 Roberts
1970s David Marr
1979 Gen. Cylinders
1986 Canny
AI Winter
1997 Norm. Cuts
1999 SIFT
2001 V&J
2001 PASCAL
2009 ImageNet
1958 Perceptron
2012 AlexNet

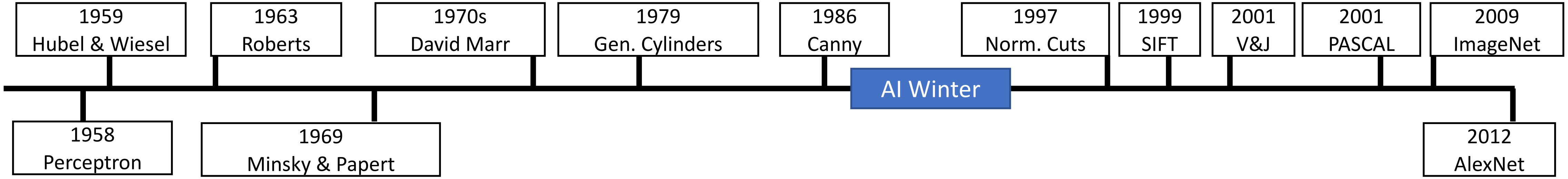
Minsky and Papert, 1969

X	Y	F(x,y)
0	0	0
0	1	1
1	0	1
1	1	0





Showed that Perceptrons could not learn the XOR function
Caused a lot of disillusionment in the field

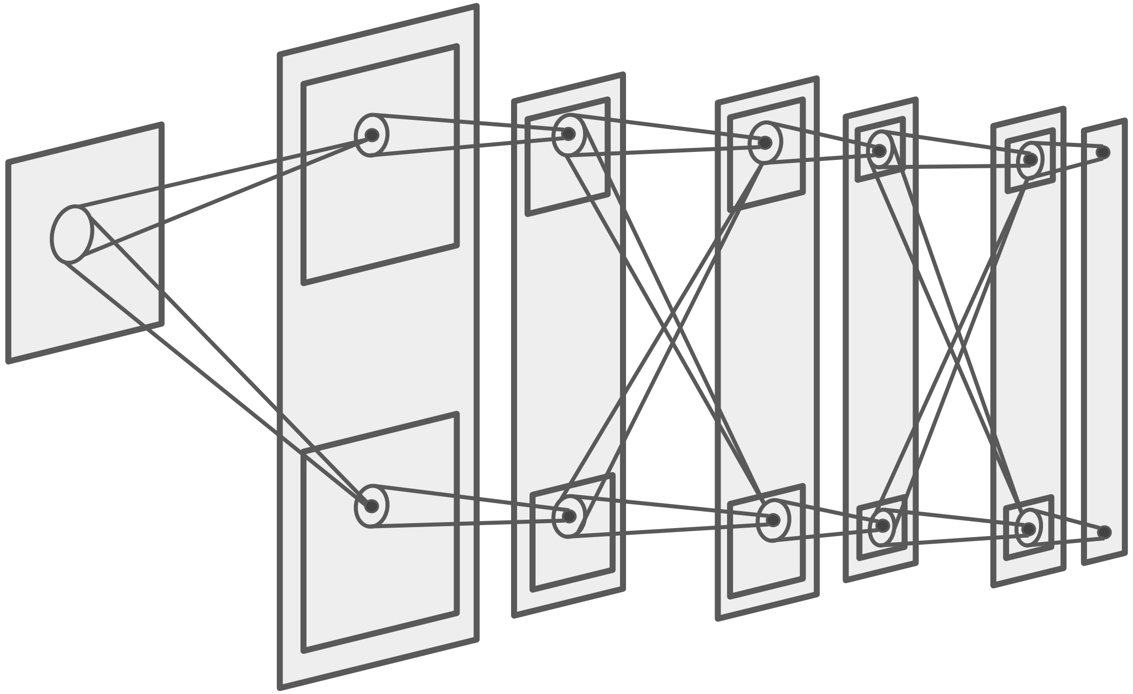


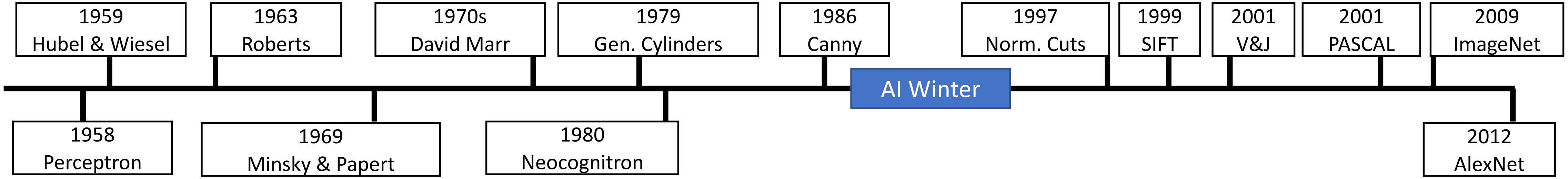
Neocognitron: Fukushima, 1980

Computational model the visual system, directly inspired by Hubel and Wiesel's hierarchy of complex and simple cells

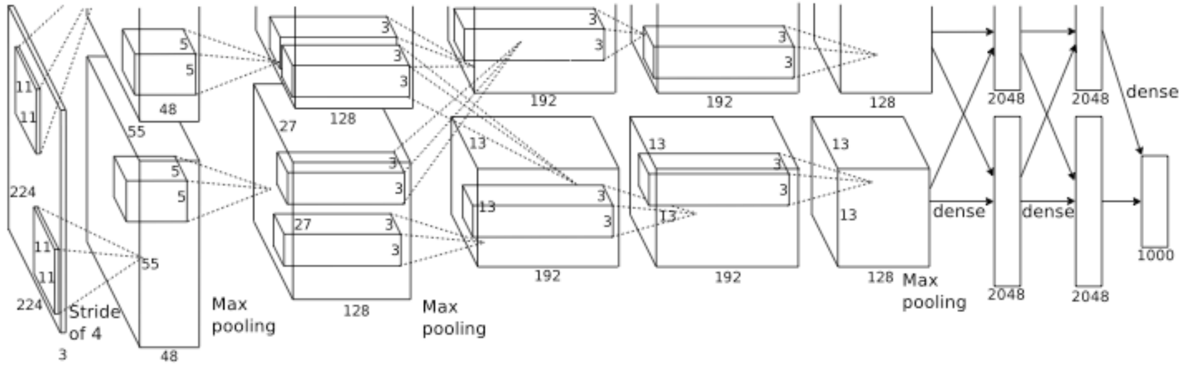
Interleaved simple cells (convolution) and complex cells (pooling)

No practical training algorithm

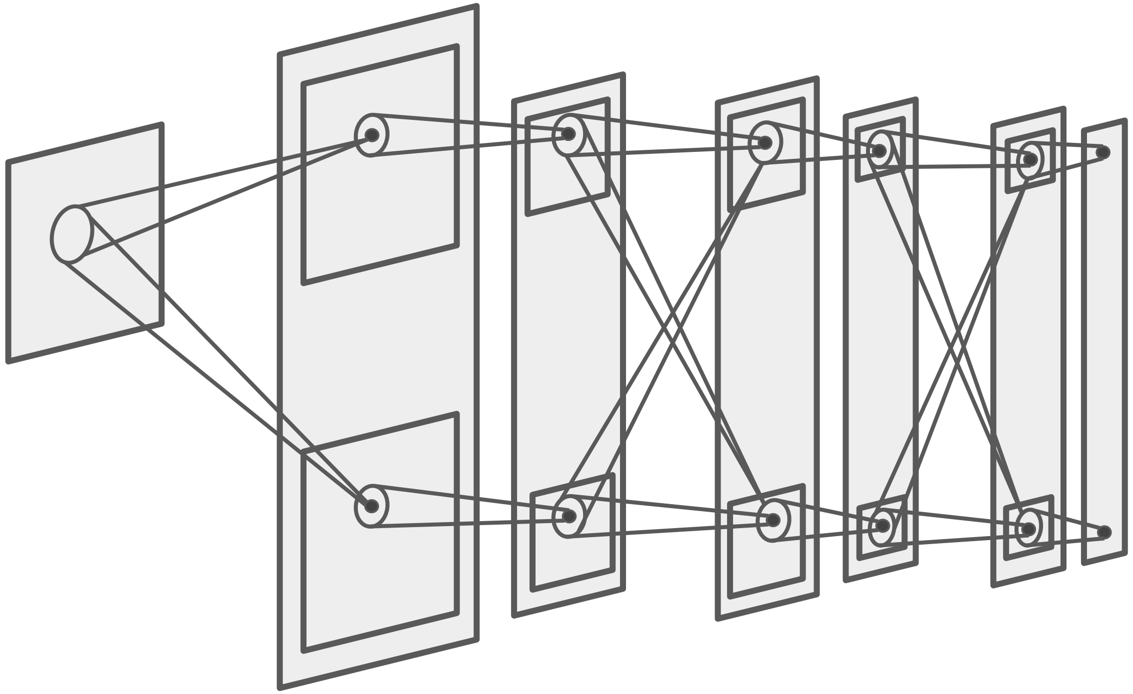




Neocognitron: Fukushima, 1980



Looks a lot like AlexNet
more than 32 years later!



