



CS231n: Deep Learning for Computer Vision

Lecture 1: Introduction

Computer Vision is everywhere!



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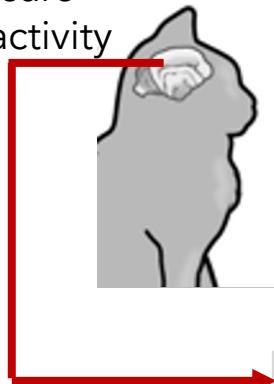
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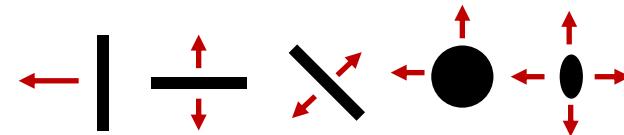
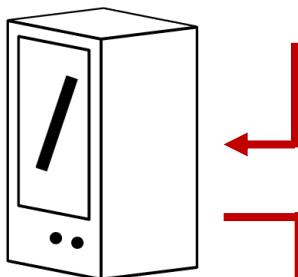
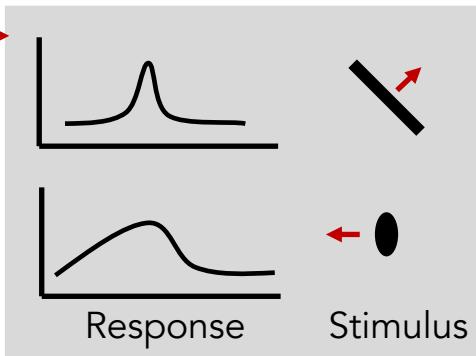
Hubel and Wiesel, 1959

Measure
brain activity



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

1959
Hubel & Wiesel

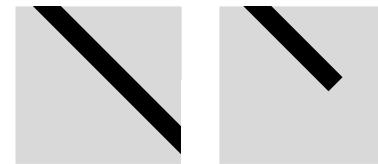


Simple cells:

Response to specific rotation and orientation

Complex cells:

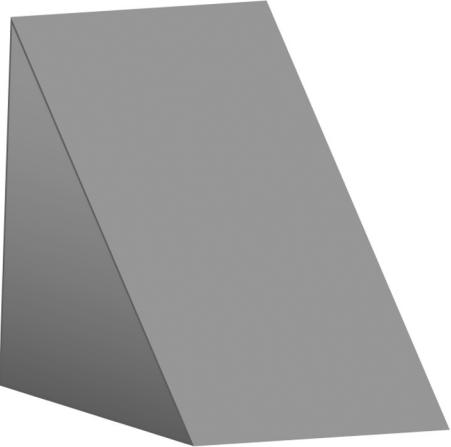
Response to light orientation and movement, some translation invariance



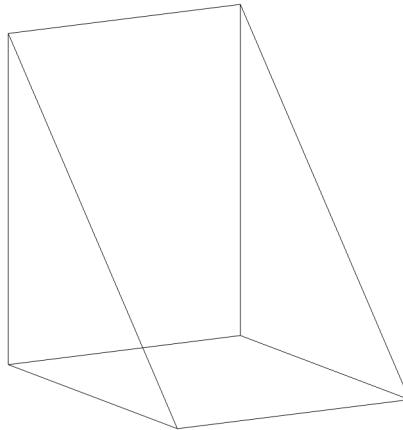
No
response

Slide inspiration: Justin Johnson

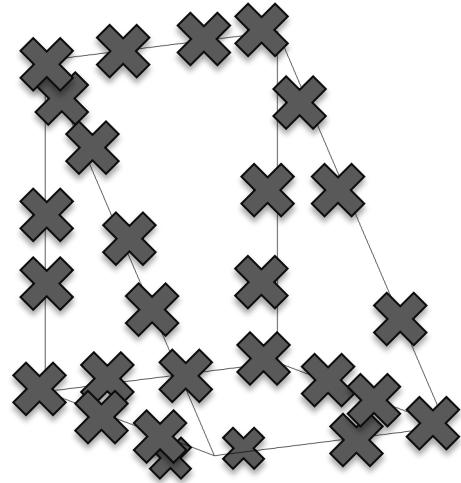
Larry Roberts, 1963



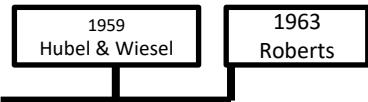
(a) Original picture



(b) Differentiated picture



(c) Feature points selected



Lawrence Gilman Roberts, "Machine Perception of Three-Dimensional Solids", 1963

Slide inspiration: Justin Johnson

MASSACHUSETTS INSTITUTE OF TECHNOLOGY
PROJECT MAC

Artificial Intelligence Group
Vision Memo. No. 100.

July 7, 1966

THE SUMMER VISION PROJECT

Seymour Papert

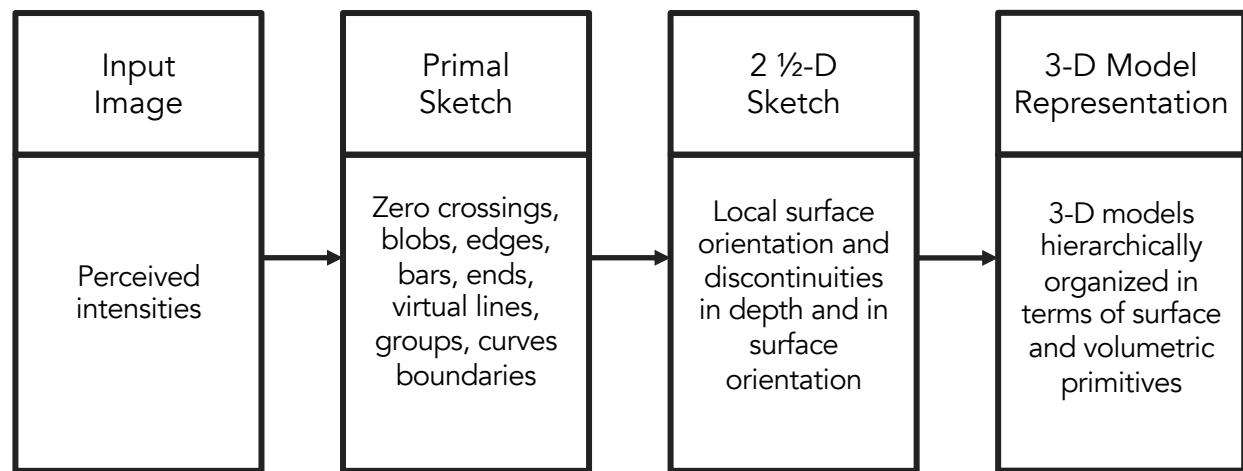
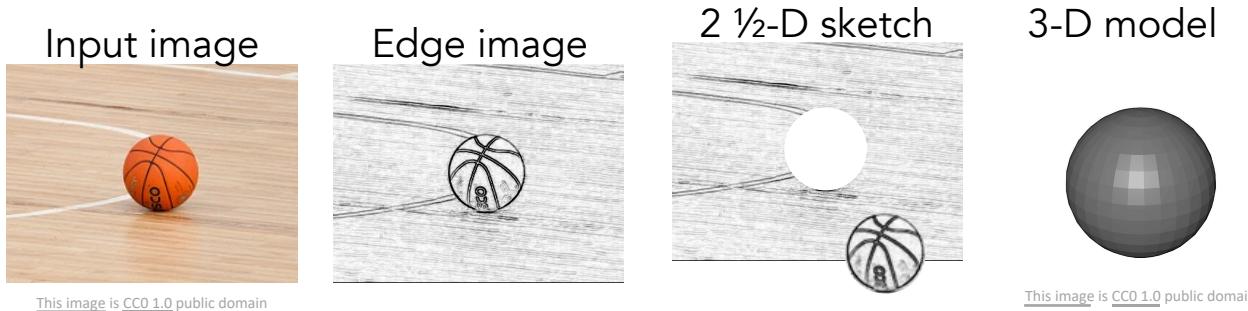
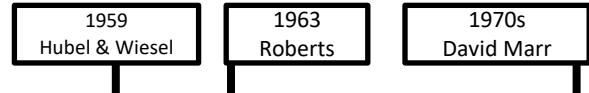
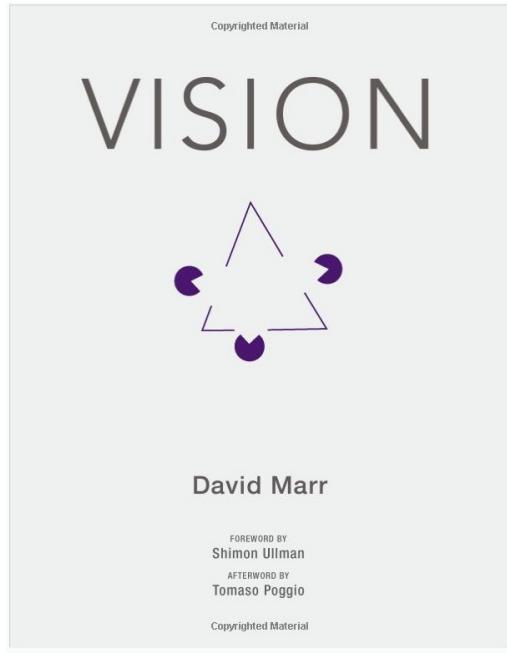
The summer vision project is an attempt to use our summer workers effectively in the construction of a significant part of a visual system. The particular task was chosen partly because it can be segmented into sub-problems which will allow individuals to work independently and yet participate in the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

1959
Hubel & Wiesel

1963
Roberts

<https://dspace.mit.edu/handle/1721.1/6125>

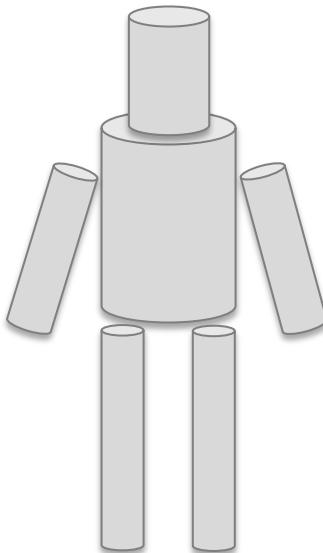
Slide inspiration: Justin Johnson



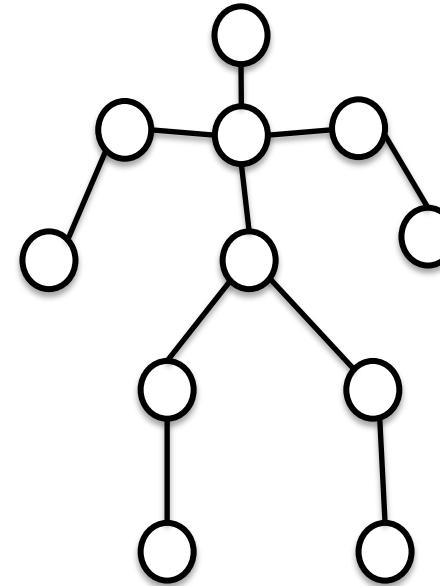
Stages of Visual Representation, David Marr, 1970s

Slide inspiration: Justin Johnson

Recognition via Parts (1970s)



Generalized Cylinders,
Brooks and Binford,
1979



Pictorial Structures,
Fischler and Elshlager, 1973



Slide inspiration: Justin Johnson

Recognition via Edge Detection (1980s)



1959
Hubel & Wiesel

1963
Roberts

1970s
David Marr

1979
Gen. Cylinders

1986
Canny

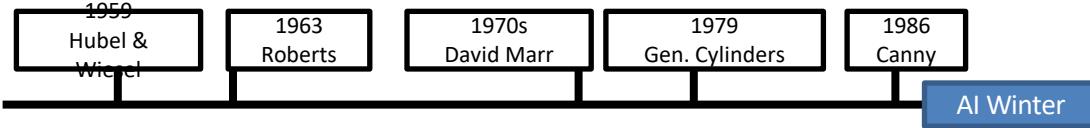
John Canny, 1986
David Lowe, 1987

Image is CC0 1.0 public domain

Slide inspiration: Justin Johnson

Arriving at an “AI winter”

- Enthusiasm (and funding!) for AI research dwindled
- “Expert Systems” failed to deliver on their promises
- But subfields of AI continues to grow
 - Computer vision, NLP, robotics, compbio, etc.



