Deep Learning

Like Magic, but Real!

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Outline

- Chapter 1: Motivation (King)

- Chapter 2: State of the Art Architectures (Xing)

Machine Learning

Making the machines sentient and intelligent. It'll take away all the jobs -- It's an existential threat to humanity -- it will lead to the SINGULARITY!

Programing: Human imposes the rules on Machine

Learning: Machine *infers* the rules (from data) for Human

Chapter 1: It's Magic!

Gee Whiz #1: Infer Color

https://arxiv.org/pdf/1603.08511.pdf
https://github.com/richzhang/colorization

http://demos.algorithmia.com/colorize-photos/

Gee Whiz #1: Infer Color

Gee Whiz #2: Capturing Style

http://dizajnsvakidan.com/kad-umjetna-neuronska-mreza-generira-tipografiju/

Original Paper: https://arxiv.org/abs/1703.07511

Gee Whiz #2: Capturing Style

Also useful for Propaganda

Gee Whiz #3: Robust Image Classification/Captioning

http://www.boredpanda.com/camouflage-owl-photography/

PREDICTED CONCEPT	PROBABILITY
tree	0.998
bark	0.998
nature	0.997
wood	0.994
owl	0.986
trunk	0.985
no person	0.965
log	0.951

https://www.clarifai.com/demo

Gee Whiz #3: Robust Image Classification/Captioning

a bird sitting on a ledge looking out the window
`logprob: -9.87`

a pair of scissors and a pair of scissors
`logprob: -6.00`

a large elephant standing in a field of grass
`logprob: -7.93`

a man riding a horse drawn carriage down a street
`logprob: -7.29`

a man is standing on a beach with a surfboard
`logprob: -10.07`

a man riding a bike down a street next to a woman
`logprob: -9.47`

Gee Whiz #4 : Voice Synthesis

https://lyrebird.ai/demo

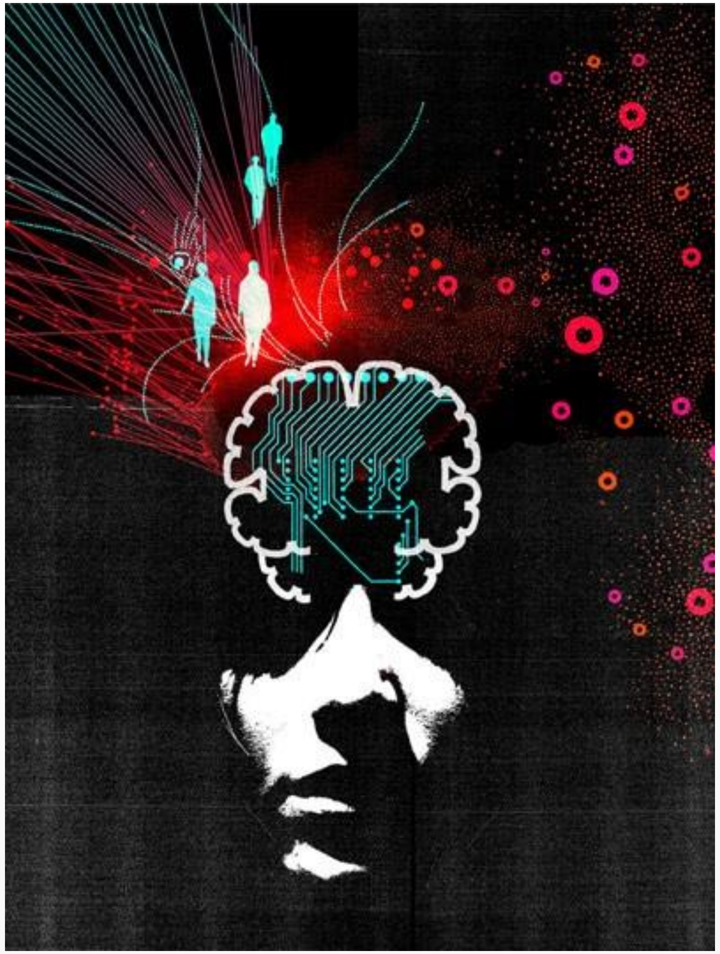
Ok—Maybe it's this much magic…

Chapter 2: It's Real.

Deep Learning is A Breakthrough Technology

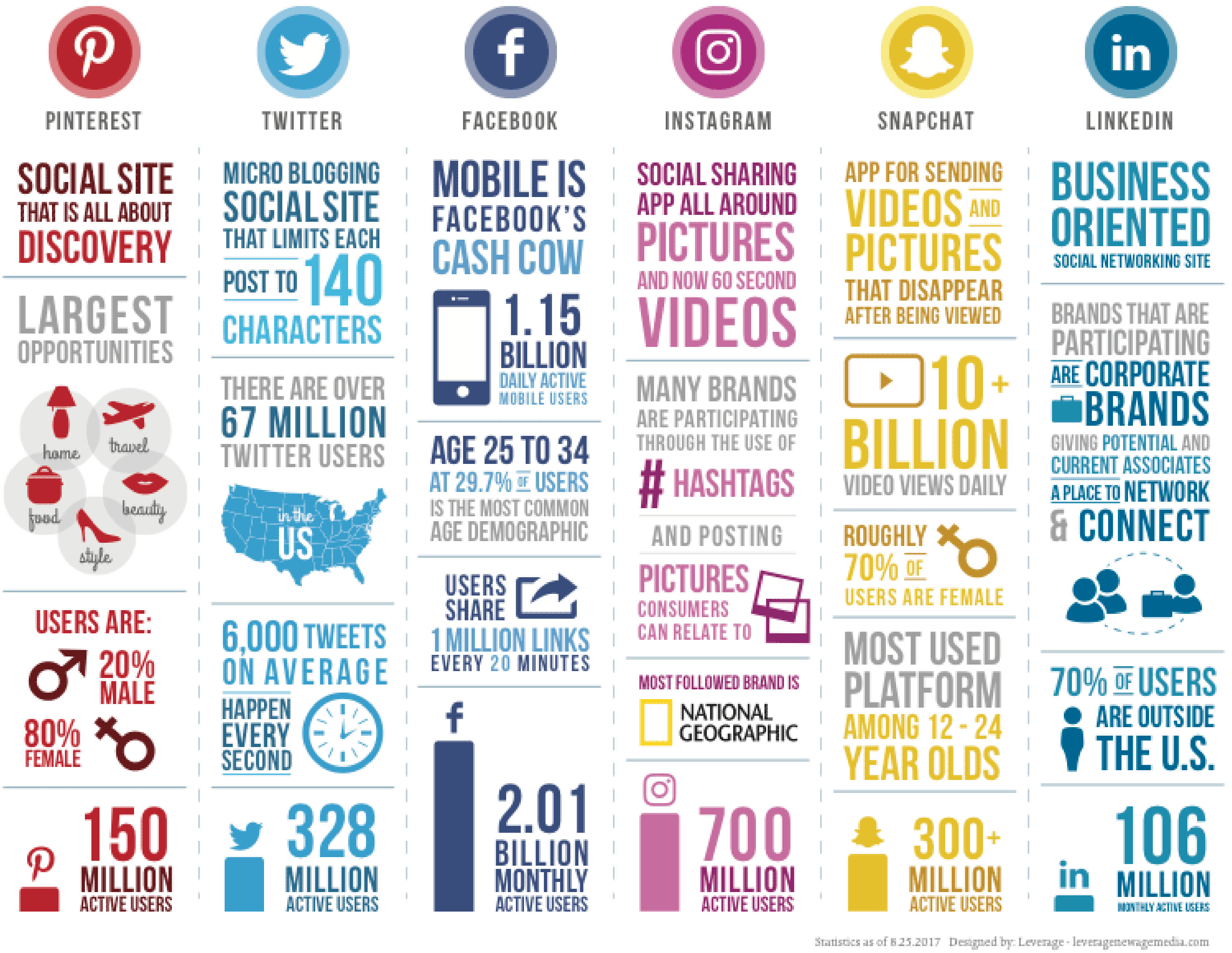
- **MIT Technology Review**: 10 breakthrough technologies