1959 Hubel & Wiesel

1963 Roberts

1970s David Marr

1979 Gen. Cylinders

1986 Canny

1997 Norm. Cuts

1999 SIFT

2001 V&J

2001 PASCAL

2009 ImageNet

AI Winter

1958 Perceptron

1969 Minsky & Papert

1980 Neocognitron

2012 AlexNet

Backprop: Rumelhart, Hinton, and Williams, 1986

Introduced backpropagation for computing gradients in neural networks

Successfully trained perceptrons with multiple layers

$$\frac{\partial E_p}{\partial w_{ji}} = \frac{\partial E_p}{\partial o_{pj}} \frac{\partial o_{pj}}{\partial w_{ji}}$$

recognizable math

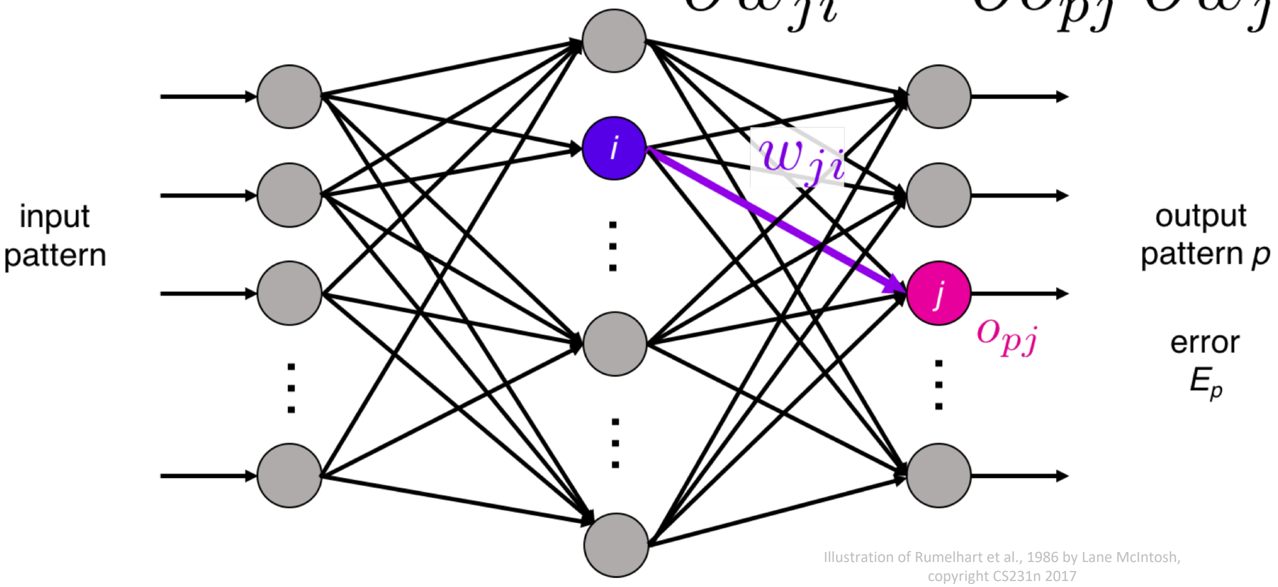


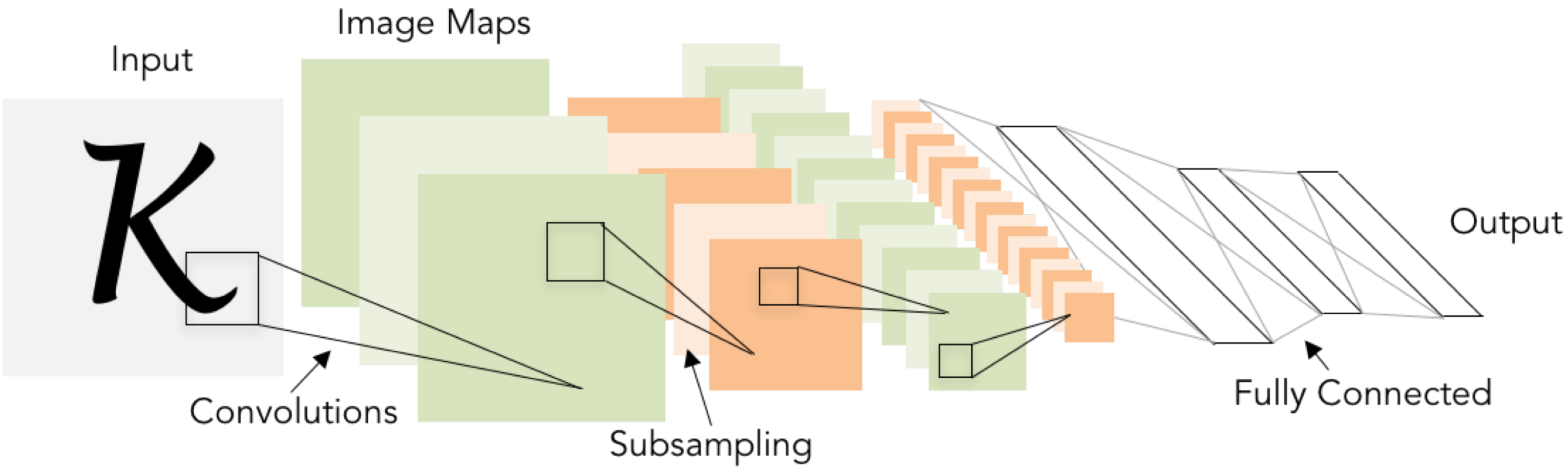
Illustration of Rumelhart et al., 1986 by Lane McIntosh, copyright CS231n 2017

1959 Hubel & Wiesel | 1963 Roberts | 1970s David Marr | 1979 Gen. Cylinders | 1986 Canny | 1997 Norm. Cuts | 1999 SIFT | 2001 V&J | 2001 PASCAL | 2009 ImageNet

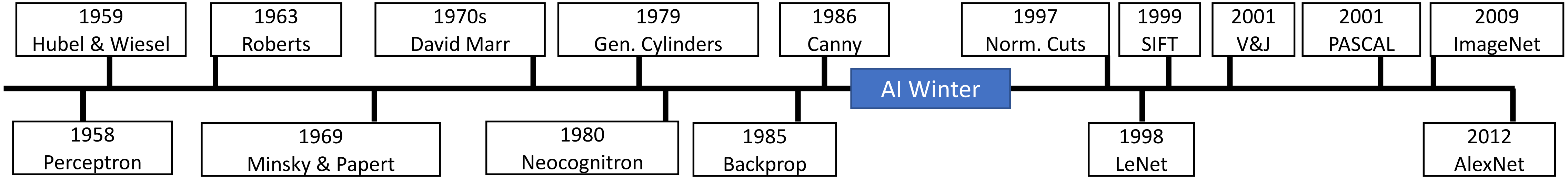
AI Winter

1958 Perceptron | 1969 Minsky & Papert | 1980 Neocognitron | 1985 Backprop | 2012 AlexNet

Convolutional Networks: LeCun et al, 1998



Applied backprop algorithm to a Neocognitron-like architecture
Learned to recognize handwritten digits
Was deployed in a commercial system by NEC, processed handwritten checks
Very similar to our modern convolutional networks!