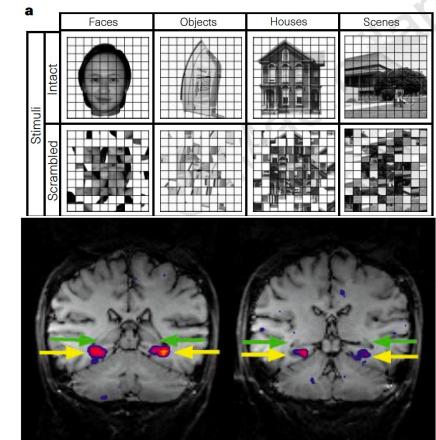
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domain

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Slide inspiration: Justin Johnson

Visual recognition is a fundamental task for visual intelligence



Recognition via Grouping (1990s)



1959
Hubel & Wiesel

1963
Roberts

1970s
David Marr

1979
Gen. Cylinders

1986
Canny

1997
Norm. Cuts

AI Winter

Normalized Cuts, Shi and Malik, 1997

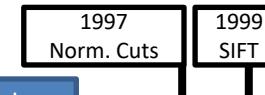
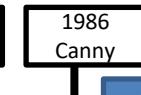
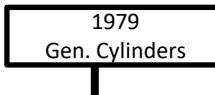
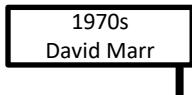
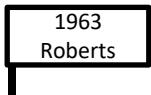
Recognition via Matching (2000s)



[Image](#) is public domain



[Image](#) is public domain



AI Winter

SIFT, David
Lowe, 1999

Slide inspiration: Justin Johnson

Face Detection

Viola and Jones, 2001

One of the first successful applications of machine learning to vision



1959
Hubel & Wiesel

1963
Roberts

1970s
David Marr

1979
Gen. Cylinders

1986
Canny

1997
Norm. Cuts

1999
SIFT

2001
V&J

AI Winter

Slide inspiration: Justin Johnson

Caltech 101 images



1959
Hubel & Wiesel

1963
Roberts

1970s
David Marr

1979
Gen. Cylinders

1986
Canny

1997
Norm. Cuts

1999
SIFT

2001
V&J

2004, 2007
Caltech101;
PASCAL

AI Winter

PASCAL Visual Object Challenge

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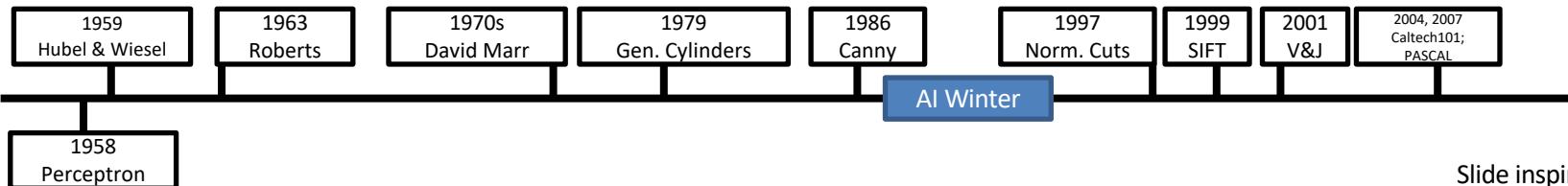
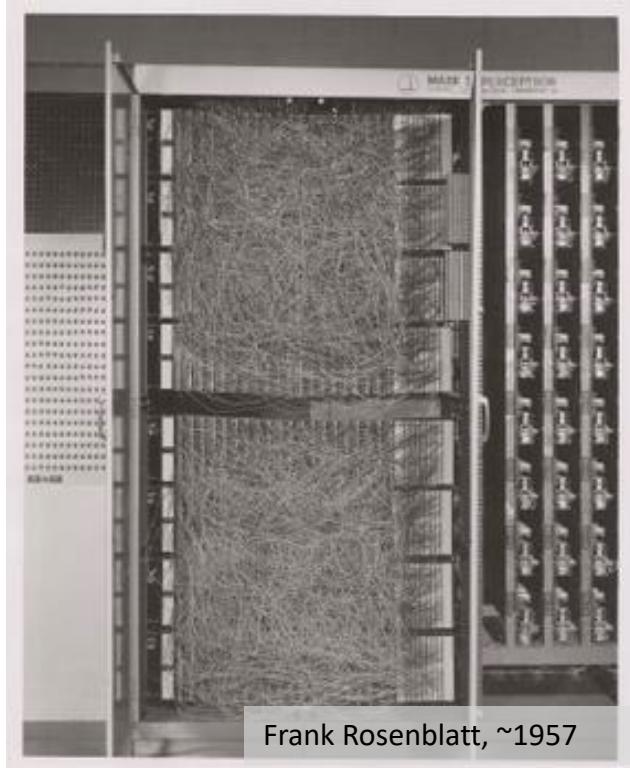
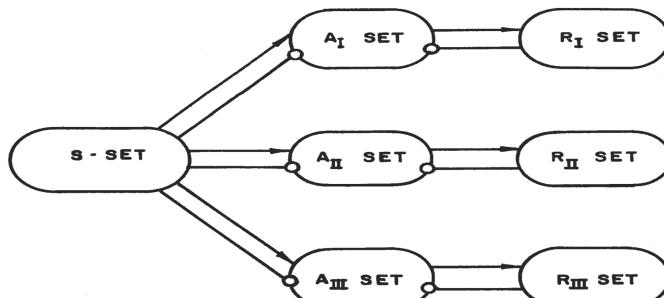
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Learning representations by back-propagating errors

David E. Rumelhart*, Geoffrey E. Hinton†
& Ronald J. Williams*

* Institute for Cognitive Science, C-015, University of California,
San Diego, La Jolla, California 92093, USA

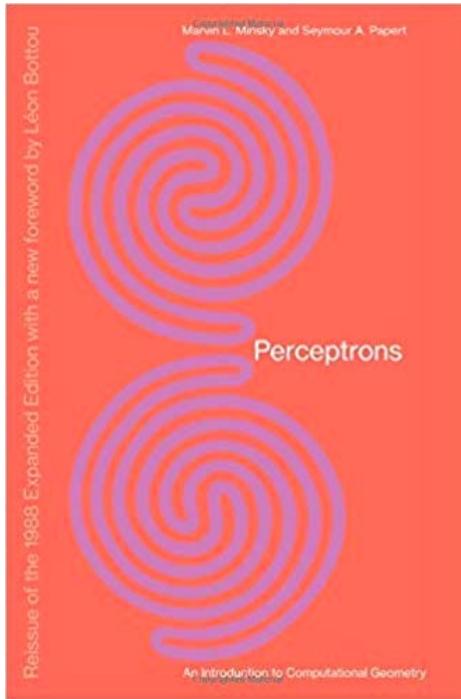
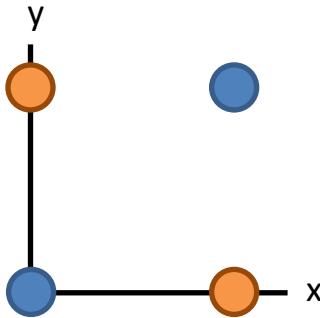
† Department of Computer Science, Carnegie-Mellon University,
Pittsburgh, Philadelphia 15213, USA



Slide inspiration: Justin Johnson

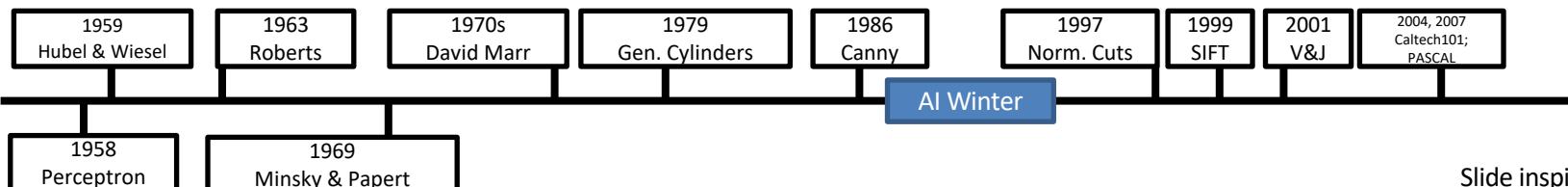
Minsky and Papert, 1969

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



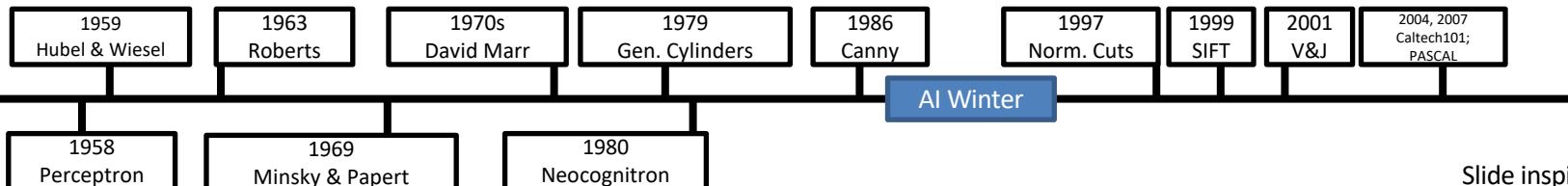
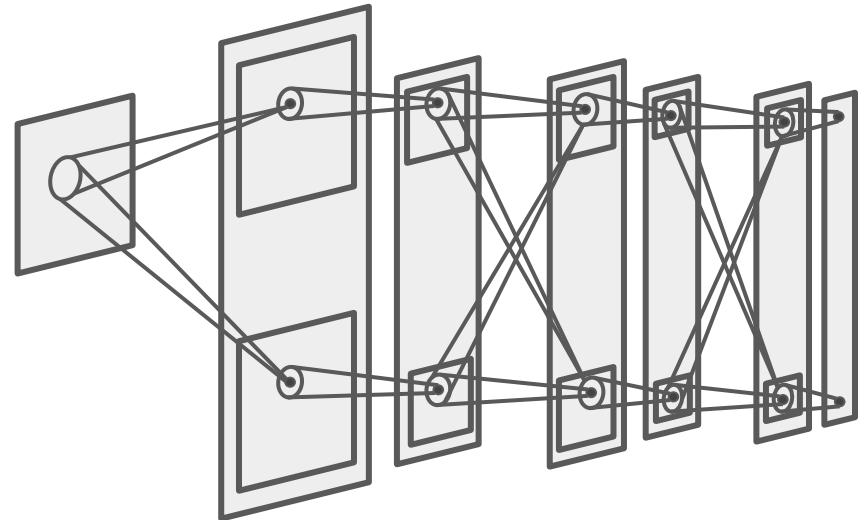
Slide inspiration: Justin Johnson