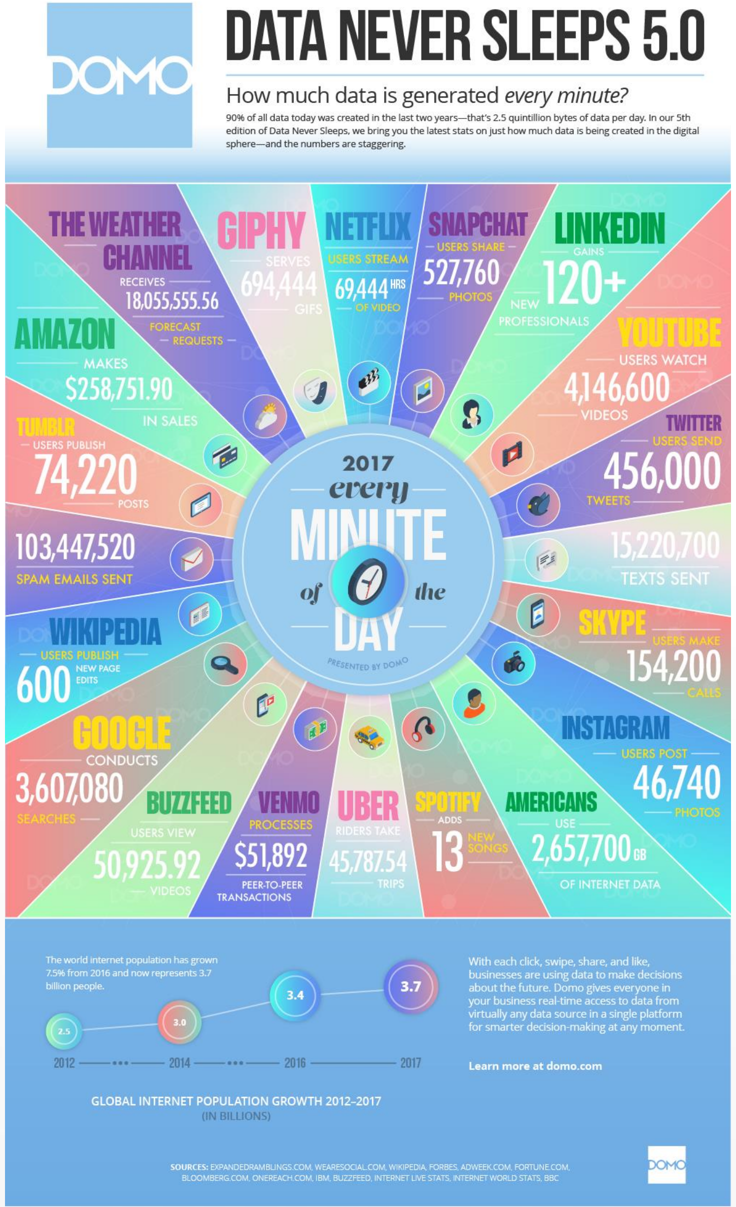
2013: Deep learning



2017: Paying with your face

Why Deep Learning?





Why Deep Learning?

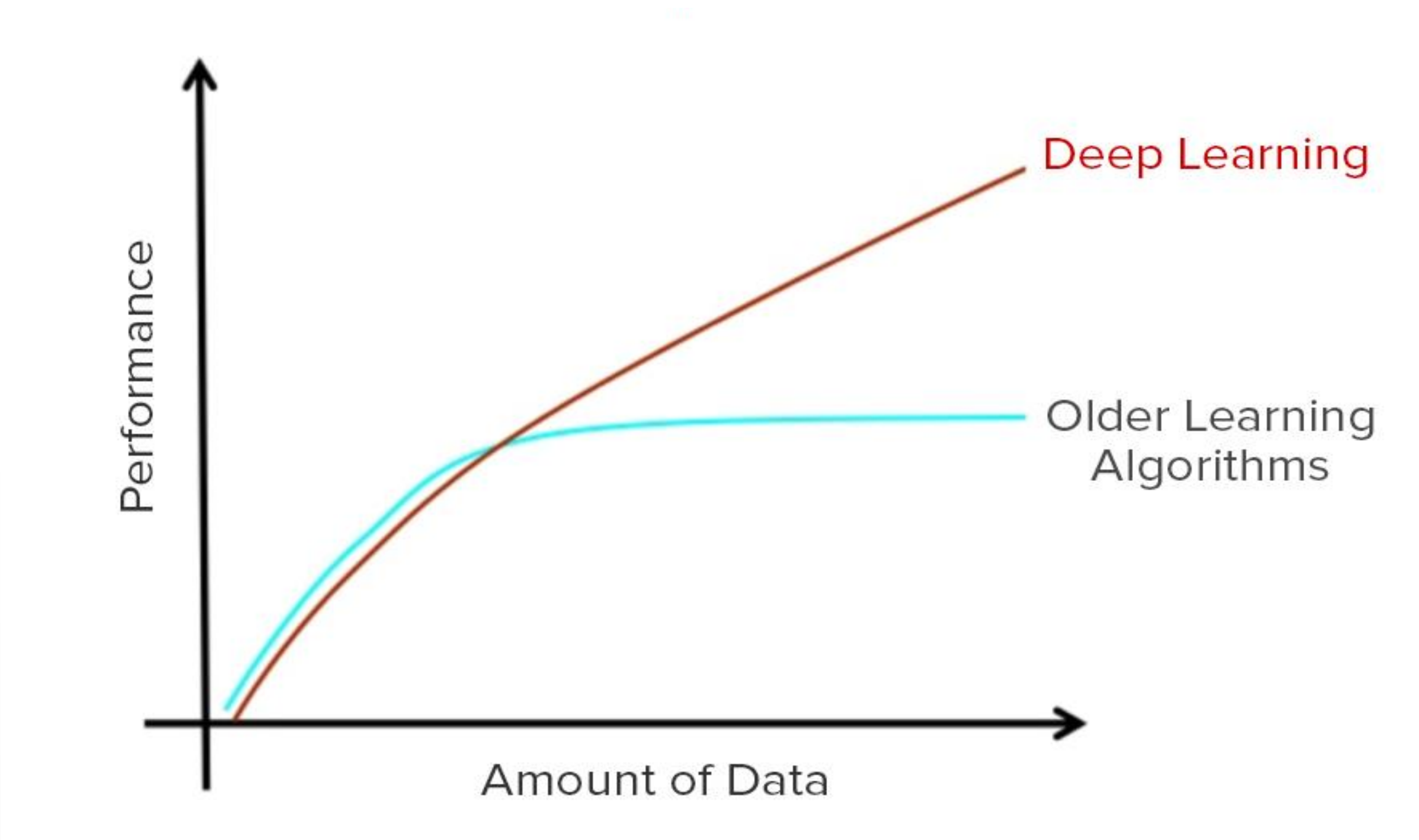


Image credit: Andrew Ng

Why Deep Learning is Taking Off?

- Data
- Computing resources
- Algorithms

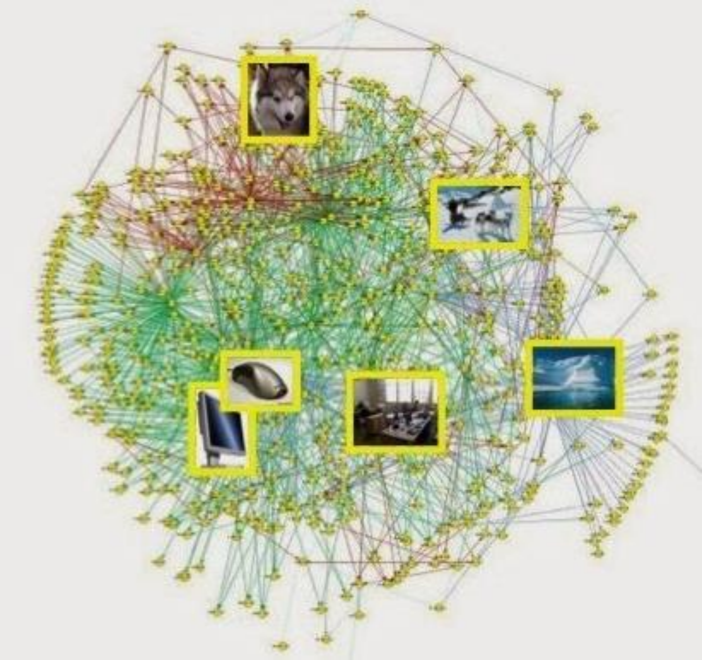


Image credit:
1. https://www.nasa.gov
2. http://www.computervisionblog.com/2015/05/deep-learning-vs-big-data-who-owns-what.html
3. https://www.nvidia.com

Taxonomy of Machine Learning Methods

Supervised

Shallow
- Support Vector Machine
- Logistic Regression
- Perceptron

Deep
- Deep Neural Net
- Convolutional Neural Net
- Recurrent Neural Net

Unsupervised

Shallow
- Denoising Autoencoder
- Restricted Boltzmann machines*
- Sparse coding*

Deep
- Deep (stacked) Denoising Autoencoder*
- Deep Belief Nets*
- Deep Boltzmann machines*
- Hierarchical Sparse Coding*

* supervised version exists

Image credit: Honglak Lee

Supervised Machine Learning

- What is this picture?