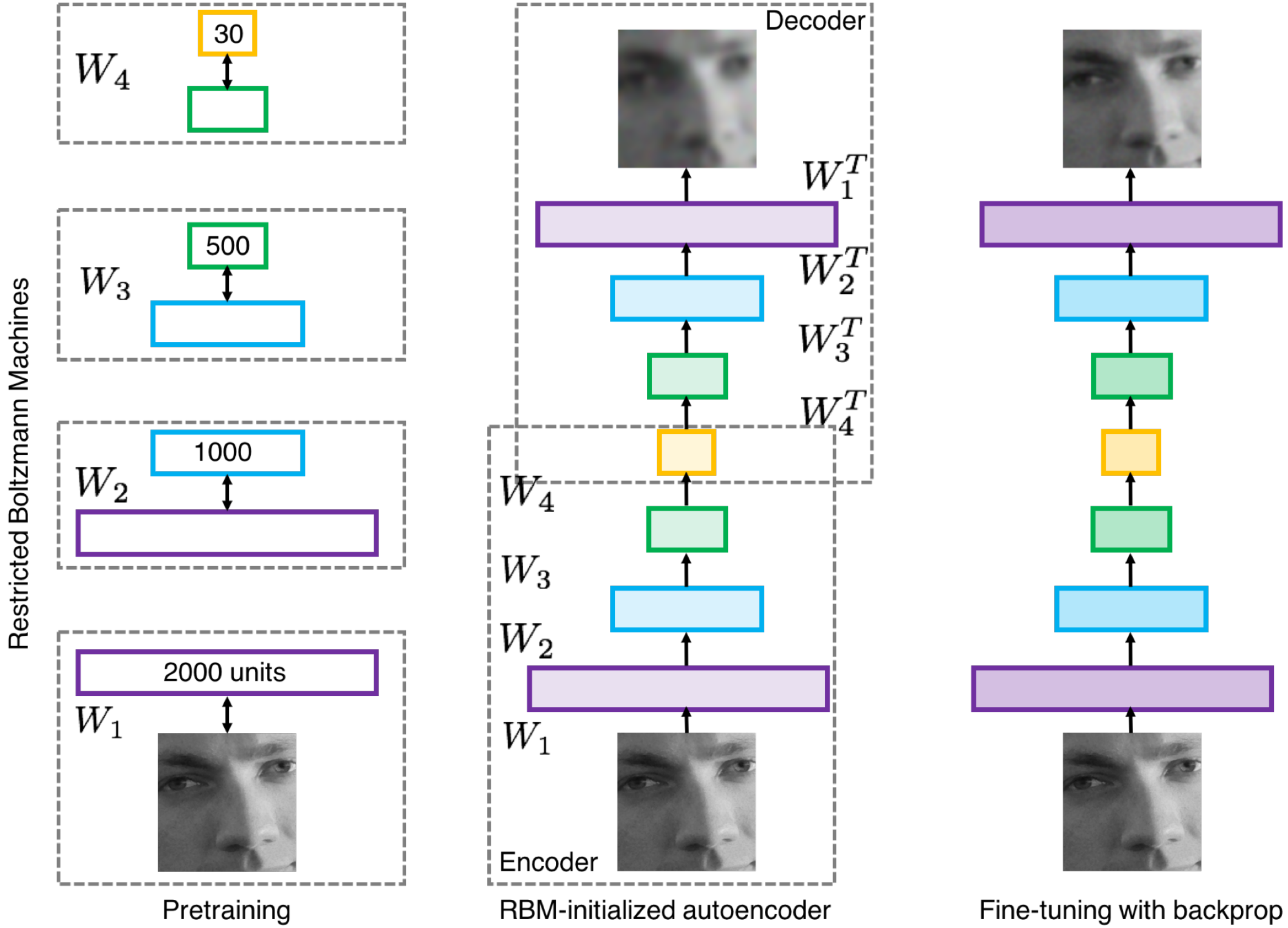


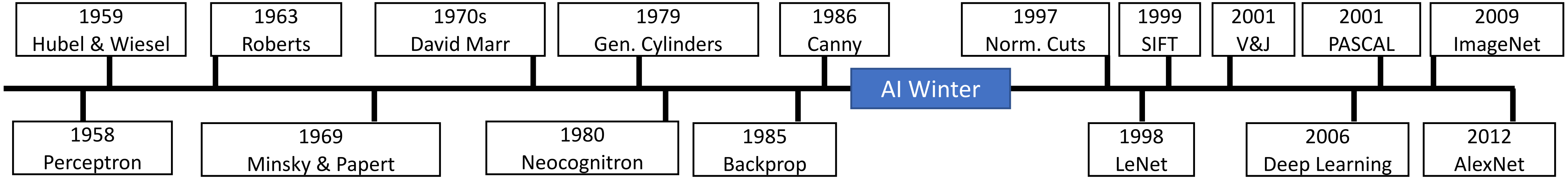
2000s: “Deep Learning”

People tried to train neural networks that were deeper and deeper

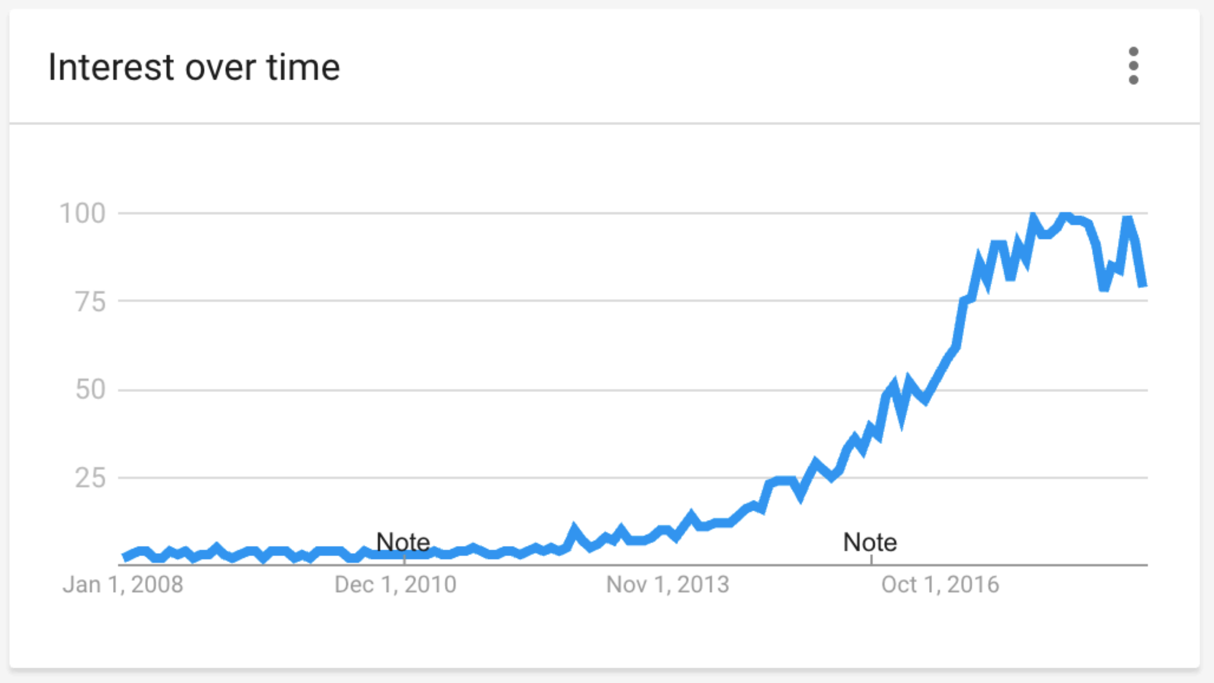
Not a mainstream research topic at this time

Hinton and Salakhutdinov, 2006
Bengio et al, 2007
Lee et al, 2009
Glorot and Bengio, 2010