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

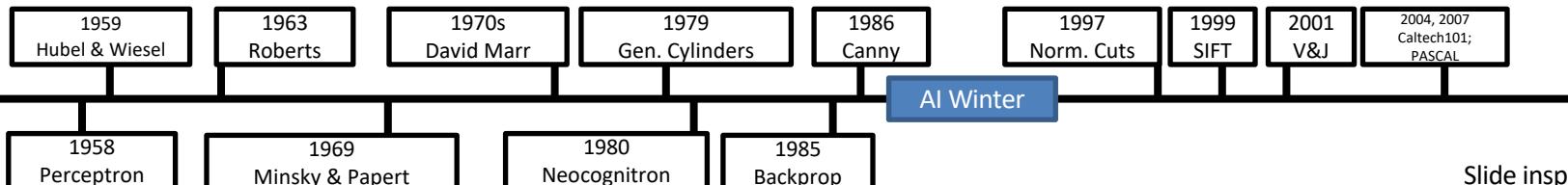
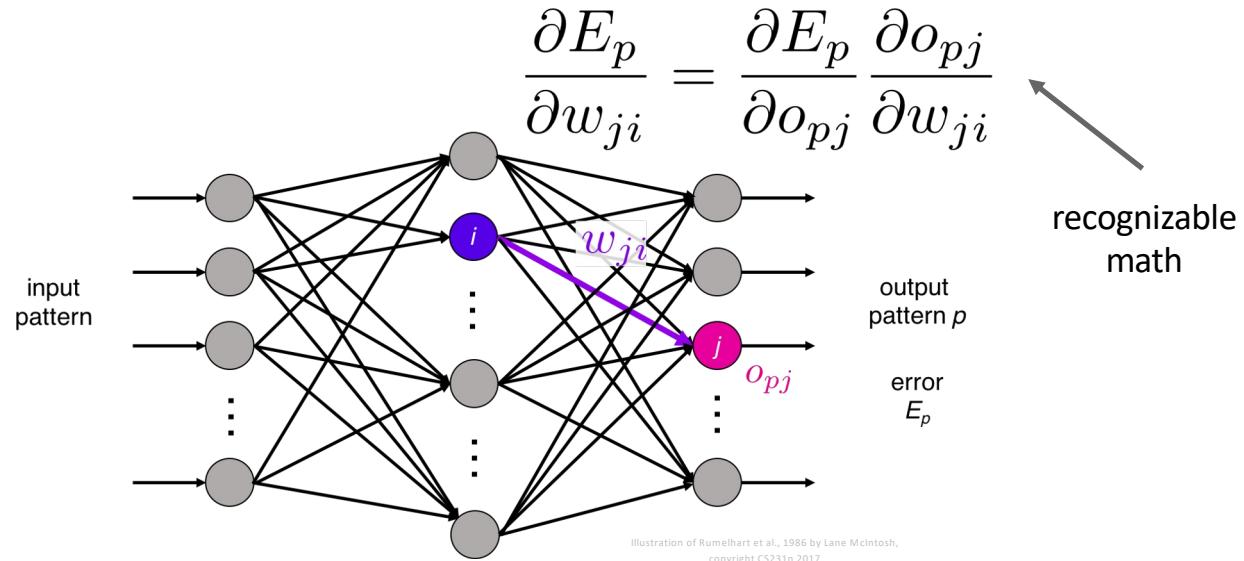


Slide inspiration: Justin Johnson

Backprop: Rumelhart, Hinton, and Williams, 1986

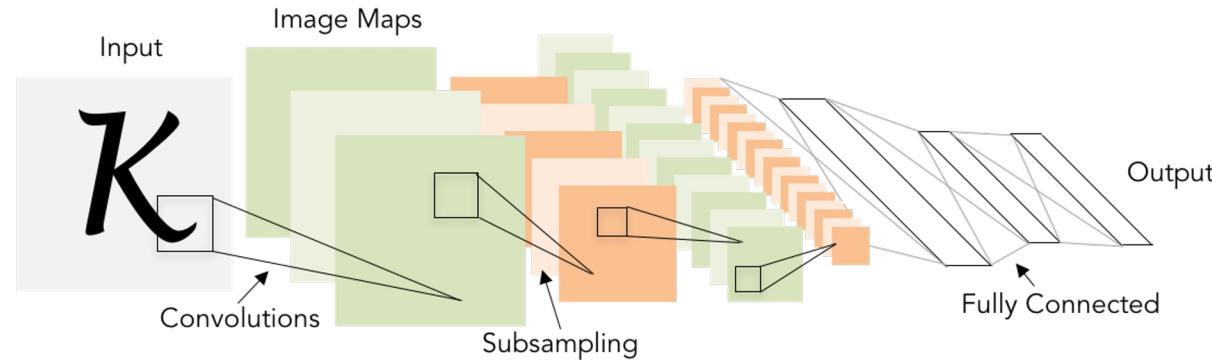
Introduced backpropagation for computing gradients in neural networks

Successfully trained perceptrons with multiple layers



Slide inspiration: Justin Johnson

Convolutional Networks: LeCun et al, 1998

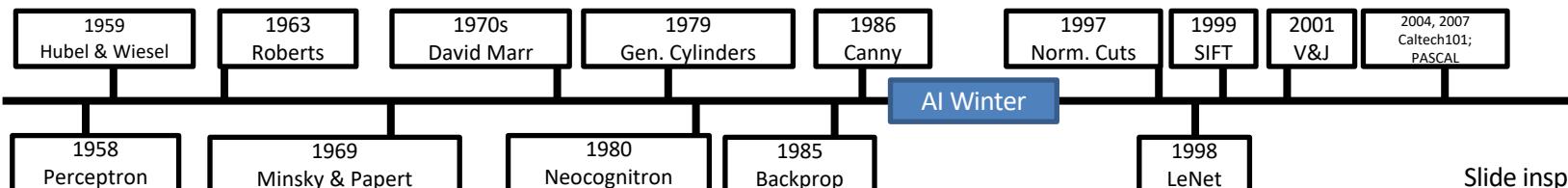


Applied backprop algorithm to a Neocognitron-like architecture

Learned to recognize handwritten digits

Was deployed in a commercial system by NEC, processed handwritten checks

Very similar to our modern convolutional networks!



Slide inspiration: Justin Johnson

2000s: “Deep Learning”

People tried to train neural networks that were deeper and deeper

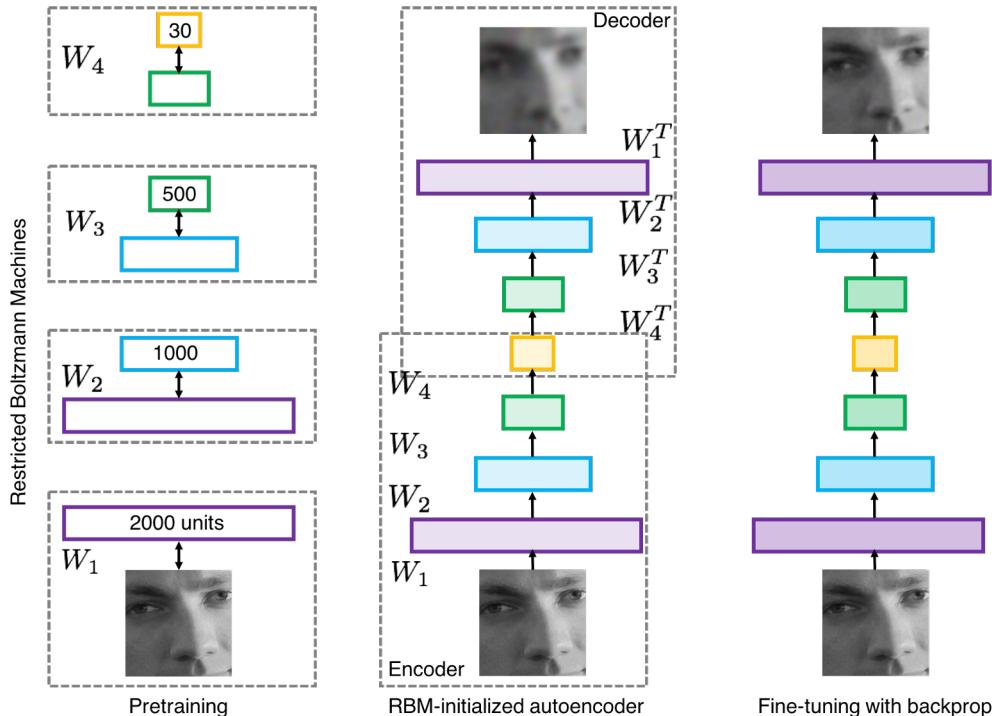
Not a mainstream research topic at this time