Model

predict

CAT

Supervised Machine Learning

- Supervised learning: training and testing.

Cat

Non
-cat

Supervised
Learning

Model

Training
Stage

New
image

Model

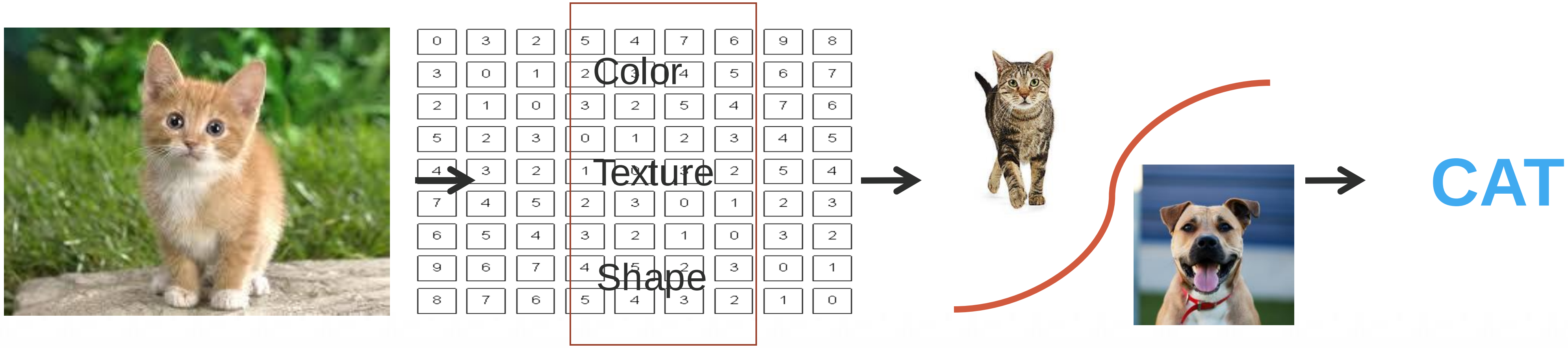
predict

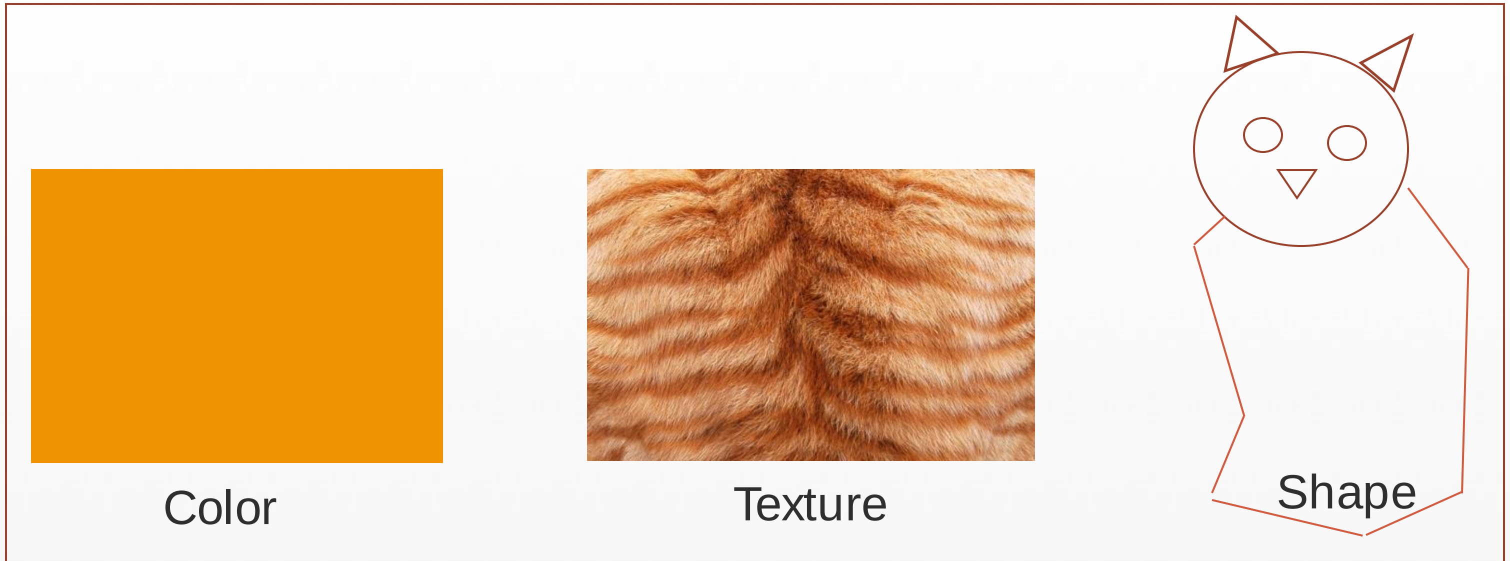
CAT

Testing
Stage

Traditional Machine Learning Recognition

- What is this picture?





Traditional Machine Learning Recognition

- What is this picture?

→

Color

Texture

Shape

→

→ **CAT**

Input images (pixels) → Feature representation (hand-crafted) → Learning algorithms (e.g., SVM) → Object detection/classification

Traditional Machine Learning Recognition

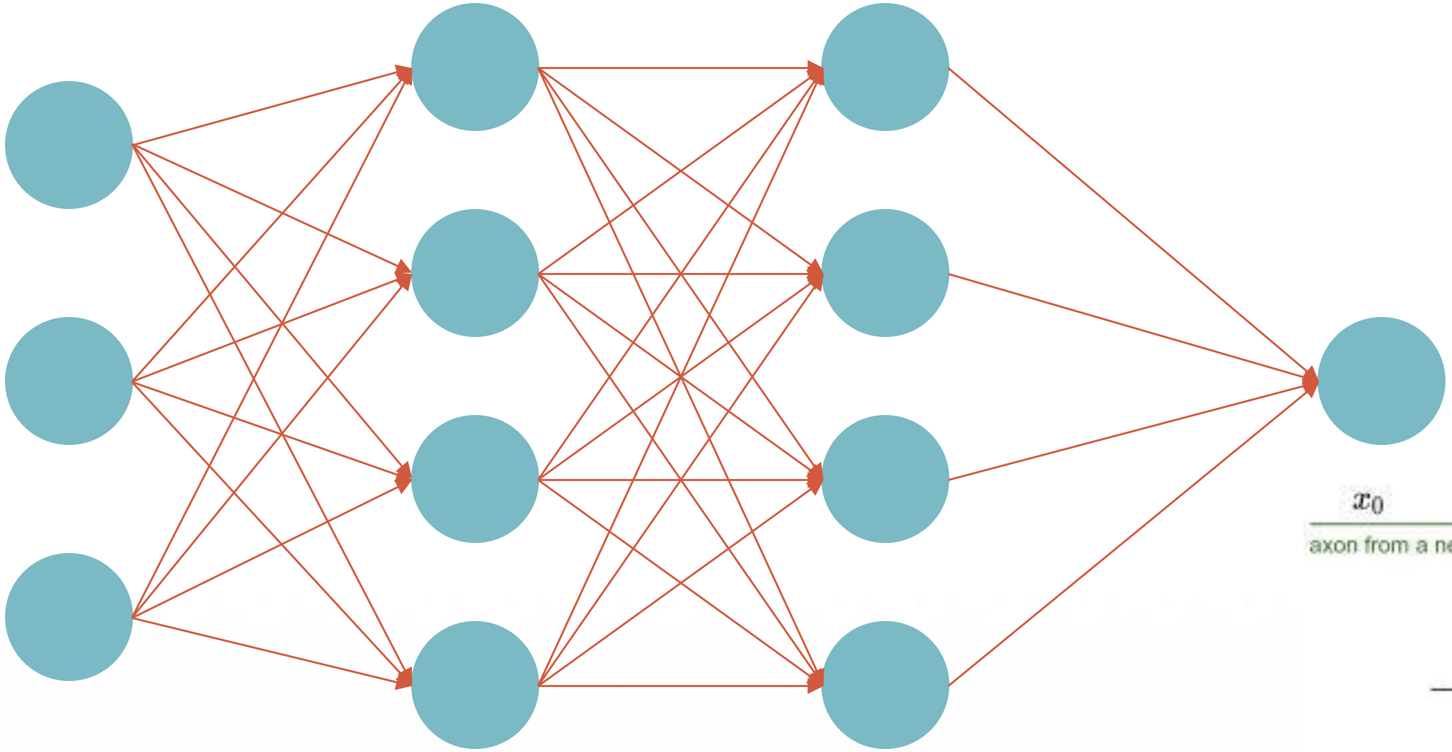
Deep Learning Recognition

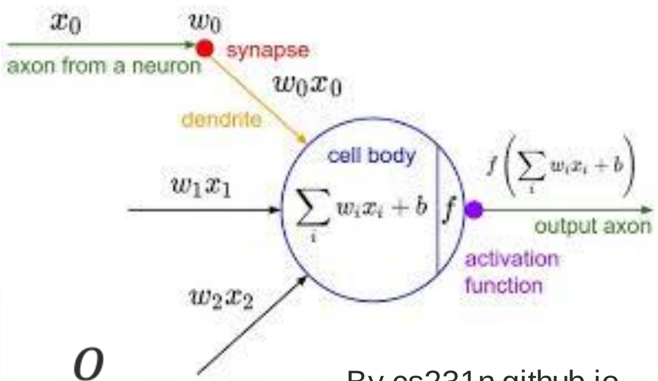
- **Deep neural networks: representation learning from raw image data.**

→ Deep neural networks (representation learning) → ???