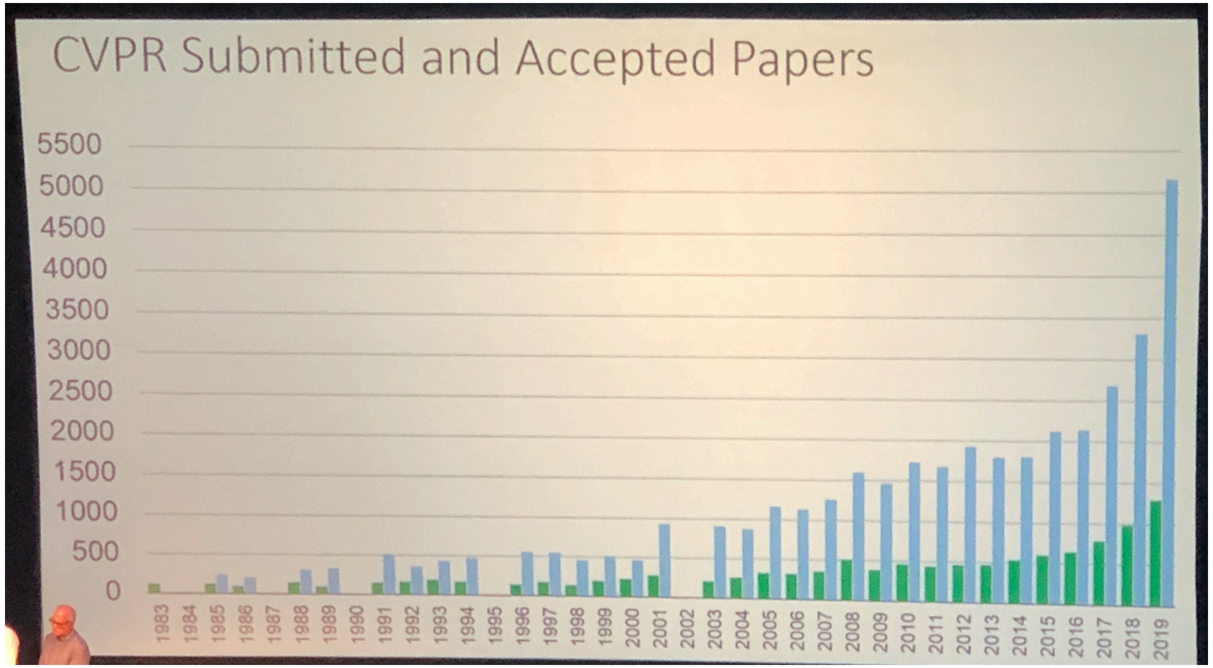




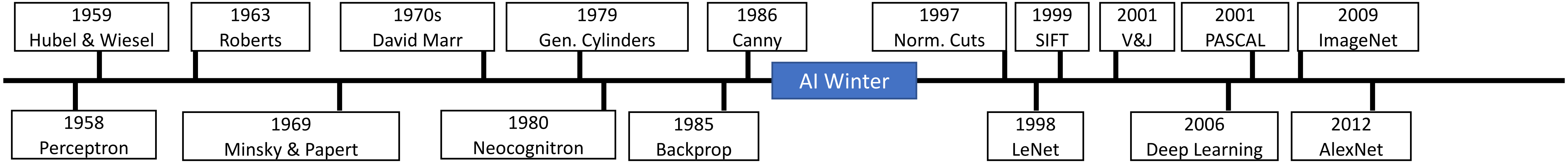
2012 to Present: Deep Learning Explosion



Google Trends: “Deep Learning”



Publications at top Computer Vision conference



2012 to Present: ConvNets are everywhere

Image Classification

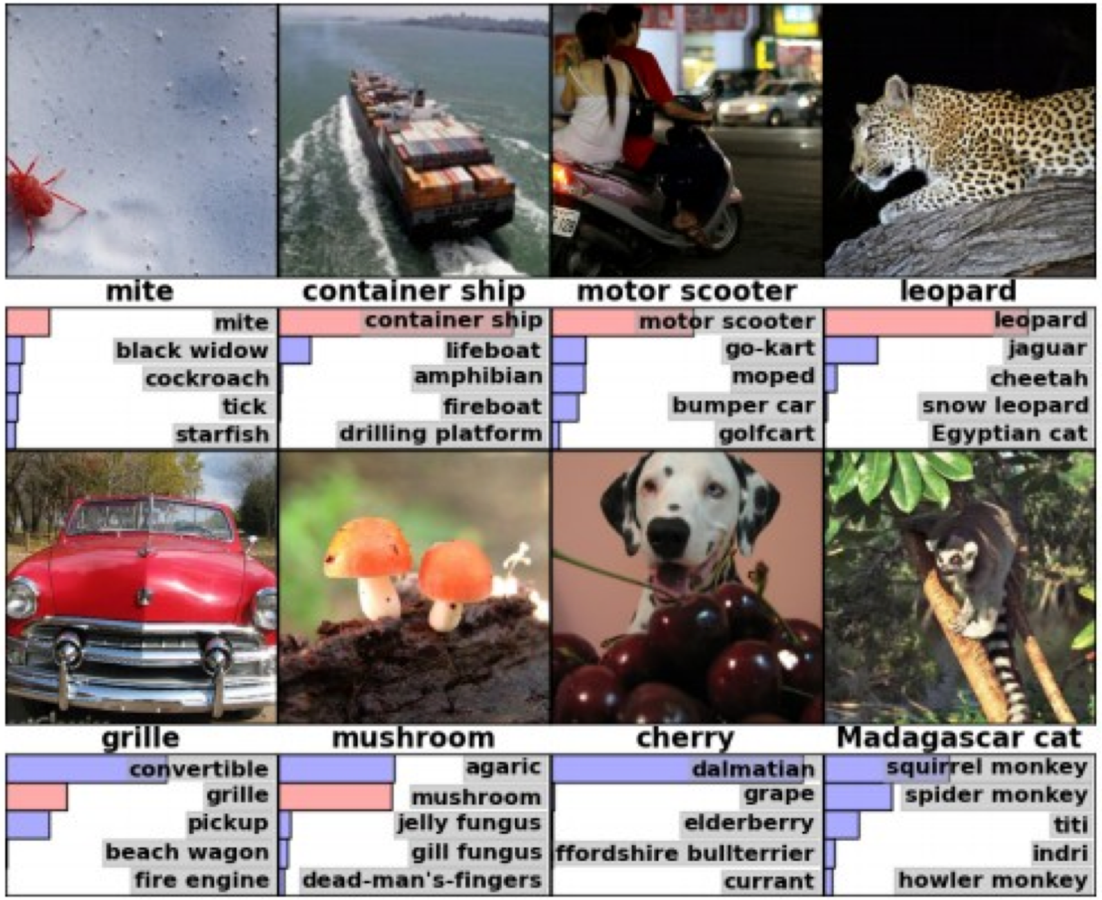
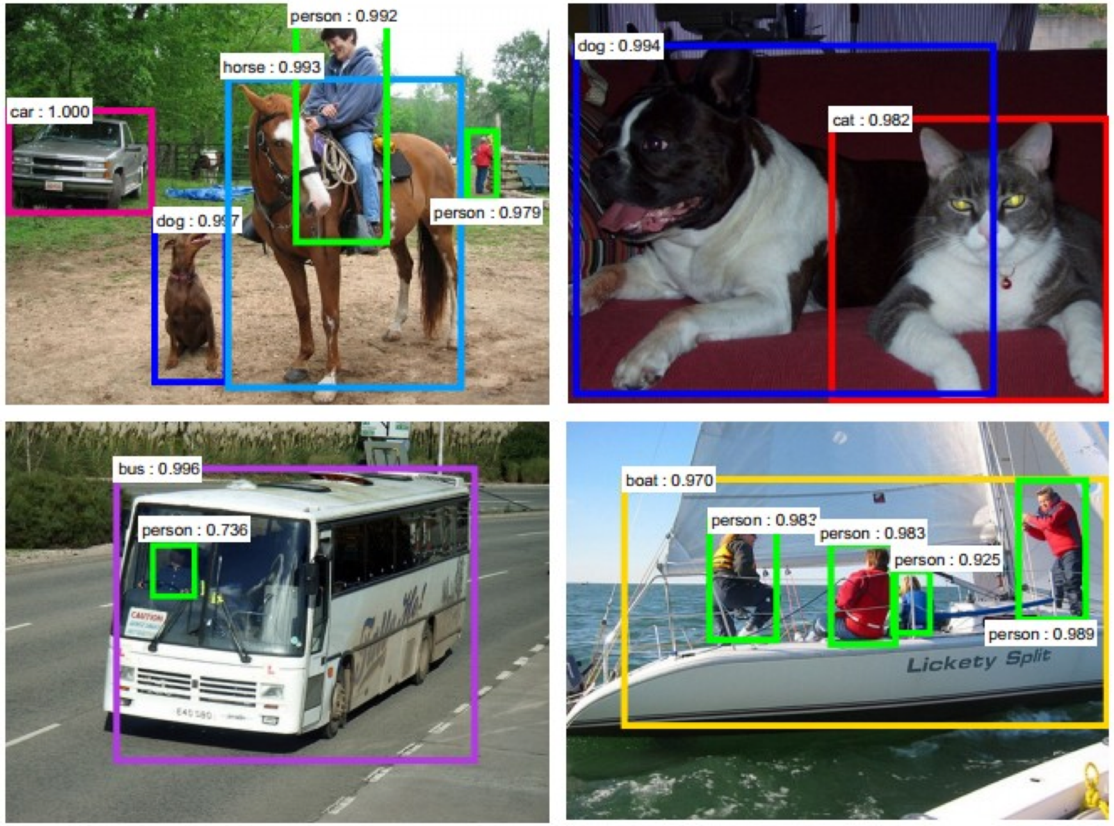