Hinton and Salakhutdinov, 2006

Bengio et al, 2007

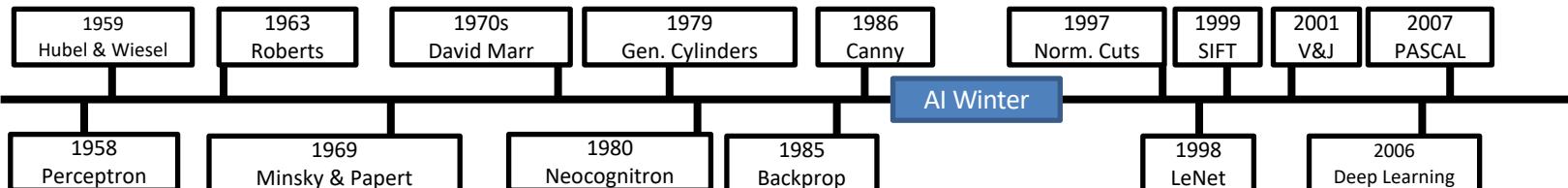
Lee et al, 2009

Glorot and Bengio, 2010



Fine-tuning with backprop

Slide inspiration: Justin Johnson



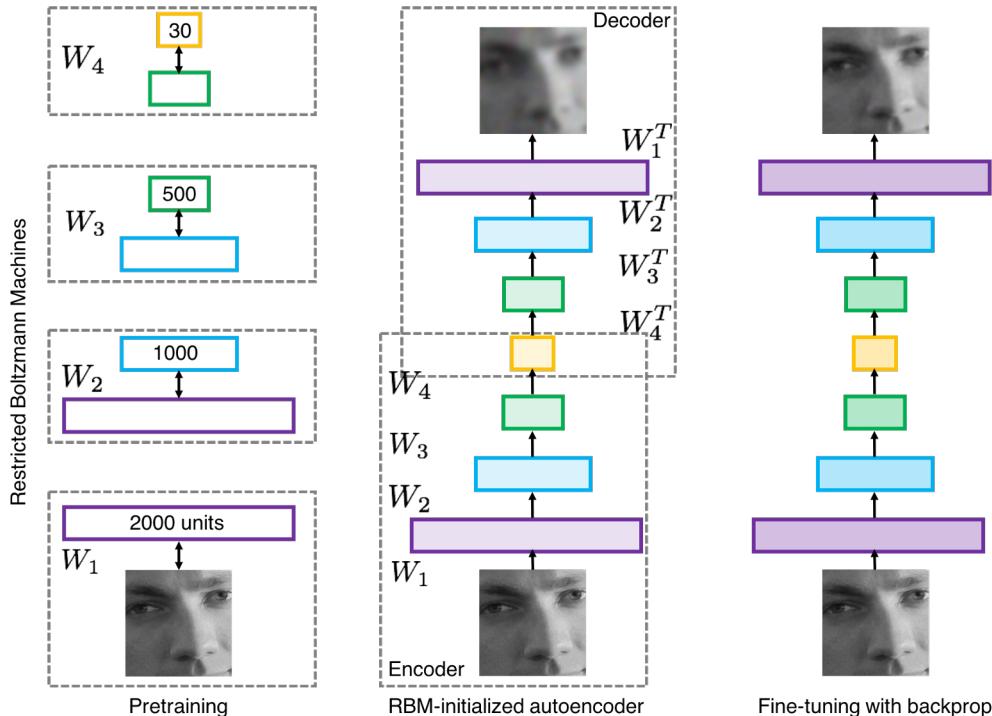
2000s: “Deep Learning”

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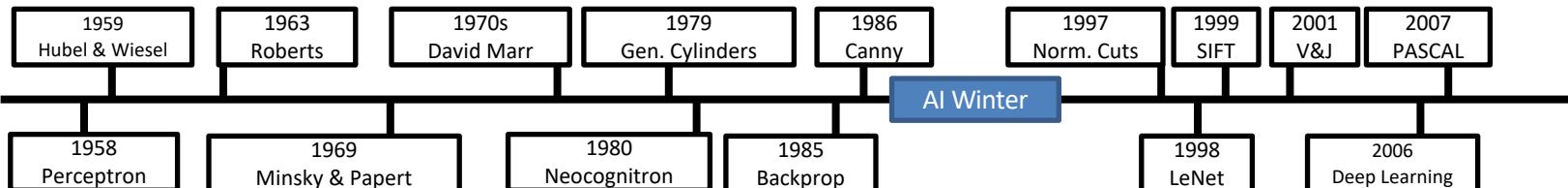
No good dataset to work on

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



Fine-tuning with backprop

Slide inspiration: Justin Johnson



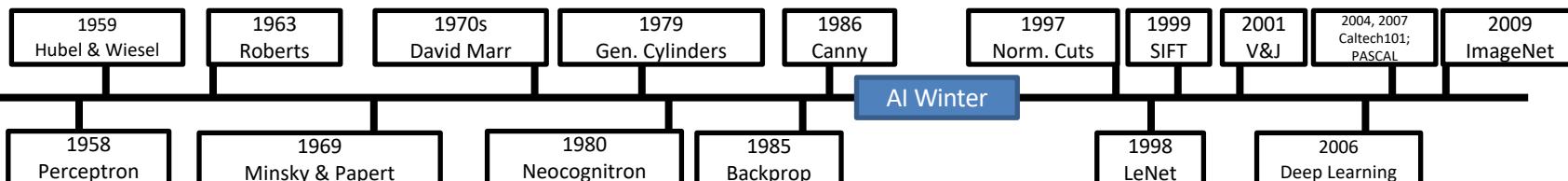
IMAGENET Large Scale Visual Recognition Challenge

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



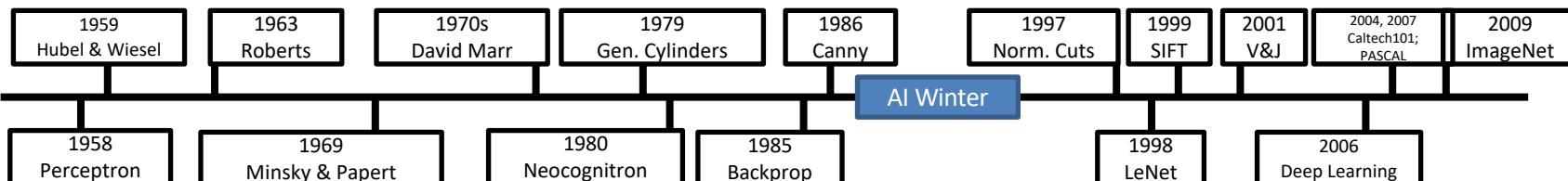
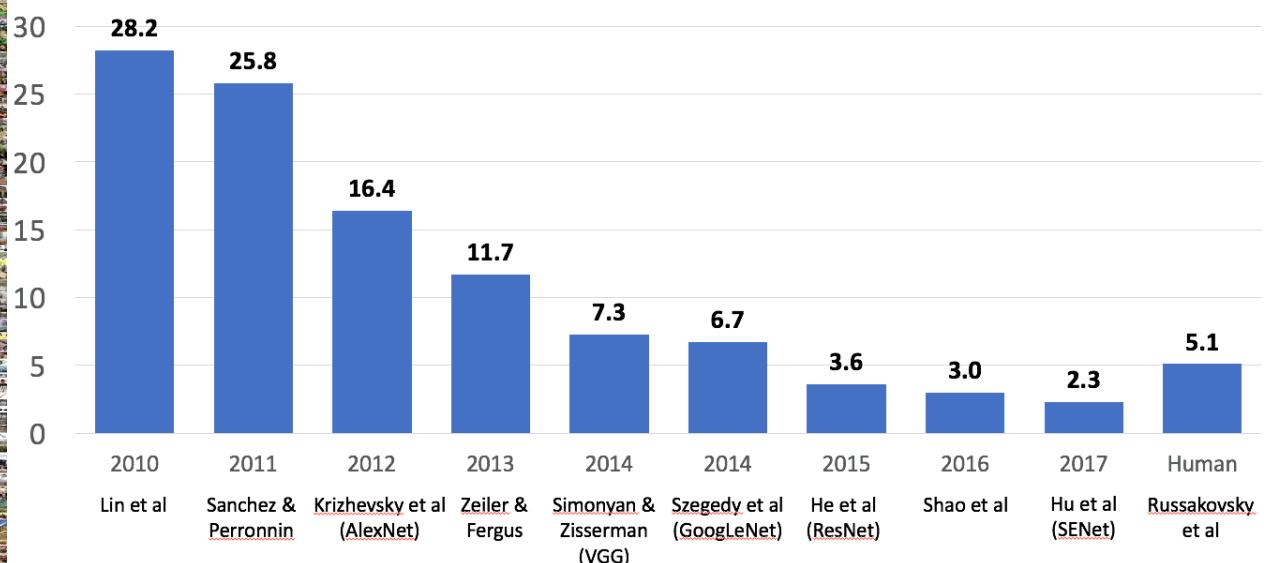
Output:
Scale
T-shirt
Steel drum
Drumstick
Mud turtle

Deng et al, 2009
Russakovsky et al. IJCV 2015

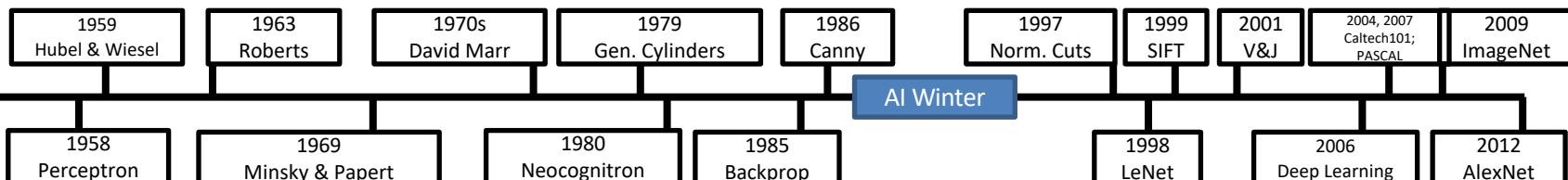
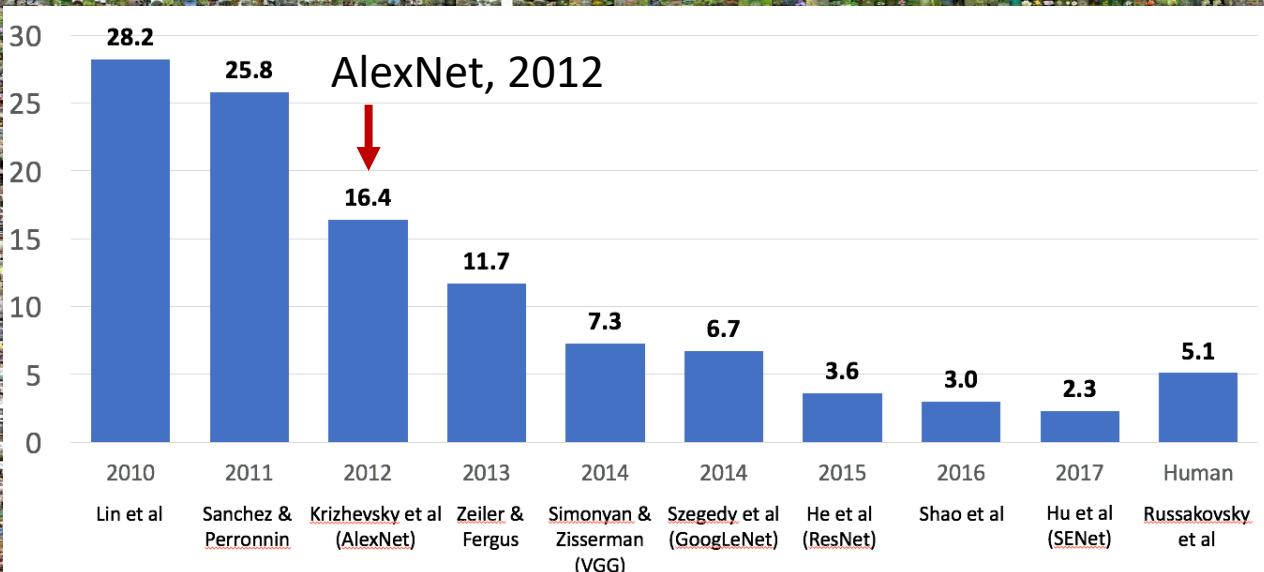