Input images (pixels) → Deep neural networks (representation learning) → Prediction

Deep Fully-connected Neural Network

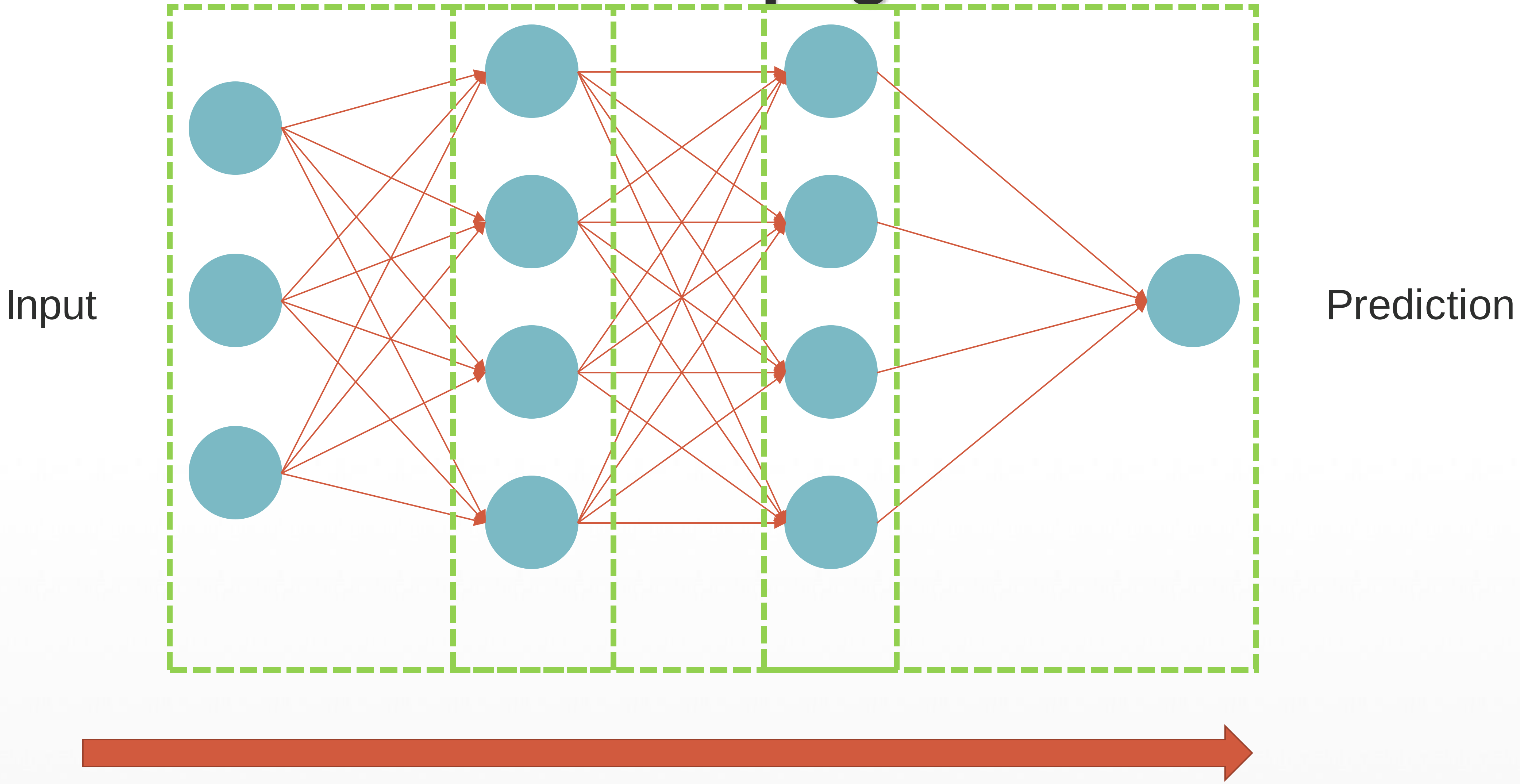




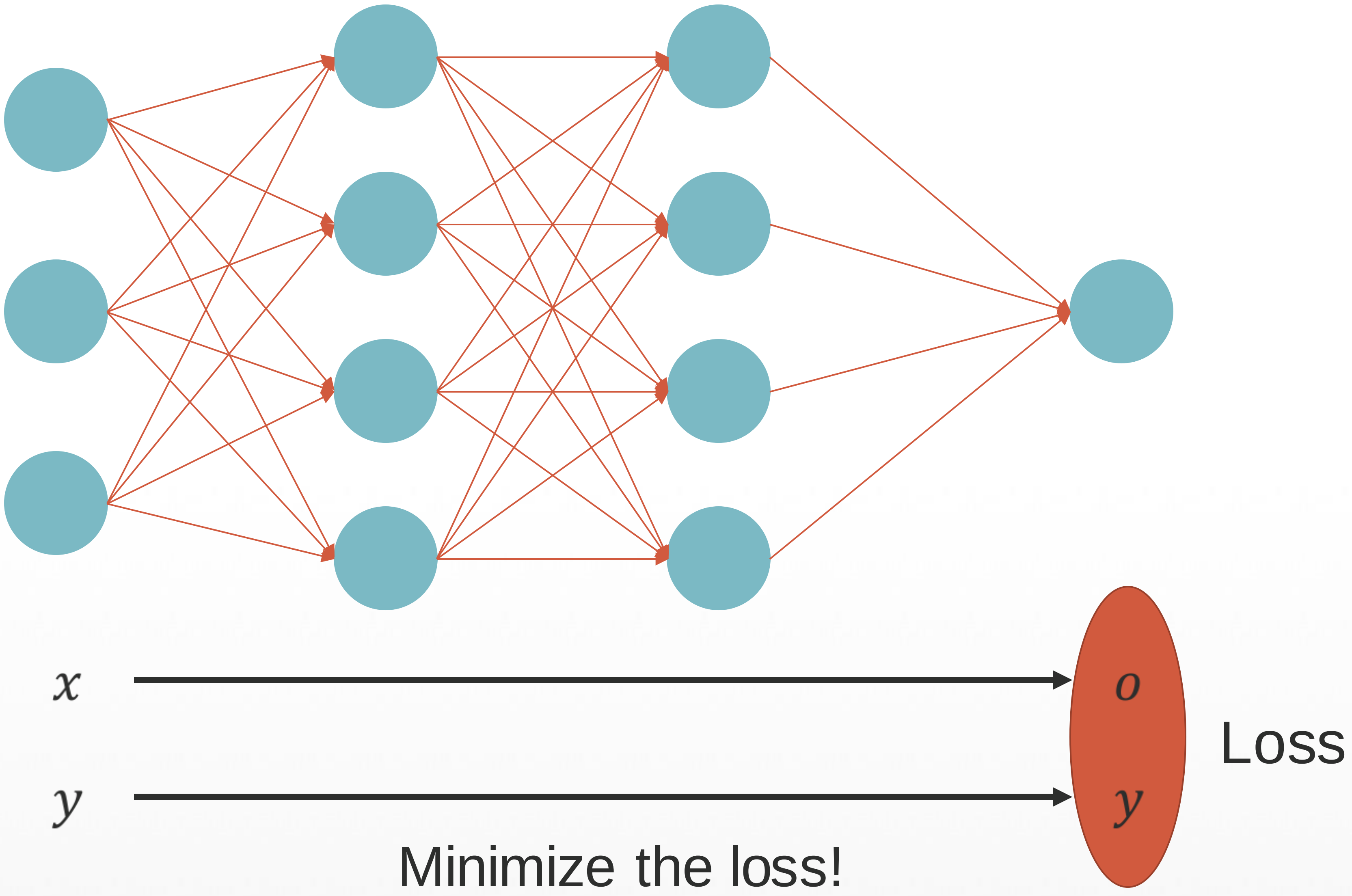
By cs231n.github.io

- Model training: 1) forward propagation, 2) loss computation, 3) backpropagation and parameter update.