Image Retrieval

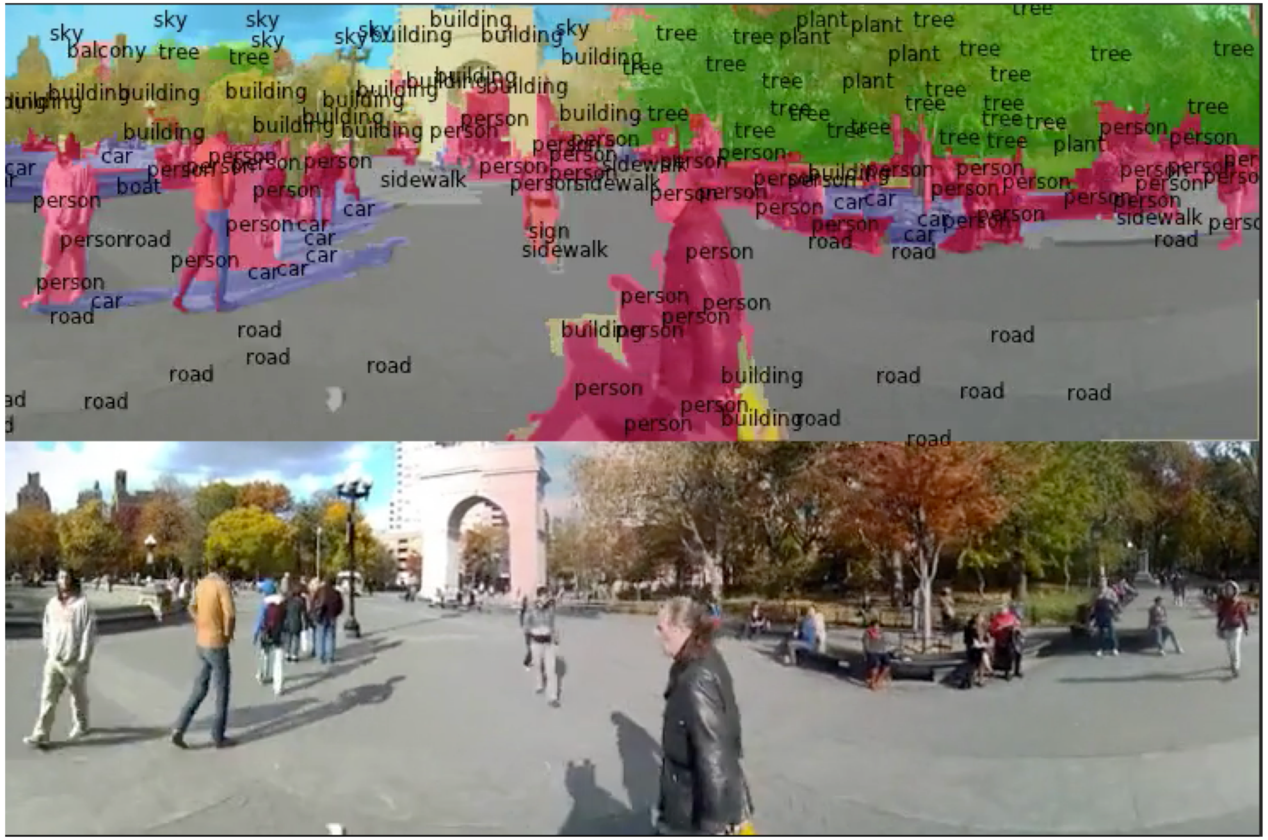
2012 to Present: ConvNets are everywhere

Object Detection



Ren, He, Girshick, and Sun, 2015

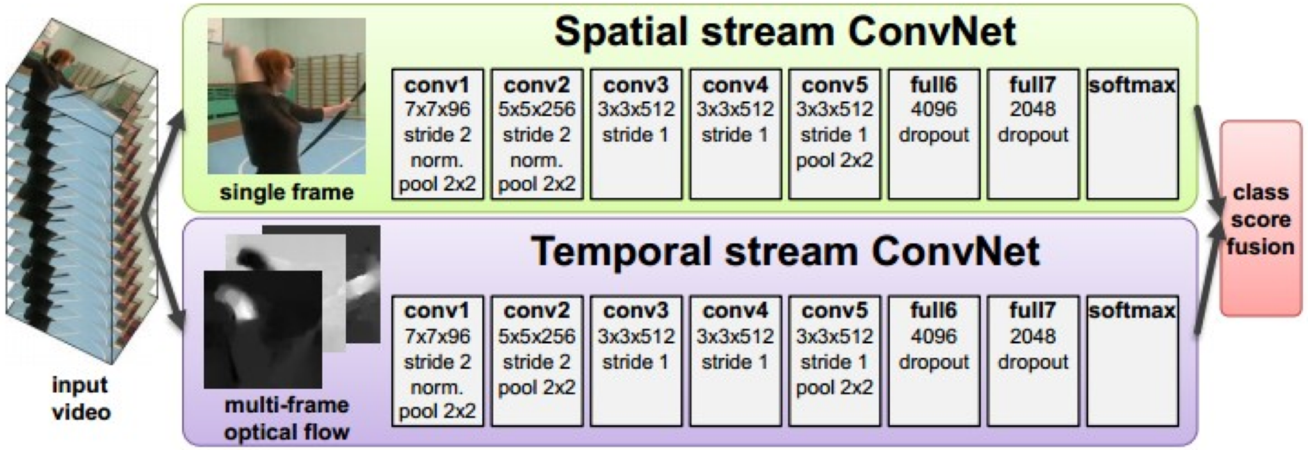
Image Segmentation



Fabaret et al, 2012

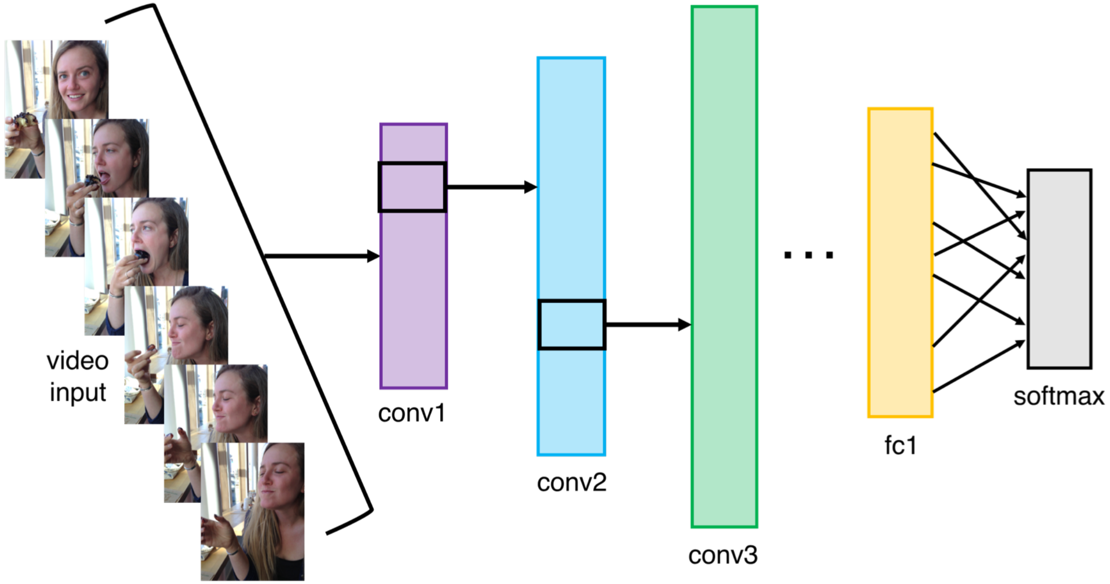
2012 to Present: ConvNets are everywhere