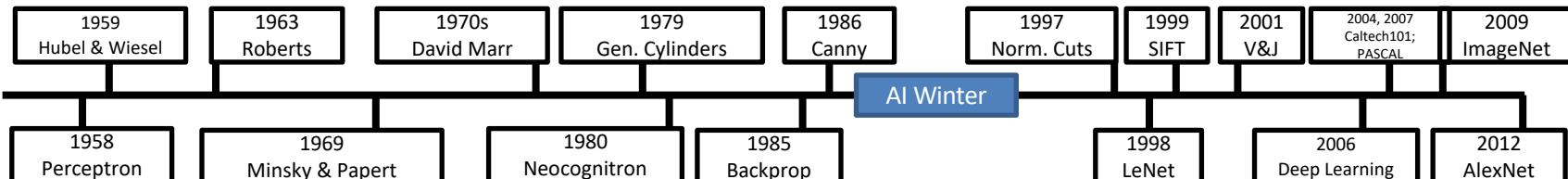
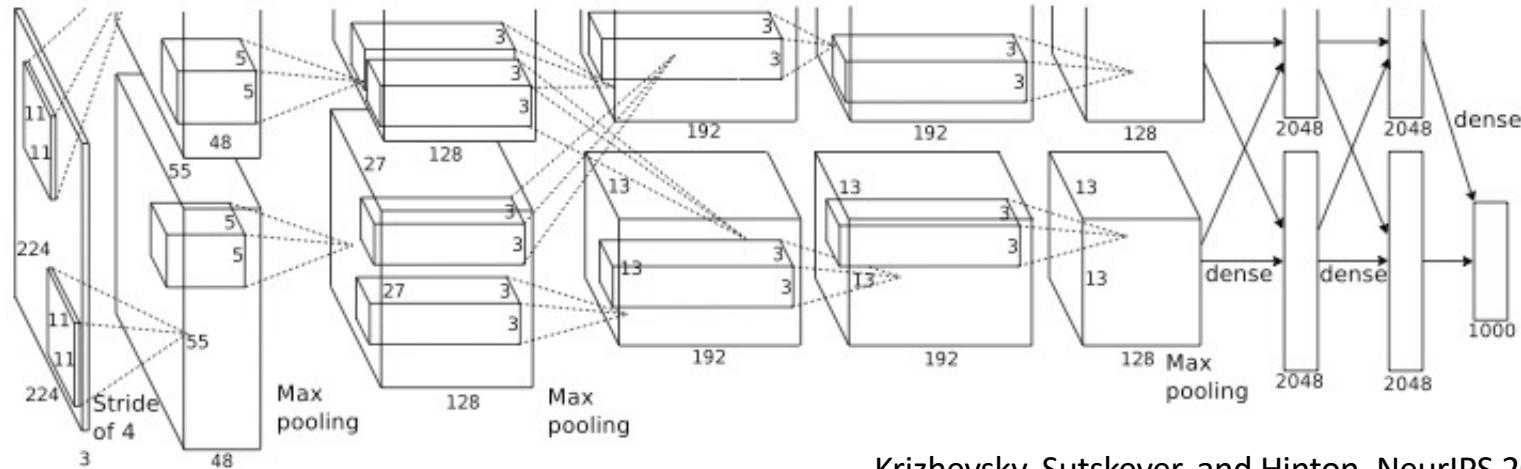
Large Scale Visual Recognition Challenge



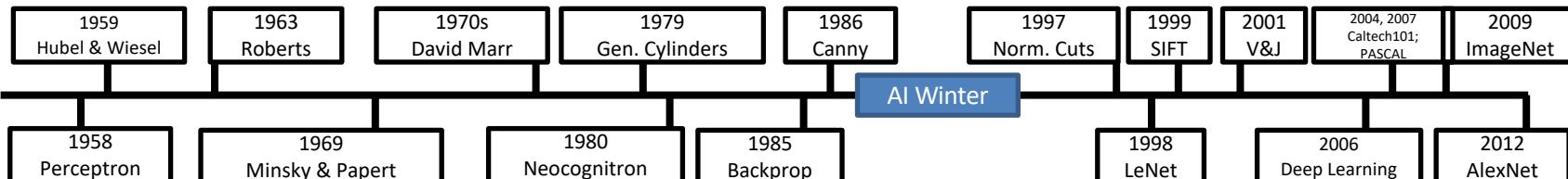
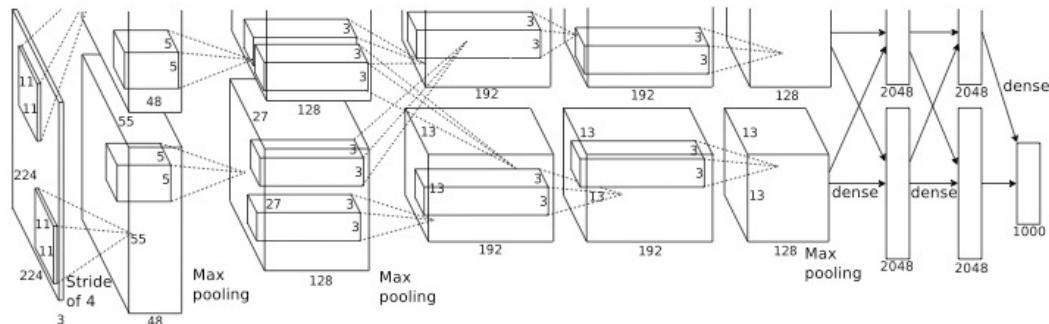
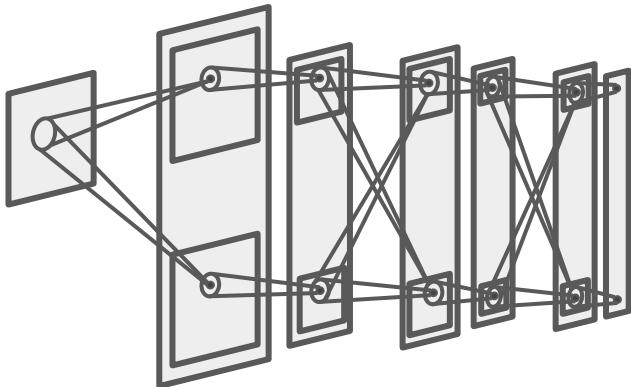
IMAGENET Large Scale Visual Recognition Challenge



AlexNet: Deep Learning Goes Mainstream

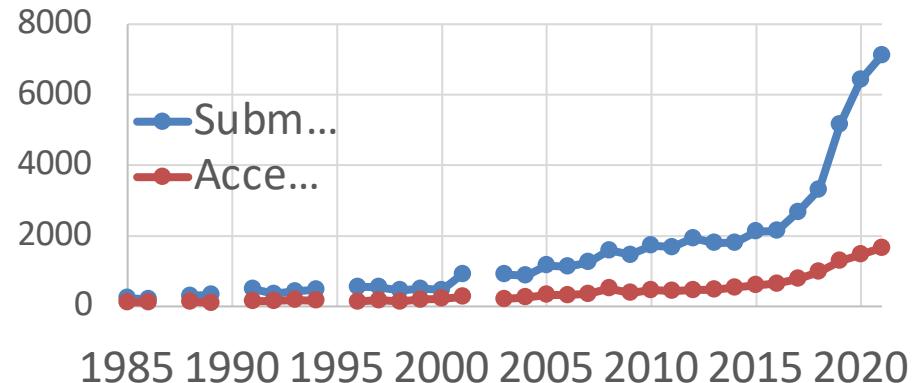


AlexNet vs. Neocognitron: 32 years apart



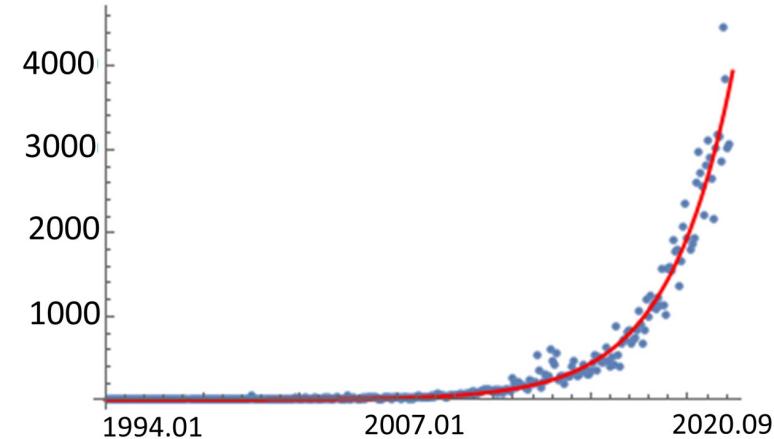
2012 to Present: Deep Learning Explosion

CVPR Papers

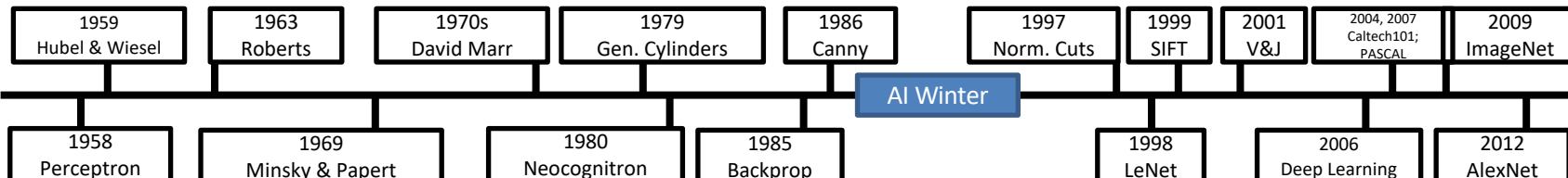


Publications at top Computer Vision conference

ML+AI arXiv papers per month



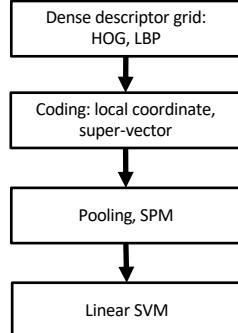
arXiv papers per month ([source](#))