Forward Propagation



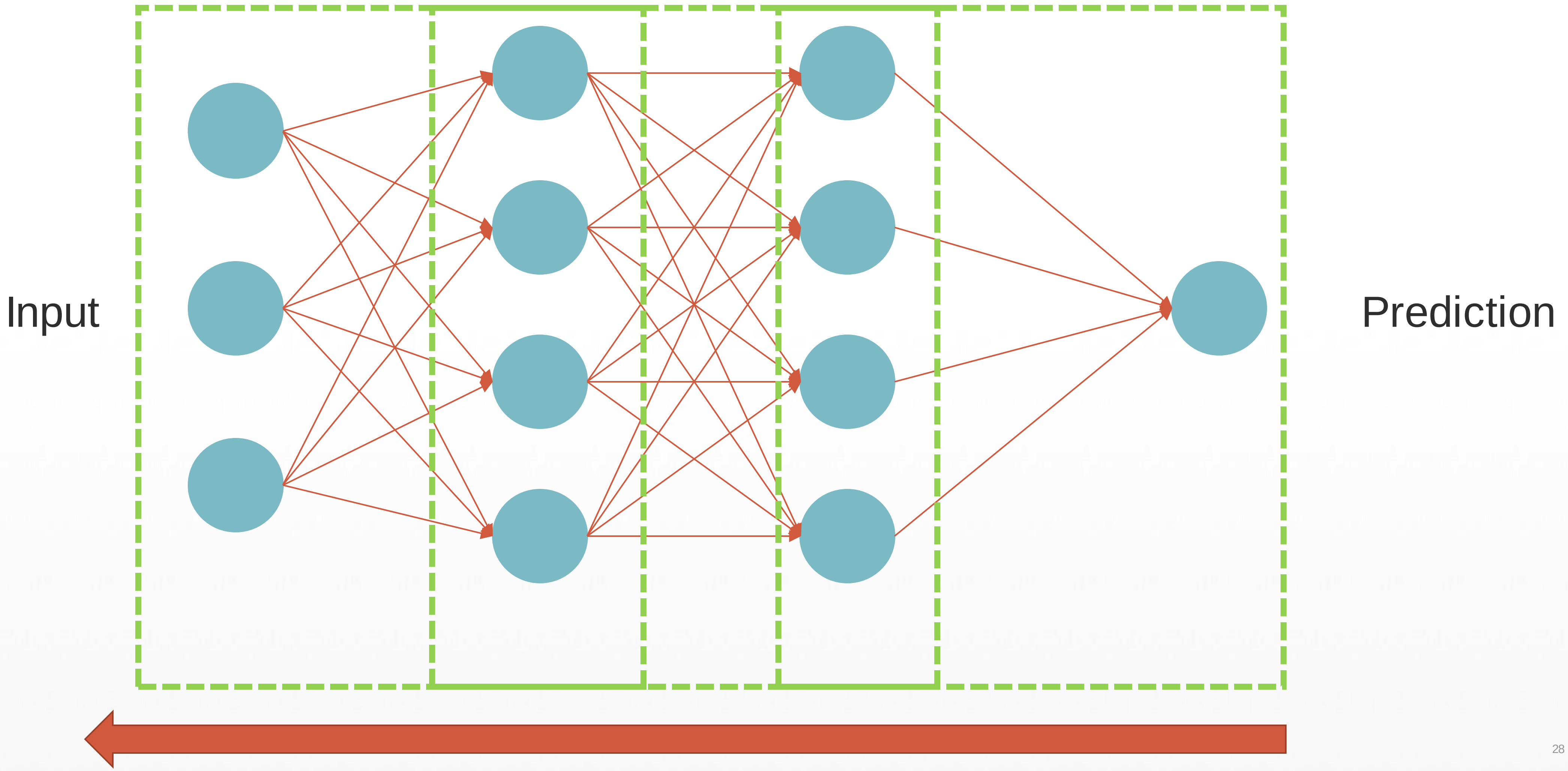
Loss Computation



x: input
y: label
o: prediction

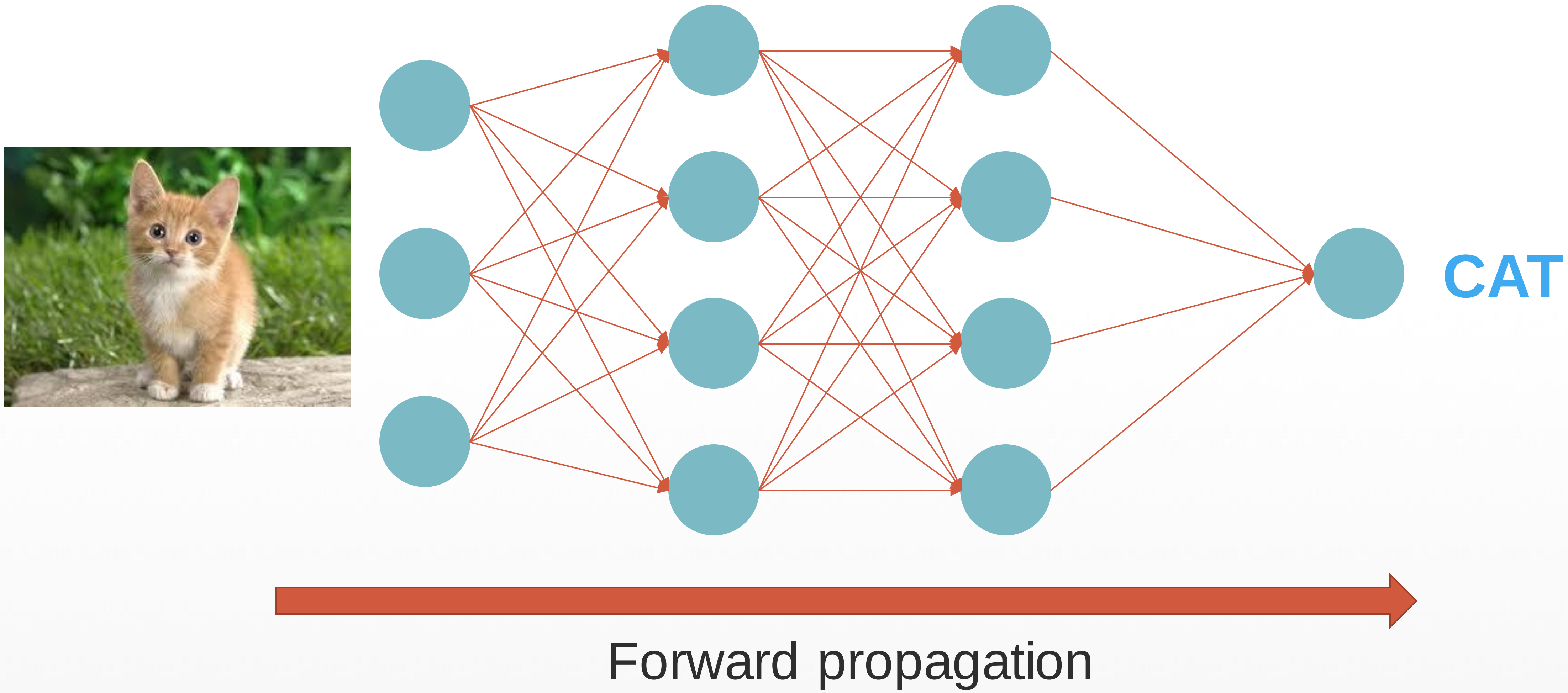
Backpropagation

- Compute gradients of loss w.r.t. to parameters using the chain rule.