Video Classification



Simonyan et al, 2014

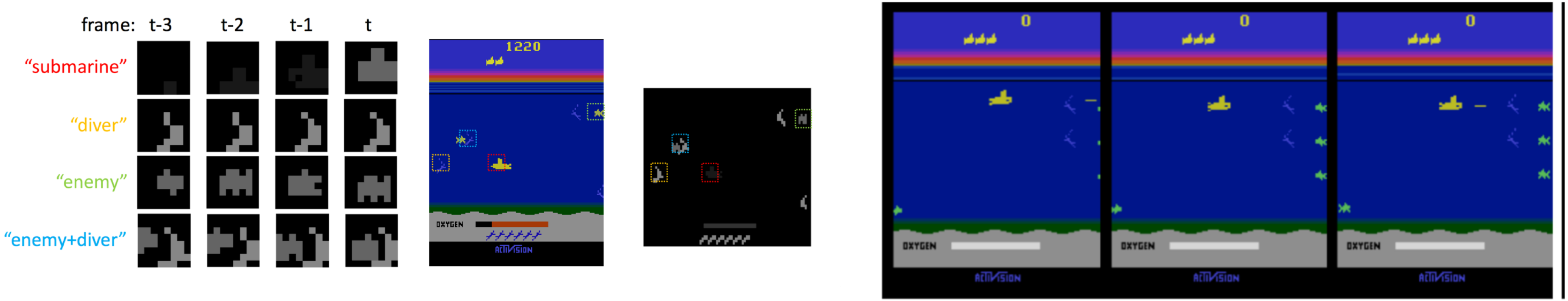
Activity Recognition



2012 to Present: ConvNets are everywhere

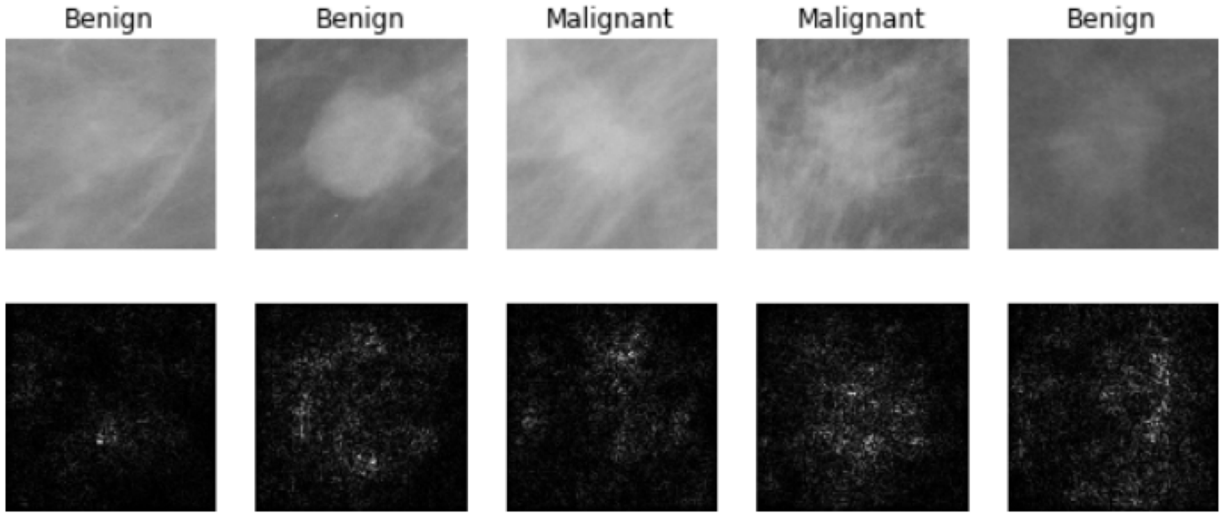
Pose Recognition (Toshev and Szegedy, 2014)

Playing Atari games (Guo et al, 2014)



2012 to Present: ConvNets are everywhere

Medical Imaging



Levy et al, 2016 Figure reproduced with permission

Galaxy Classification

Dieleman et al, 2014

From left to right: public domain by NASA, usage permitted by ESA/Hubble, public domain by NASA, and public domain.

Whale recognition

[Kaggle Challenge]

This image by Christin Khan is in the public domain and originally came from the U.S. NOAA.

2012 to Present: ConvNets are everywhere

Image Captioning

Vinyals et al, 2015
Karpathy and Fei-Fei, 2015

A white teddy bear sitting in the grass

A man in a baseball uniform throwing a ball

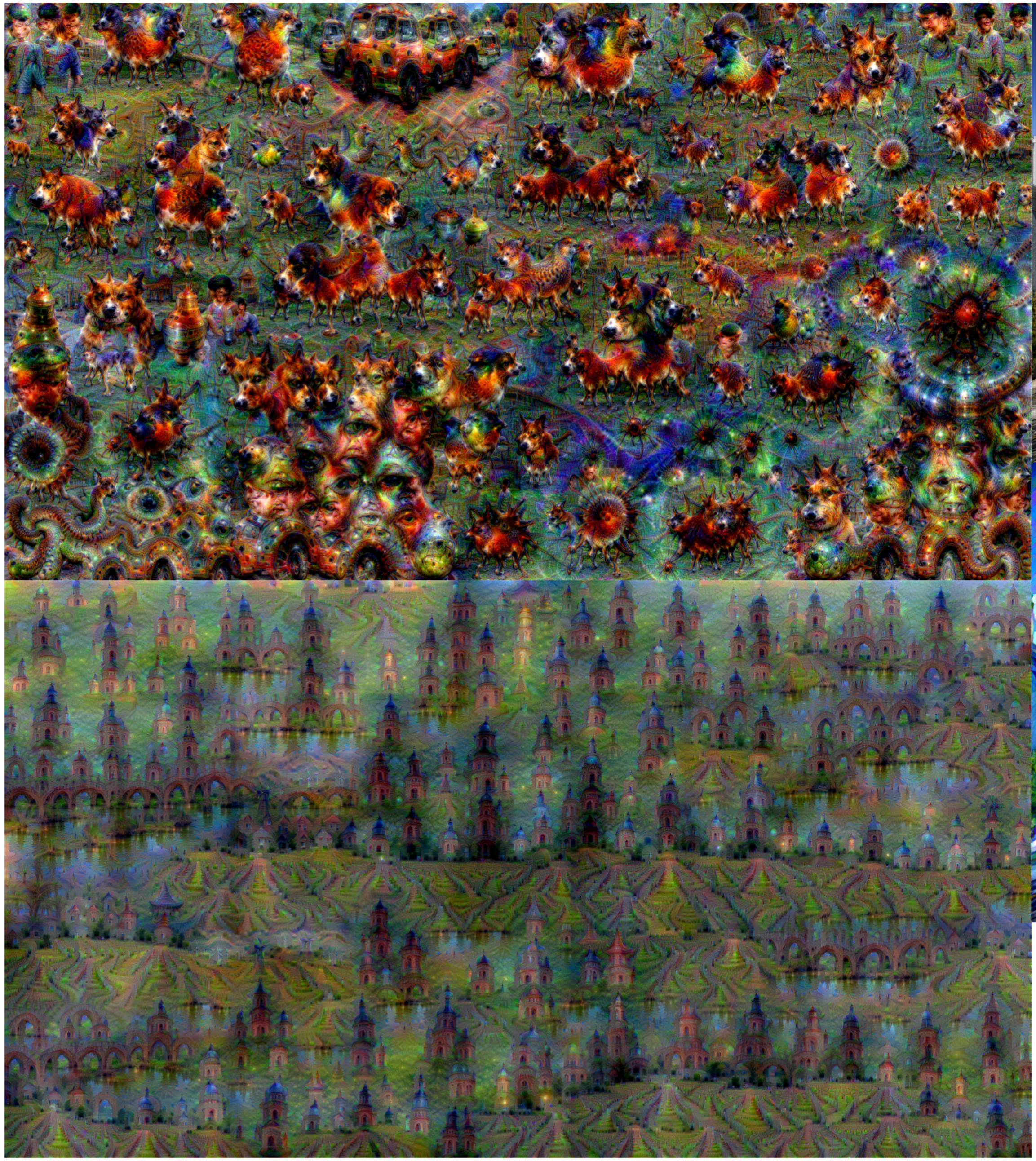
A woman is holding a cat in her hand

A man riding a wave on top of a surfboard

A cat sitting on a suitcase on the floor

A woman standing on a beach holding a surfboard

Captions generated by Justin Johnson using Neuraltalk2

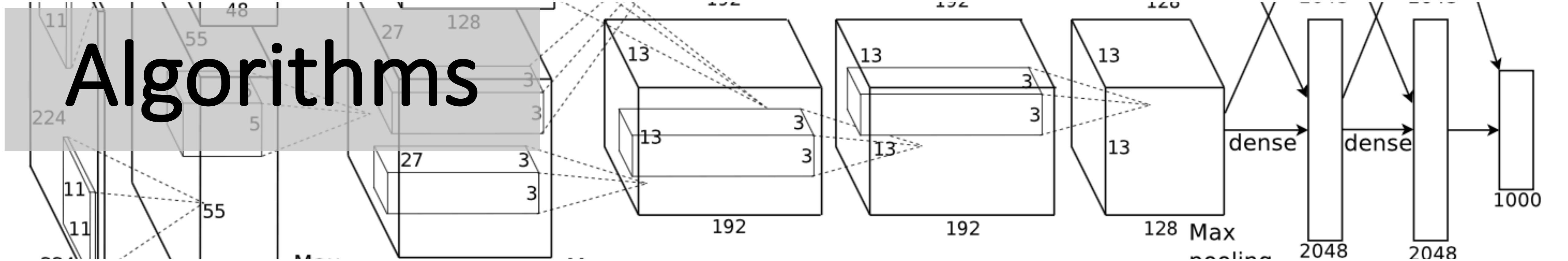


Figures copyright Justin Johnson, 2015. Reproduced with permission. Generated using the Inceptionism approach from a blog post by Google Research.