2012 to Present: Deep Learning is Everywhere

Year 2010

NEC-UIUC

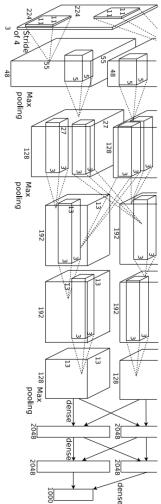


[Lin CVPR 2011]

Lion image by Swissfrog
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Year 2012

SuperVision



[Krizhevsky NIPS 2012]

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Year 2014

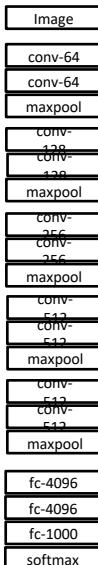
GoogLeNet

- Pooling
- Convolution
- Softmax
- Other



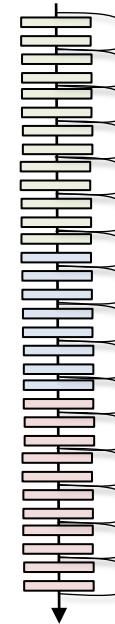
[Szegedy arxiv 2014] [Simonyan arxiv 2014]

VGG



Year 2015

MSRA



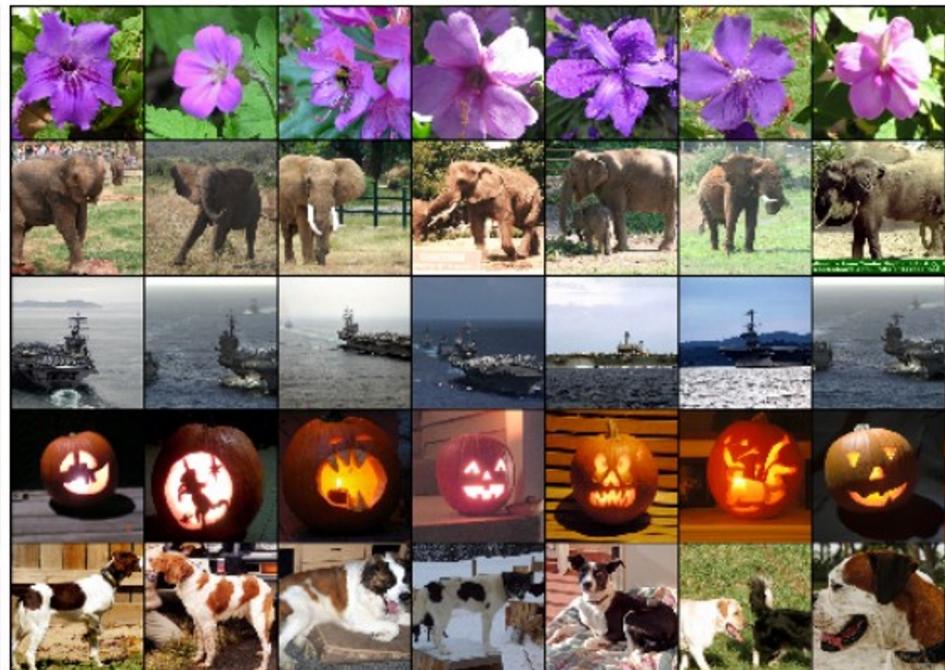
[He ICCV 2015]

2012 to Present: Deep Learning is Everywhere

Image Classification



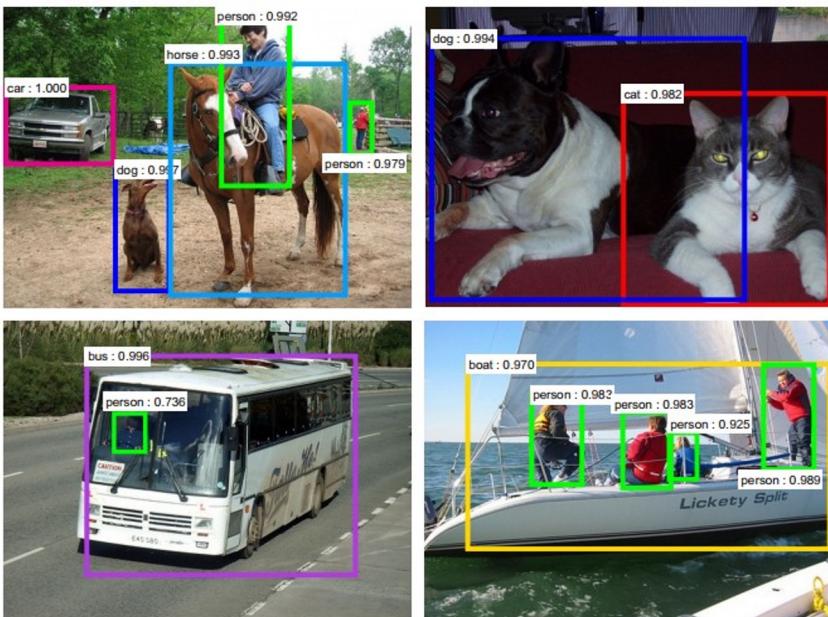
Image Retrieval



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

2012 to Present: Deep Learning is Everywhere

Object Detection



Ren, He, Girshick, and Sun, 2015

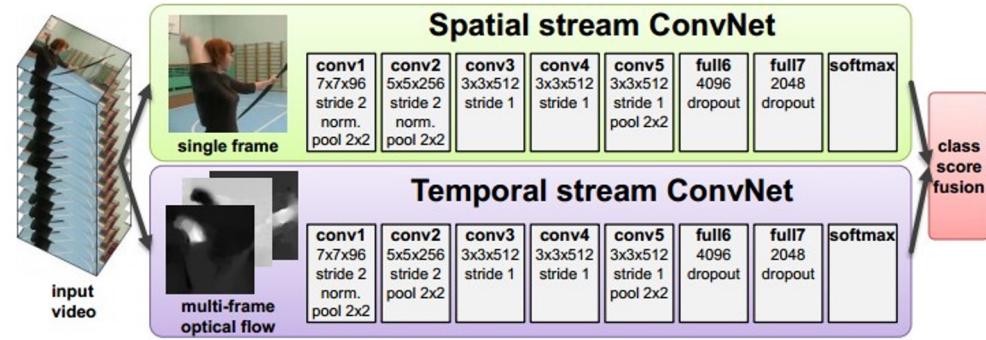
Image Segmentation



Fabaret et al, 2012

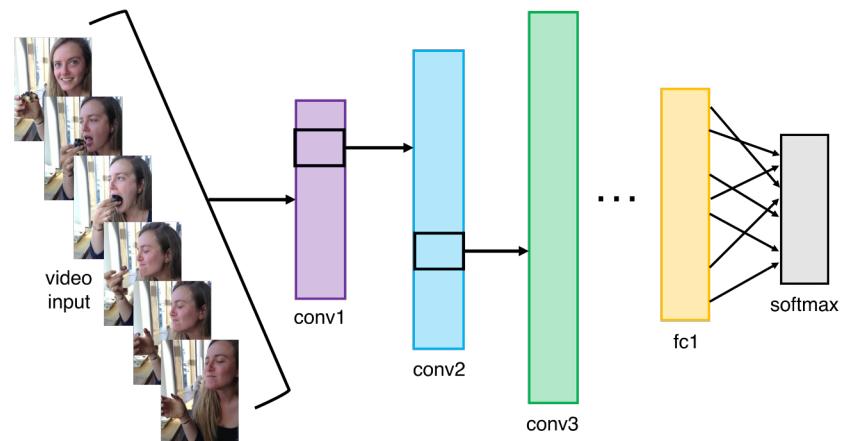
2012 to Present: Deep Learning is Everywhere

Video Classification



Simonyan et al, 2014

Activity Recognition

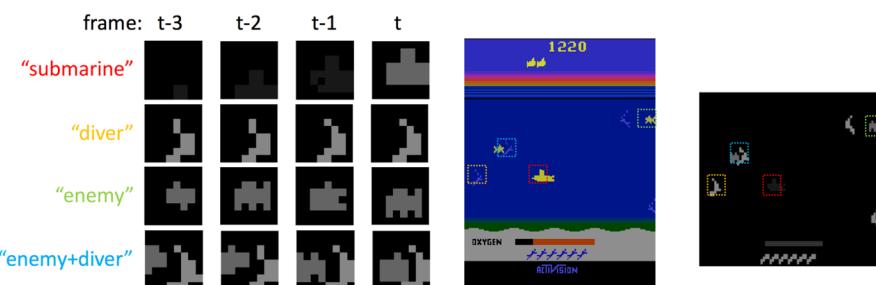


2012 to Present: Deep Learning is Everywhere

Pose Recognition (Toshev and Szegedy, 2014)

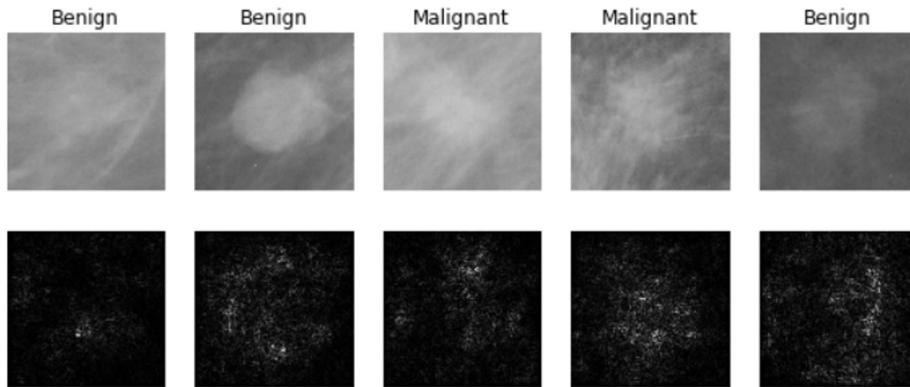


Playing Atari games (Guo et al, 2014)