Testing

- Model inference or testing: only conduct forward propagation



Convolutional Neural network (CNN)

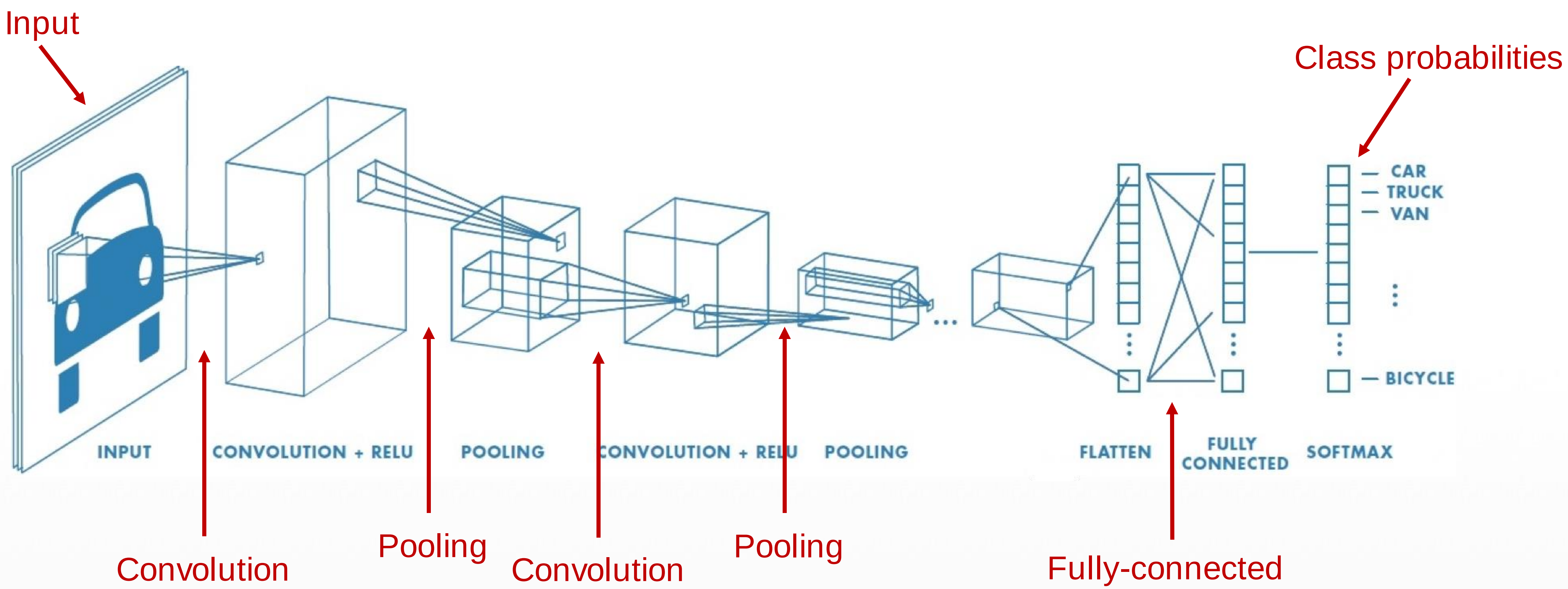


Image credit: Mathworks

Convolutional Neural network (CNN)

- Fully connected: each unit in the current layer connects all units in the previous layer.
- For a 200 x 200 image with 40000 hidden units
  - **1.6 billion** parameters
- A deep neural network would have multiple layers.

- **One solution: weight sharing!**

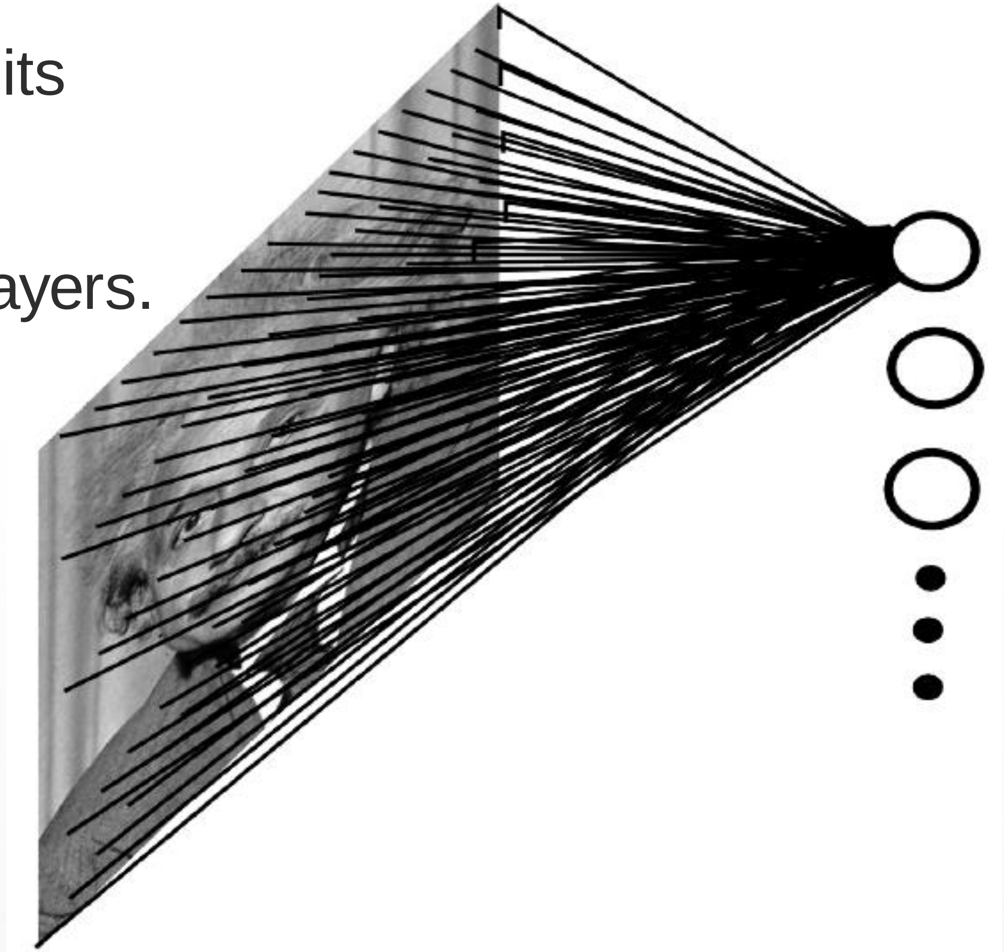


Image credit: LeCun Yann and Marc'Aurelio Ranzato

Convolutional Layer

- Convolutional layer: share parameters across different locations.