Original image is CC0 public domain
Starry Night and Tree Roots by Van Gogh are in the public domain
Bokeh image is in the public domain
Stylized images copyright Justin Johnson, 2017;
reproduced with permission

Mordvinsev et al, 2015
Gatys et al, 2016

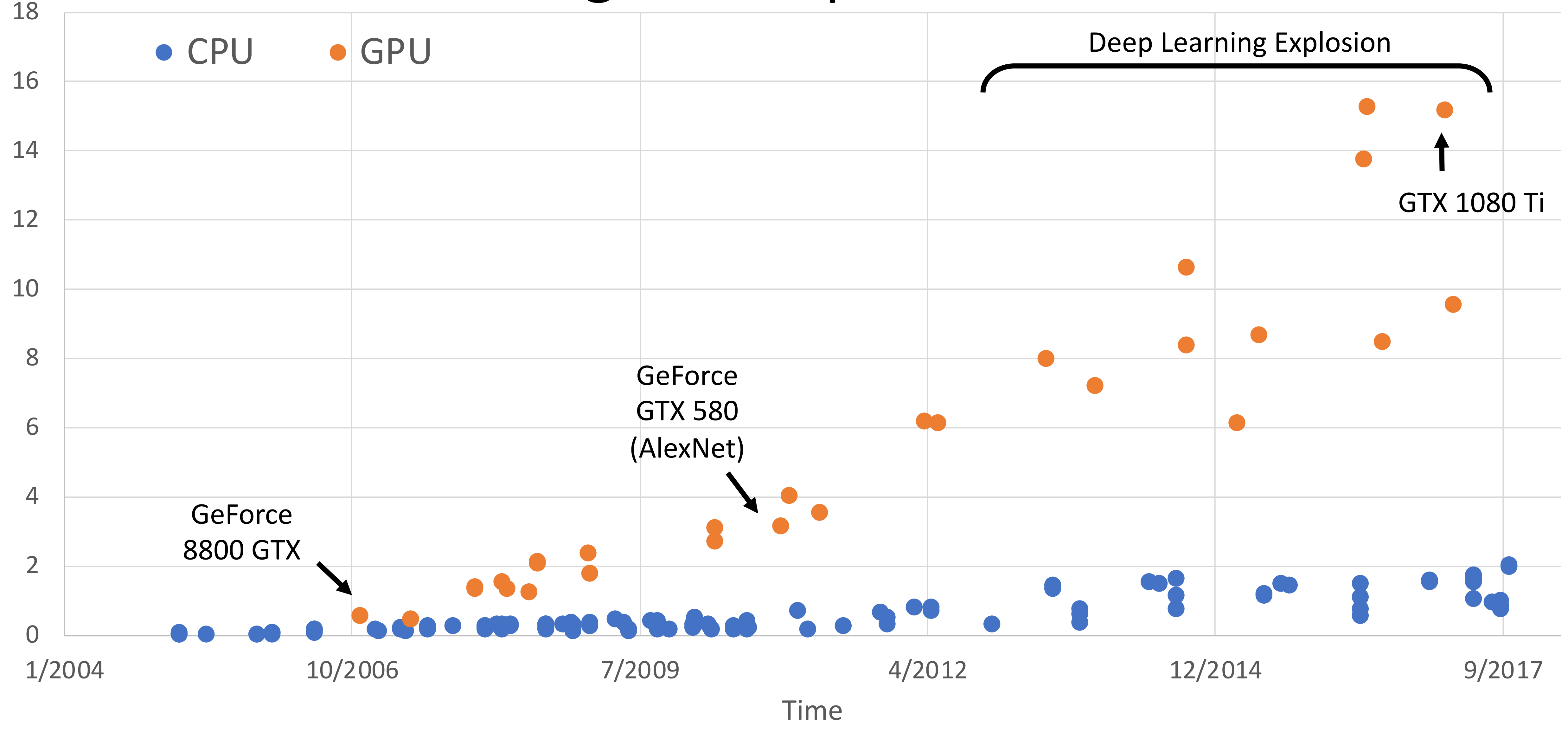
Algorithms



Data

Computation

GigaFLOPs per Dollar



2018 Turing Award

- 1958 Perceptron
- 1959 Hubel & Wiesel
- 1963 Roberts
- 1969 Minsky & Papert
- 1970s David Marr
- 1979 Gen. Cylinders
- 1980 Neocognitron
- 1985 Backprop
- 1986 Canny
- AI Winter
- 1997 Norm. Cuts
- 1998 LeNet
- 1999 SIFT
- 2001 V&J
- 2001 PASCAL
- 2006 Deep Learning
- 2009 ImageNet
- 2012 AlexNet
- 2018 Turing Award

Despite our success, computer vision still has a long way to go…

Example credit: Andrej Karpathy

Computer Vision Technology Can Better Our Lives

Today's Agenda

- A brief history of computer vision and deep learning

- Course overview and logistics

1958 Perceptron
1959 Hubel & Wiesel
1963 Roberts
1969 Minsky & Papert
1970s David Marr
1979 Gen. Cylinders
1980 Neocognitron
1985 Backprop
1986 Canny
AI Winter
1997 Norm. Cuts
1998 LeNet
1999 SIFT
2001 V&J
2001 PASCAL
2006 Deep Learning
2009 ImageNet
2012 AlexNet
2018 Turing Award

Today's Agenda

- A brief history of computer vision and deep learning
- Course overview and logistics

1958 Perceptron
1959 Hubel & Wiesel
1963 Roberts
1969 Minsky & Papert
1970s David Marr
1979 Gen. Cylinders
1980 Neocognitron
1985 Backprop
1986 Canny
AI Winter
1997 Norm. Cuts
1998 LeNet
1999 SIFT
2001 V&J
2001 PASCAL
2006 Deep Learning
2009 ImageNet
2012 AlexNet
2018 Turing Award
2019 This class