2012 to Present: Deep Learning is Everywhere

Medical Imaging



Levy et al, 2016

Figure reproduced with permission

Whale recognition



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Galaxy Classification



Dieleman et al, 2014

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Kaggle Challenge

2012 to Present: Deep Learning is Everywhere



*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*



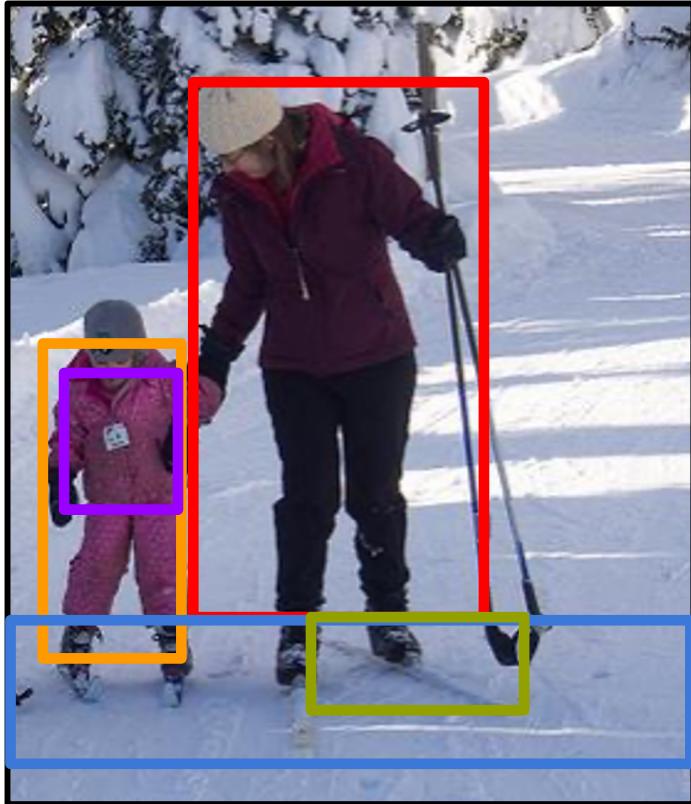
*A woman standing on a
beach holding a surfboard*

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

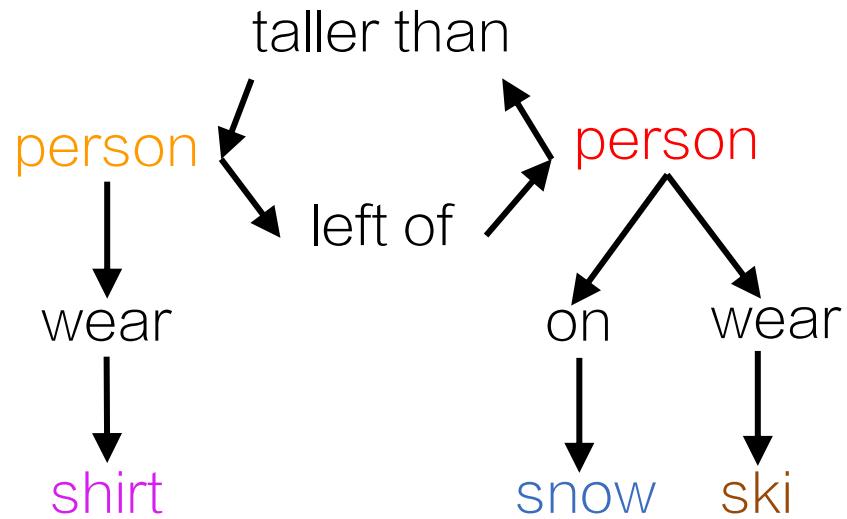
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<https://pixabay.com/en/teal-plush-teddy-bear-toy-1623436/>
<https://pixabay.com/en/surf-wave-summer-sport-litoral-1668716/>
<https://pixabay.com/en/woman-female-model-portrait-adult-983967/>
<https://pixabay.com/en/handstand-lake-meditation-496008/>
<https://pixabay.com/en/baseball-player-shortstop-infield-1045263/>

Captions generated by Justin Johnson using [Neuraltalk2](#)

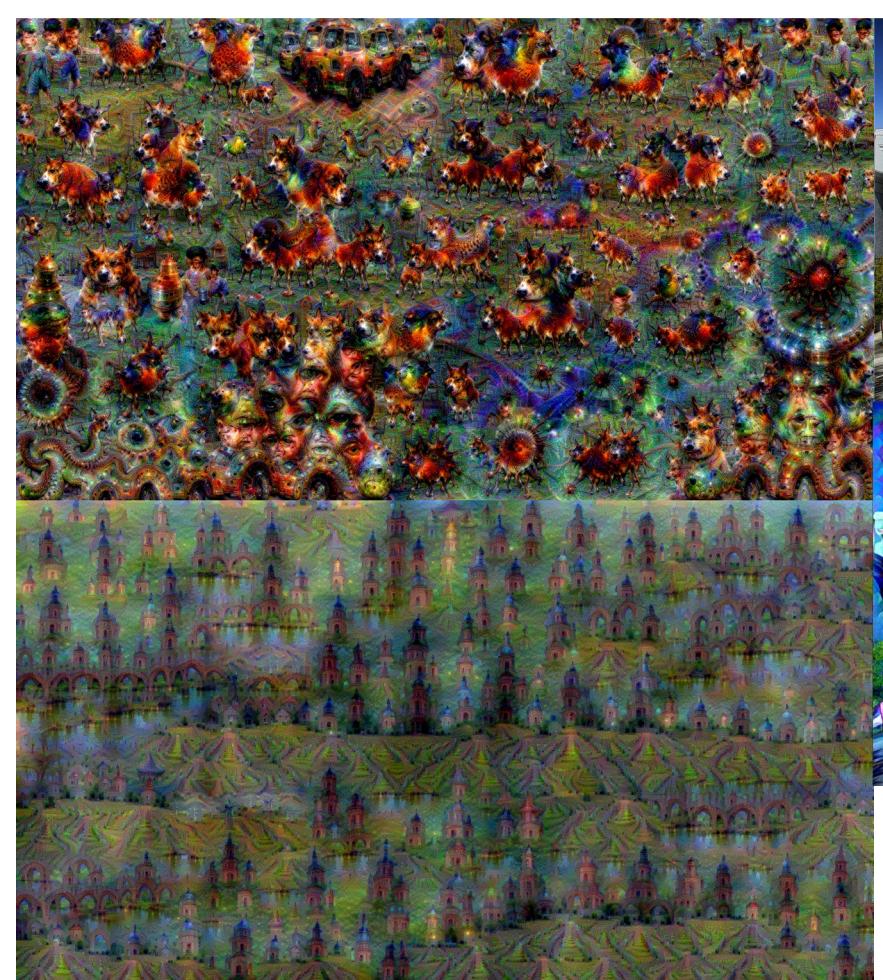
2012 to Present: Deep Learning is Everywhere



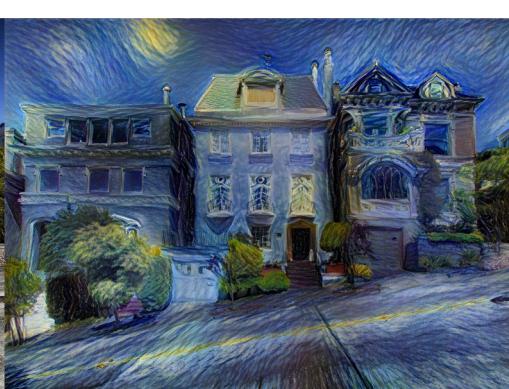
Results:
spatial, comparative, asymmetrical,
verb, prepositional



Krishna*, Lu*, Bernstein, Fei-Fei, ECCV 2016



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



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Bokeh image is in the public domain
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reproduced with permission

Mordvinsev et al, 2015
Gatys et al, 2016

Slide inspiration: Justin Johnson

2012 to Present: Deep Learning is Everywhere

TEXT PROMPT

an armchair in the shape of an avocado. an armchair imitating an avocado.

AI-GENERATED IMAGES



Slide inspiration: Justin Johnson

2012 to Present: Deep Learning is Everywhere

TEXT PROMPT

an armchair in the shape of a peach. an armchair imitating a peach.

AI-GENERATED IMAGES



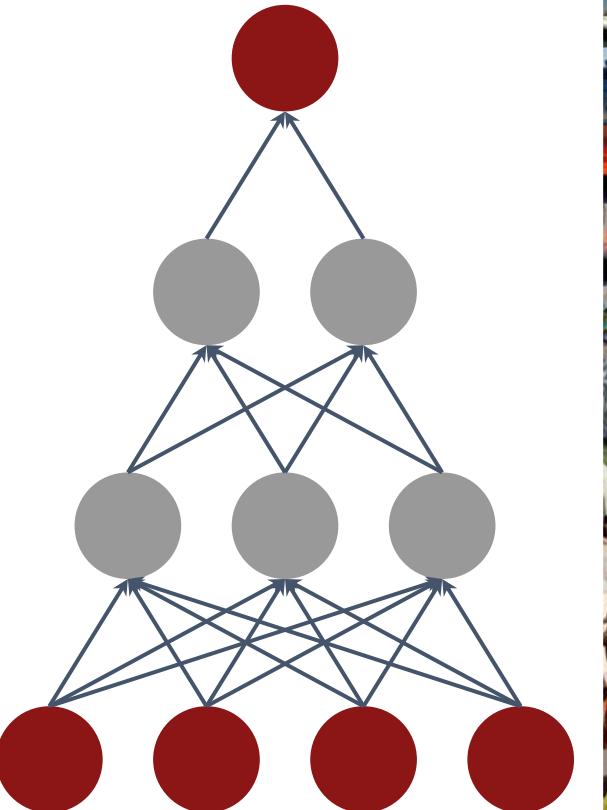
Slide inspiration: Justin Johnson



Computation

April 2, 2024

April 2, 2024



Algorithms



Data

GFLOP per Dollar

● CPU ● GPU (FP32)