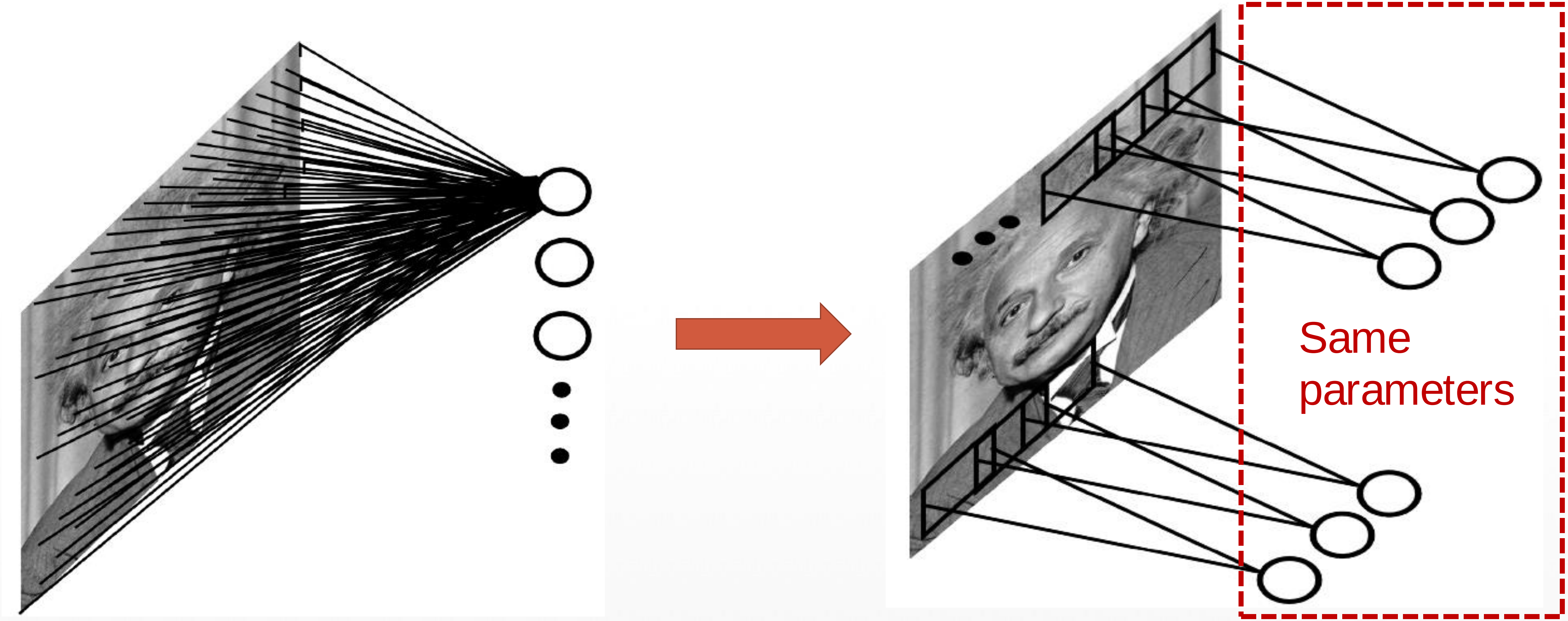
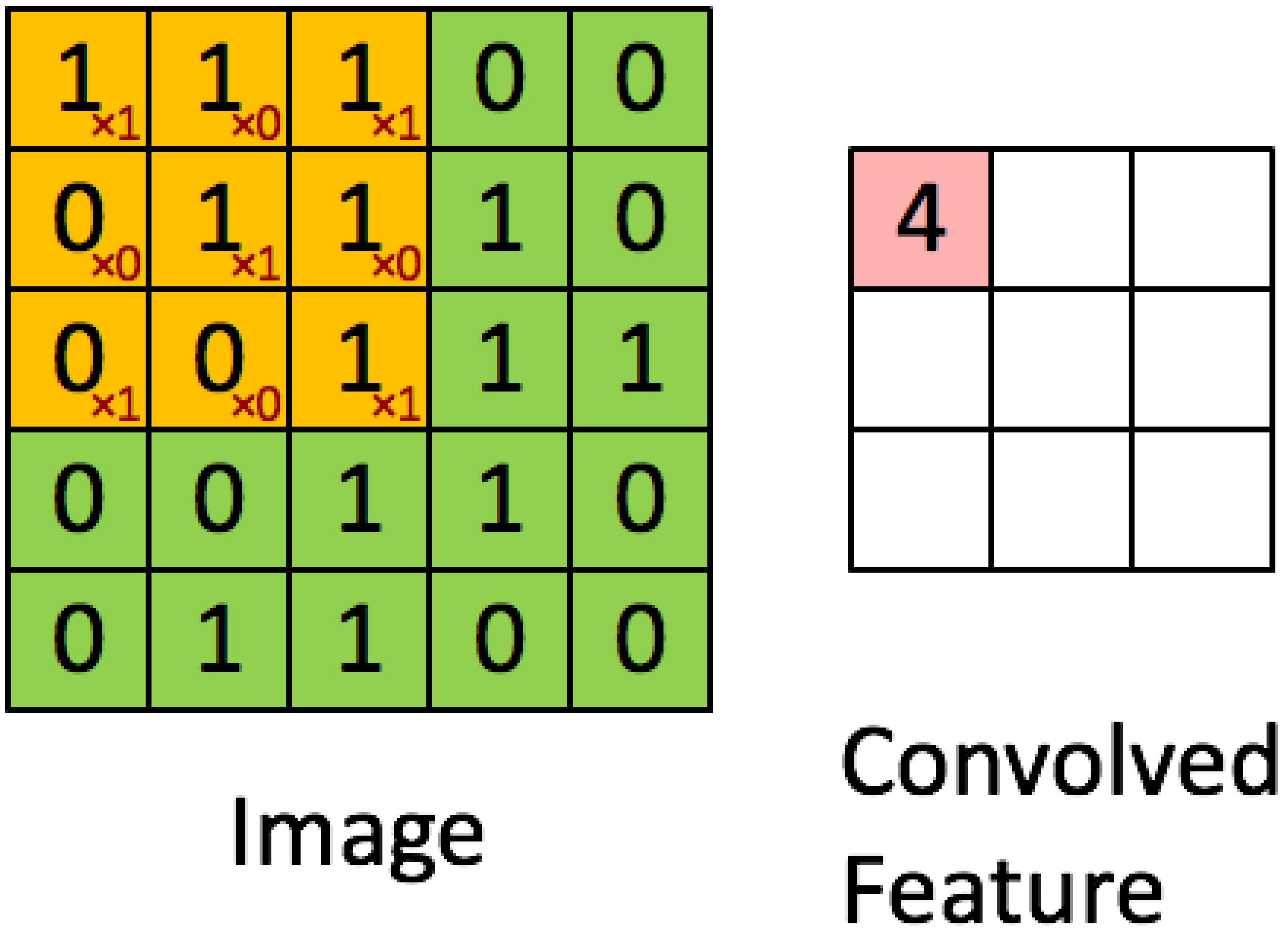


Image credit: LeCun Yann and Marc'Aurelio Ranzato

Convolutional Layer

1	0	1
0	1	0
1	0	1

Kernel



1. http://www.wildml.com/2015/11/understanding-convolutional-neural-networks-for-nlp/

Convolutional Layer

- Learn multiple kernels.
- For a 200 x 200 image with 100 kernels
    - Filer size: 10 x 10
    - Parameters: 10K

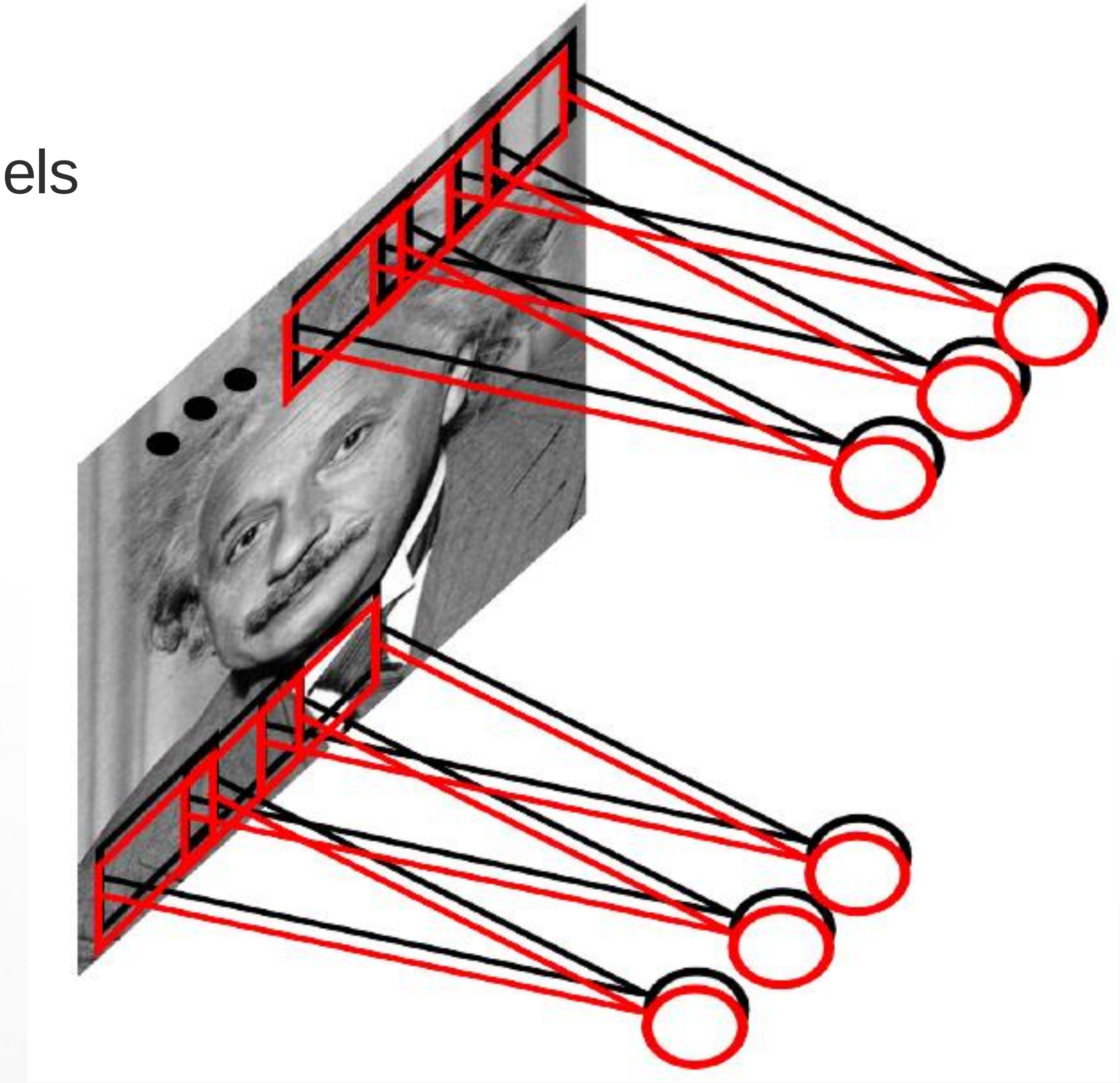


Image credit: LeCun Yann and Marc'Aurelio Ranzato

Convolutional Layer

- Filters learned in the first convolutional layer in CNN (AlexNet).