Course Staff

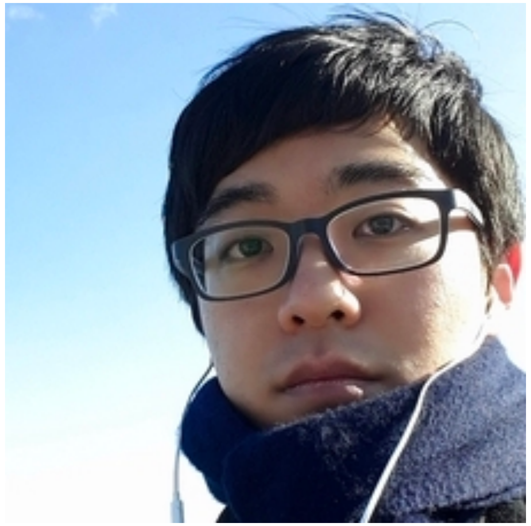
Instructor

Justin Johnson
Assistant Professor, CSE

Graduate Student Instructors

Yunseok Jang
PhD student, CSE

Video understanding,
Generative models



Kibok Lee
PhD student, CSE

Robustness,
Generalization

Luowei Zhao
PhD student, RI

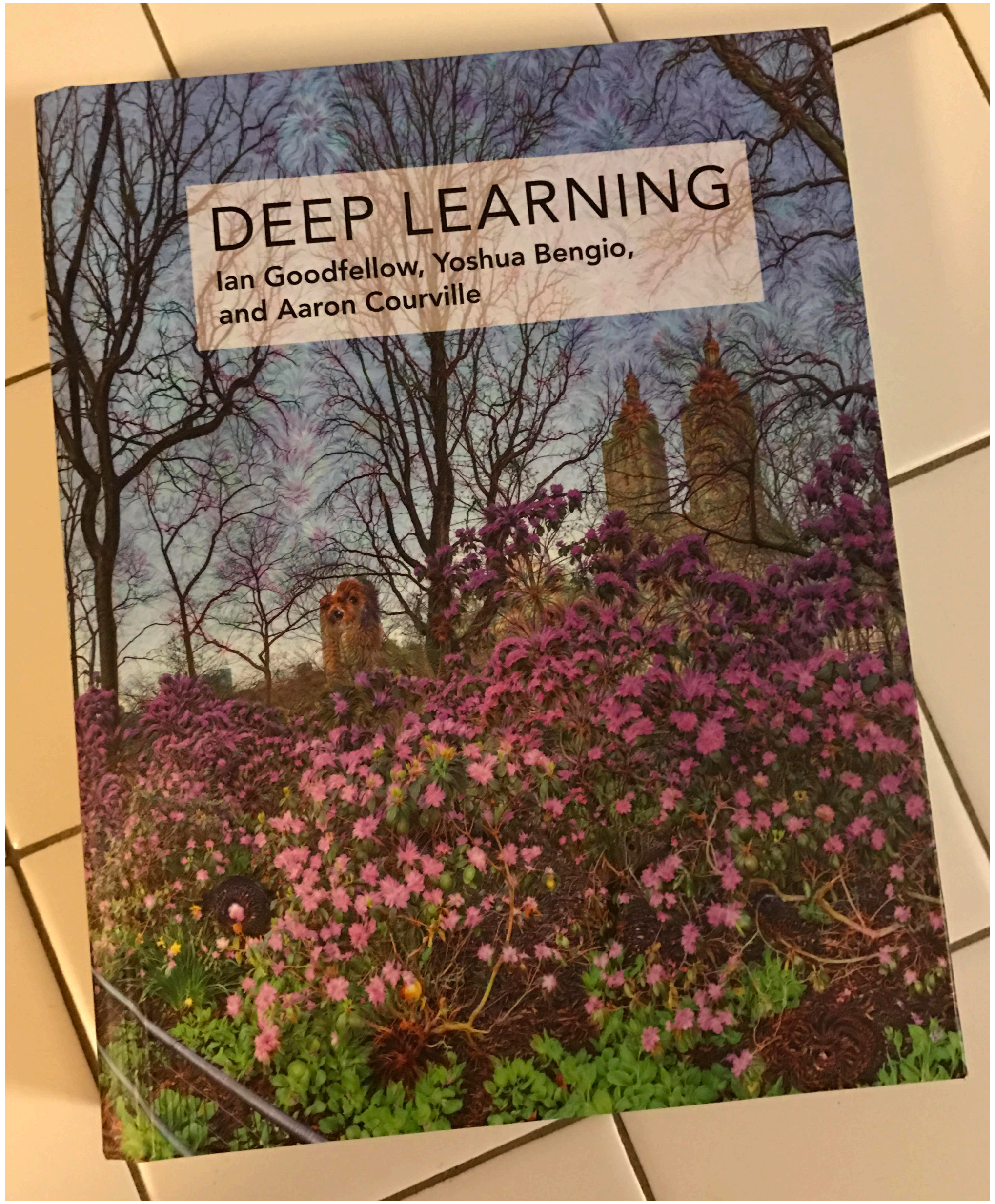
Vision & Language

How to contact us

- Course Website: https://web.eecs.umich.edu/~justincj/teaching/eecs498/
  - Syllabus, schedule, assignments, slides, lecture videos, etc
- Piazza: https://piazza.com/class/k01uvwqmf8c4nb
  - (Almost) all questions about the course should go here!
  - We will also use Piazza to communicate with you
  - Use private questions if you want to post code
- Canvas:
  - For turning in homework assignments
- Google Calendar: For office hours (starting next week)
- Email: Only for sensitive, confidential issues

Optional Textbook

- *Deep Learning* by Goodfellow, Bengio, and Courville
- Free online



Course Content and Grading

- 6 programming assignments (10% each)
  - Homework assignments will use Python, PyTorch, and Google Colab
- Midterm Exam (20%)
- Final Exam (20%)
- Late policy
  - 3 free late days to use on assignments
  - Once free late days are exhausted, 25% penalty per day

Course Content and Grading

- 6 programming assignments (10% each)
  - Homework assignments will use Python, PyTorch, and Google Colab
- Midterm Exam (20%)
- Final Exam (20%)
- Late policy
  - 3 free late days to use on assignments
  - Once free late days are exhausted, 25% penalty per day

Collaboration Policy

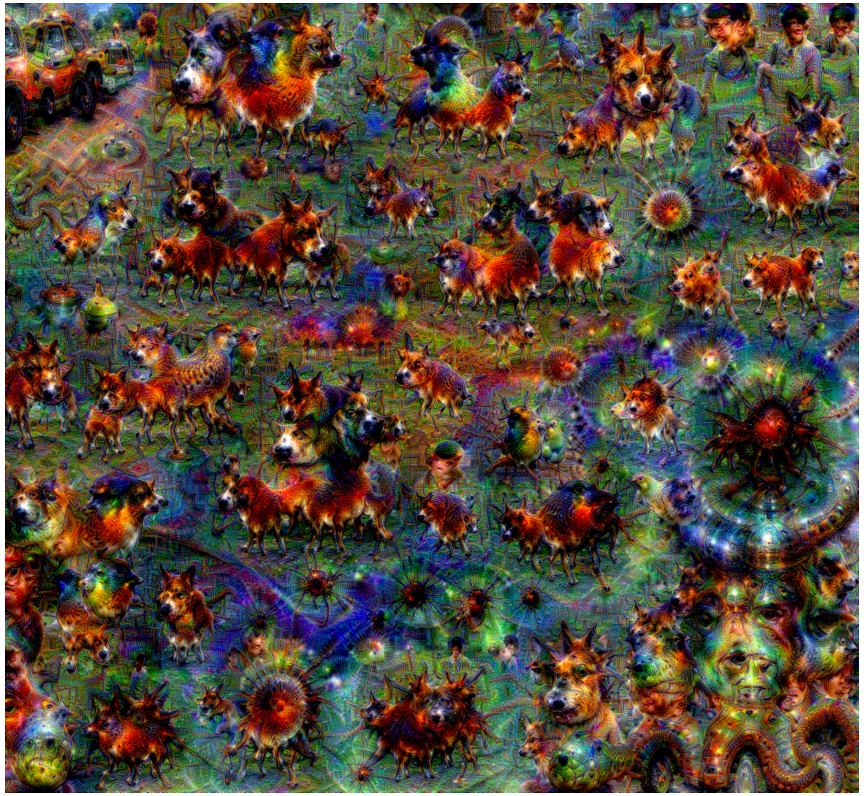
- **Rule 1**: Don't look at solutions or code that are not your own; everything you submit should be your own work
- **Rule 2**: Don't share your solution code with others; however discussing ideas or general strategies is fine and encouraged
- **Rule 3**: Indicate in your submissions anyone you worked with
- Turning in something late / incomplete is better than violating the honor code

Course Philosophy

- Thorough and Detailed.
  - This not “Learn PyTorch in 90 days”, nor “Deep Learning in 10 lines of code”
  - Understand how to write from scratch, debug, and train convolutional and other types of deep neural networks
  - We prefer to write from scratch, rather than rely on existing implementations
- Practical
  - Focus on practical techniques for training and debugging neural networks
  - Will use state-of-the-art software tools like PyTorch and TensorFlow
- State of the art
  - Most material we cover is research published in the last 5 years

Course Philosophy

- Will also cover some fun topics:
  - Image captioning (with RNNs)
  - DeepDream, Artistic Style Transfer



Course Structure

- First half: Fundamentals
  - Details of how to implement and train different types of networks
  - Fully-connected networks, convolutional networks, recurrent networks
  - How to train and debug, very detailed
- Second half: Applications and “Researchy” topics
  - Object detection, image segmentation, 3D vision, videos
  - Attention, Transformers
  - Vision and Language
  - Generative models: GANs, VAEs, etc
  - Less detailed: provide overview and references, but skip some details

First homework assignment

- Will be released over the weekend
- Due one week after release
- Monday’s lecture will be enough to complete it

Next time: Image Classification