RTX 3080 →

RTX 3090 →

Deep Learning Explosion

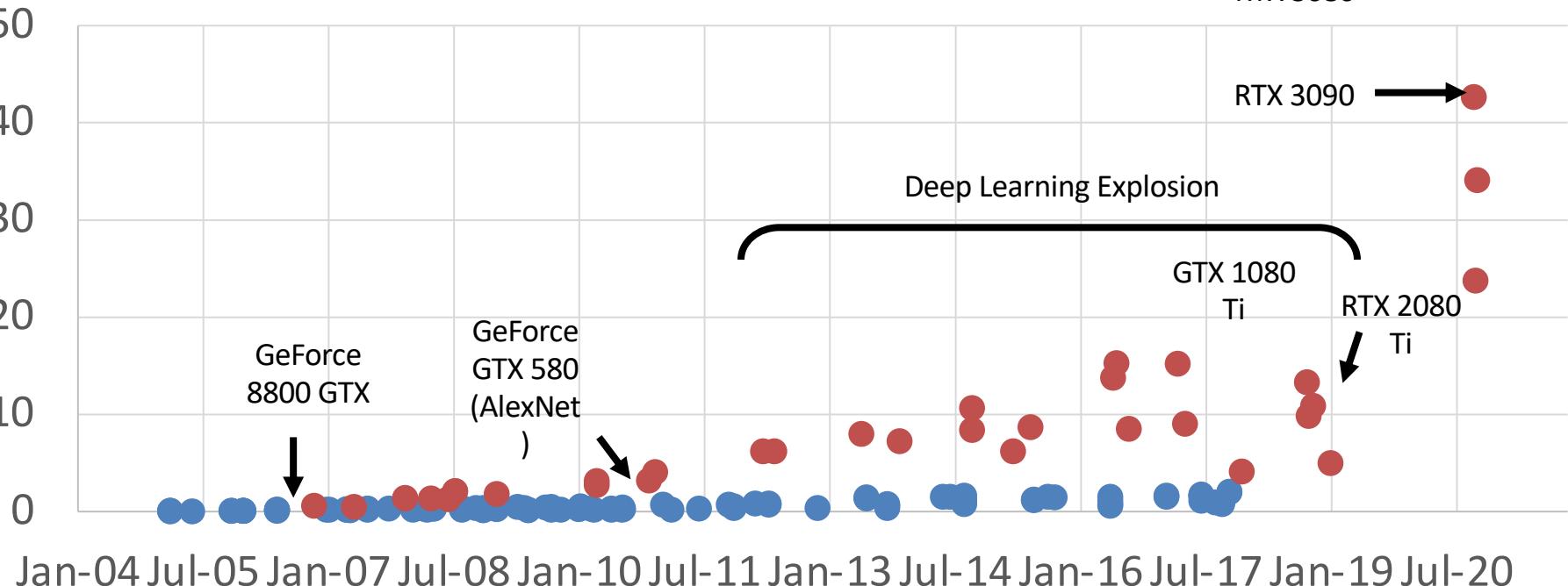
GTX 1080

Ti

RTX 2080
Ti

GeForce
8800 GTX

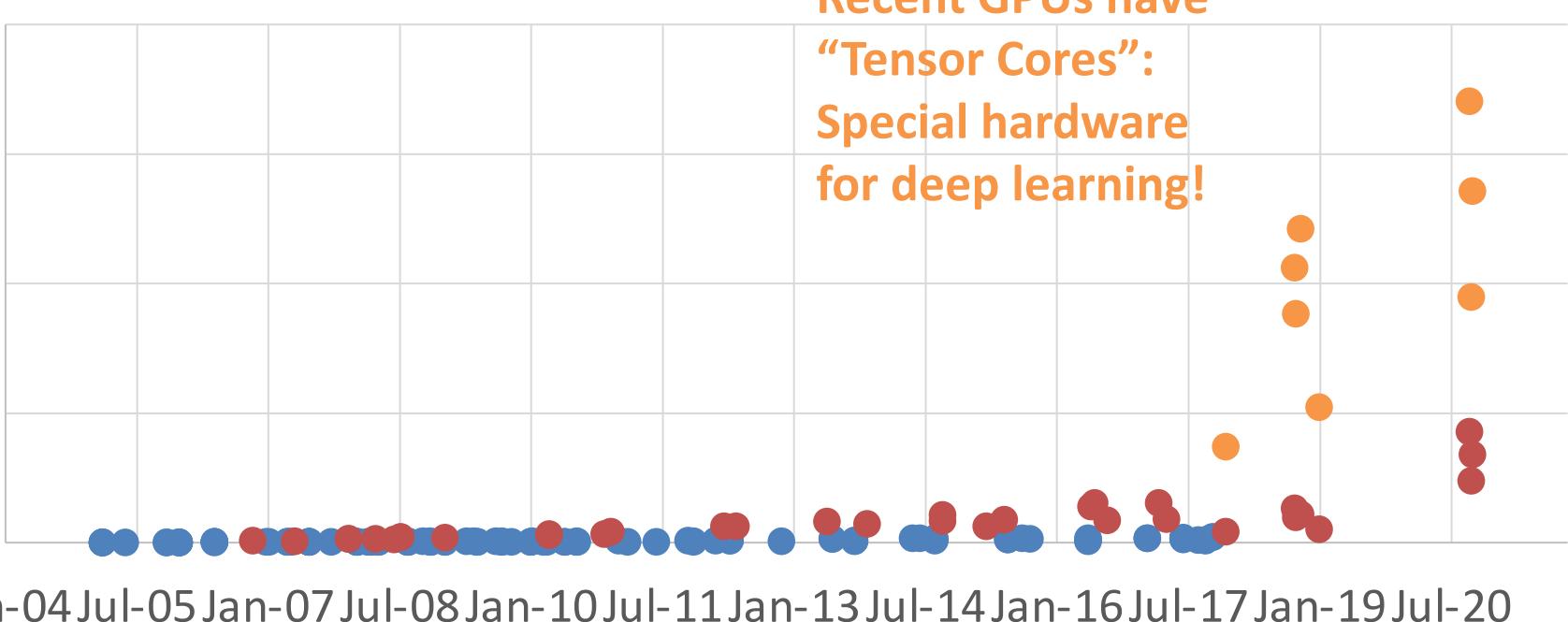
GeForce
GTX 580
(AlexNet
)



GFLOP per Dollar

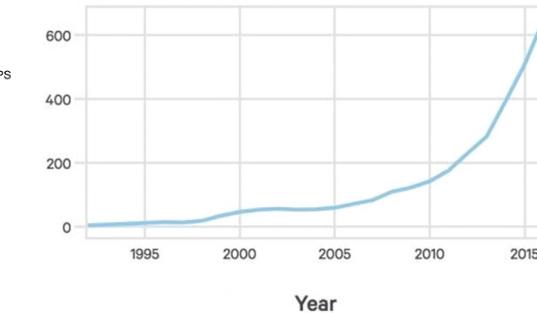
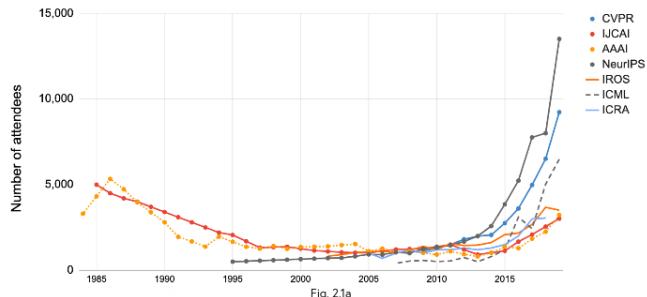
● CPU ● GPU (FP32) ● GPU (Tensor Core)

Recent GPUs have
“Tensor Cores”:
Special hardware
for deep learning!



AI's Explosive Growth & Impact

Attendance at large conferences (1984-2019)
Source: Conference provided data.

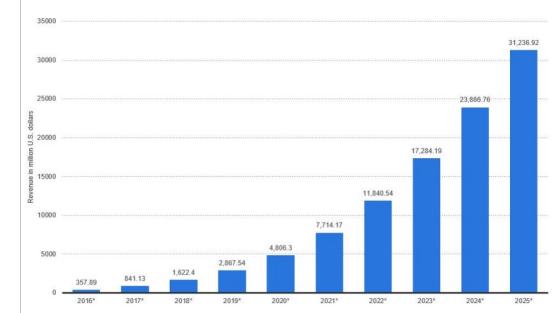


**Number of attendance
At AI conferences**

Source: The Gradient

**Startups Developing AI
Systems**

Source: Crunchbase, VentureSource, Sand
Hill Econometrics

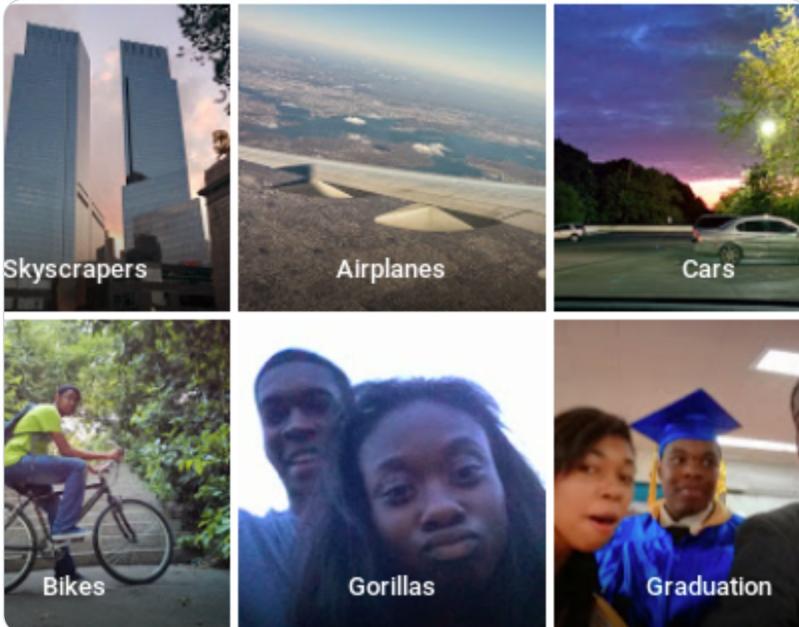


**Enterprise Application AI
Revenue**

Source: Statista

Computer Vision Can Cause Harm

Harmful Stereotypes



Barocas et al., "The Problem With Bias: Allocative Versus Representational Harms in Machine Learning", SIGCIS 2017

Kate Crawford, "The Trouble with Bias", NeurIPS 2017 Keynote

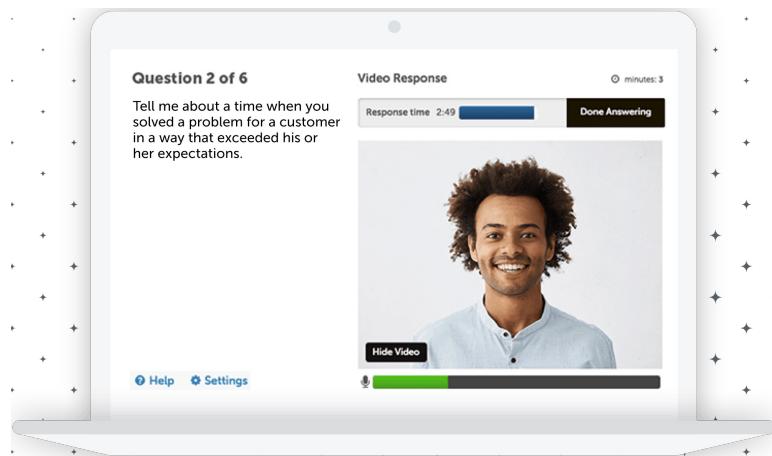
Source: <https://twitter.com/jackyalcine/status/615329515909156865> (2015)

Affect people's lives

Technology

A face-scanning algorithm increasingly decides whether you deserve the job

HireVue claims it uses artificial intelligence to decide who's best for a job. Outside experts call it 'profoundly disturbing.'



Source: <https://www.washingtonpost.com/technology/2019/10/22/ai-hiring-face-scanning-algorithm-increasingly-decides-whether-you-deserve-job/>
<https://www.hirevue.com/platform/online-video-interviewing-software>

Example Credit: Timnit Gebru

Computer Vision Can Save Lives

How to take care of seniors while keeping them safe?

- Early Symptom Detection of COVID-19
- Manage Chronic Conditions
- Monitor Patients with Mild Symptoms

Versatile

- Mobility
- Infection
- Sleep
- Diet

Scalable

- Low-cost
- Burden-free

And there is a lot we don't know how to do



https://fedandfit.com/wp-content/uploads/2020/06/summer-activities-for-kids_optimized-scaled.jpeg



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