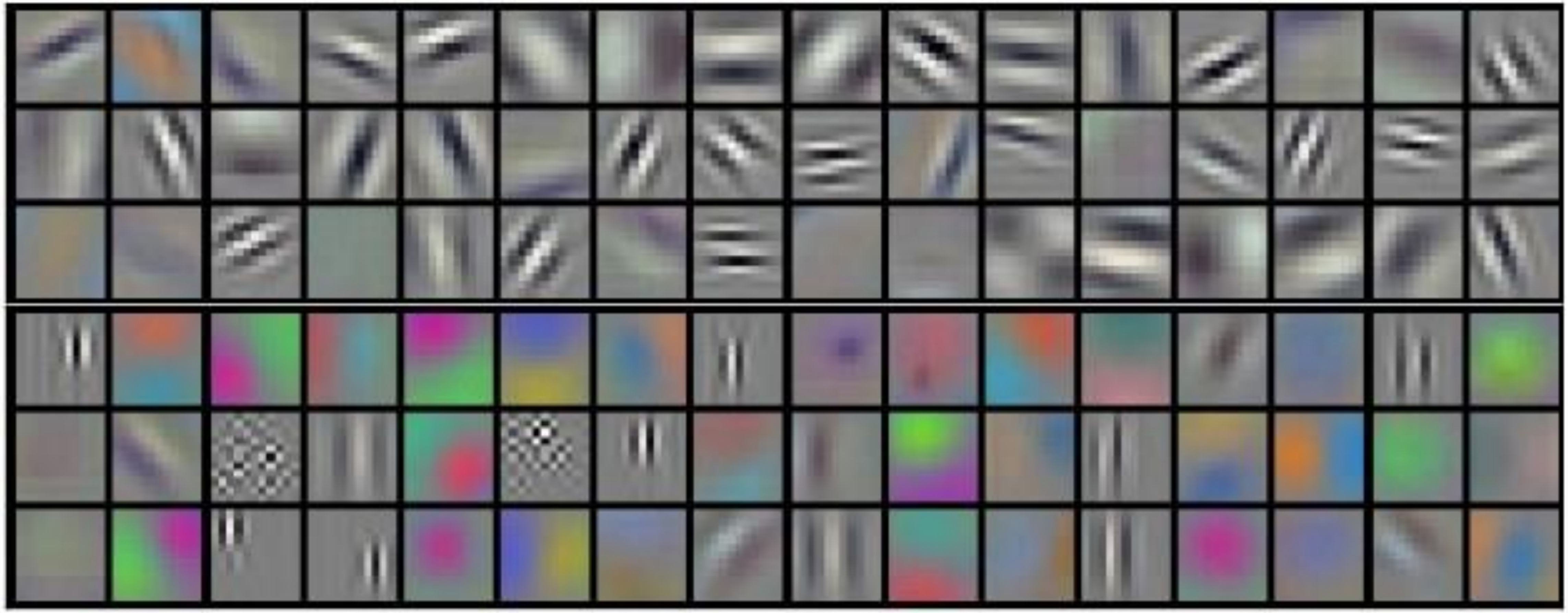
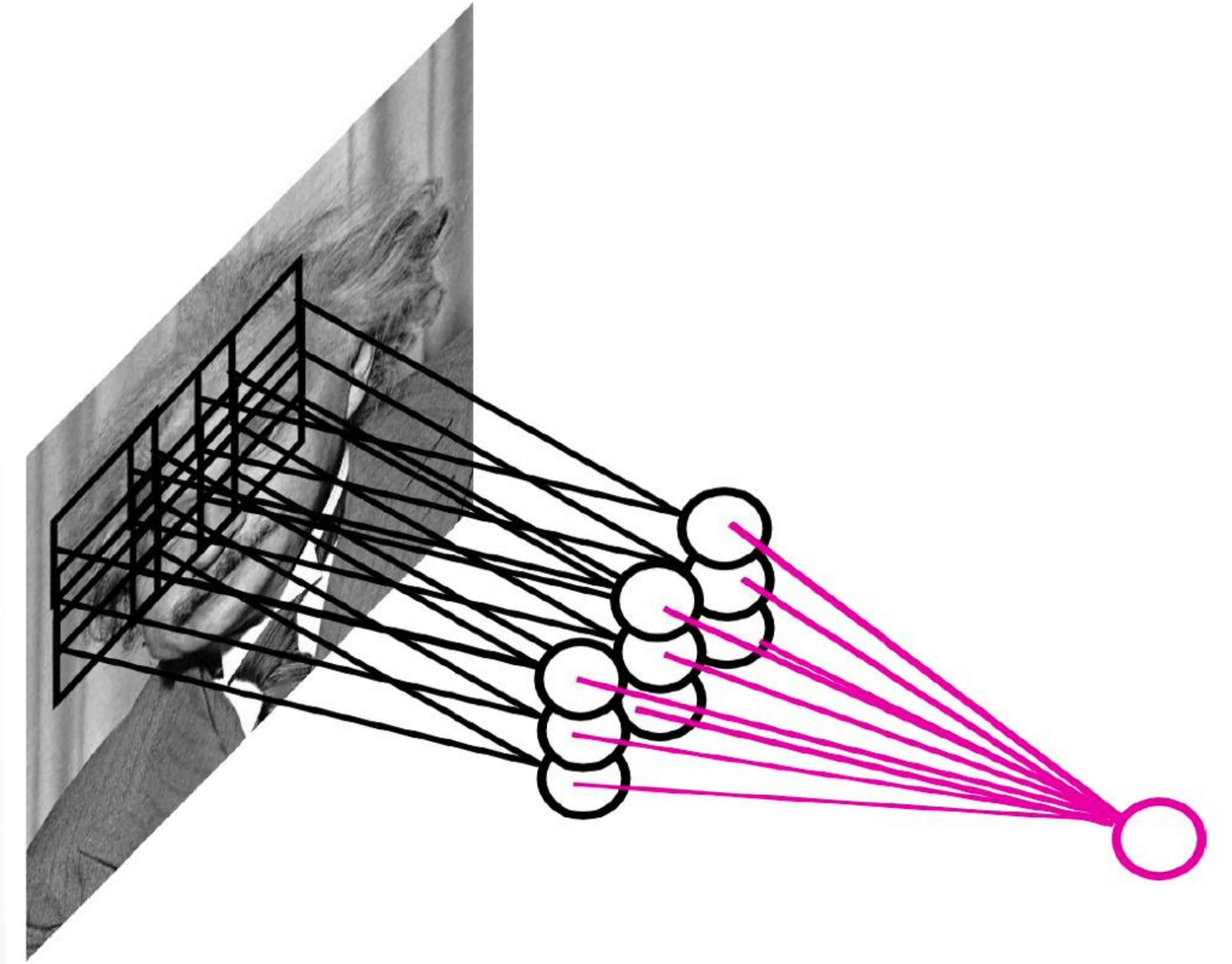
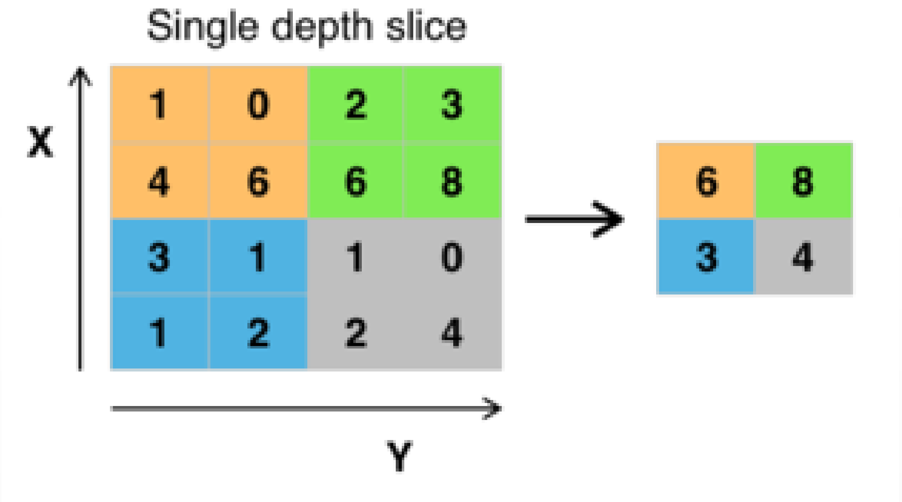


Image credit: cs231n

Pooling Layer

- Pooling: robust to small distortions and reduce number of units.





Max pooling: 2 x 2

Image credit: LeCun Yann and Marc'Aurelio Ranzato

CNN Achievements

- LeNet
- AlexNet
- VGGNet
- GoogLeNet (and variants)
- ResNet

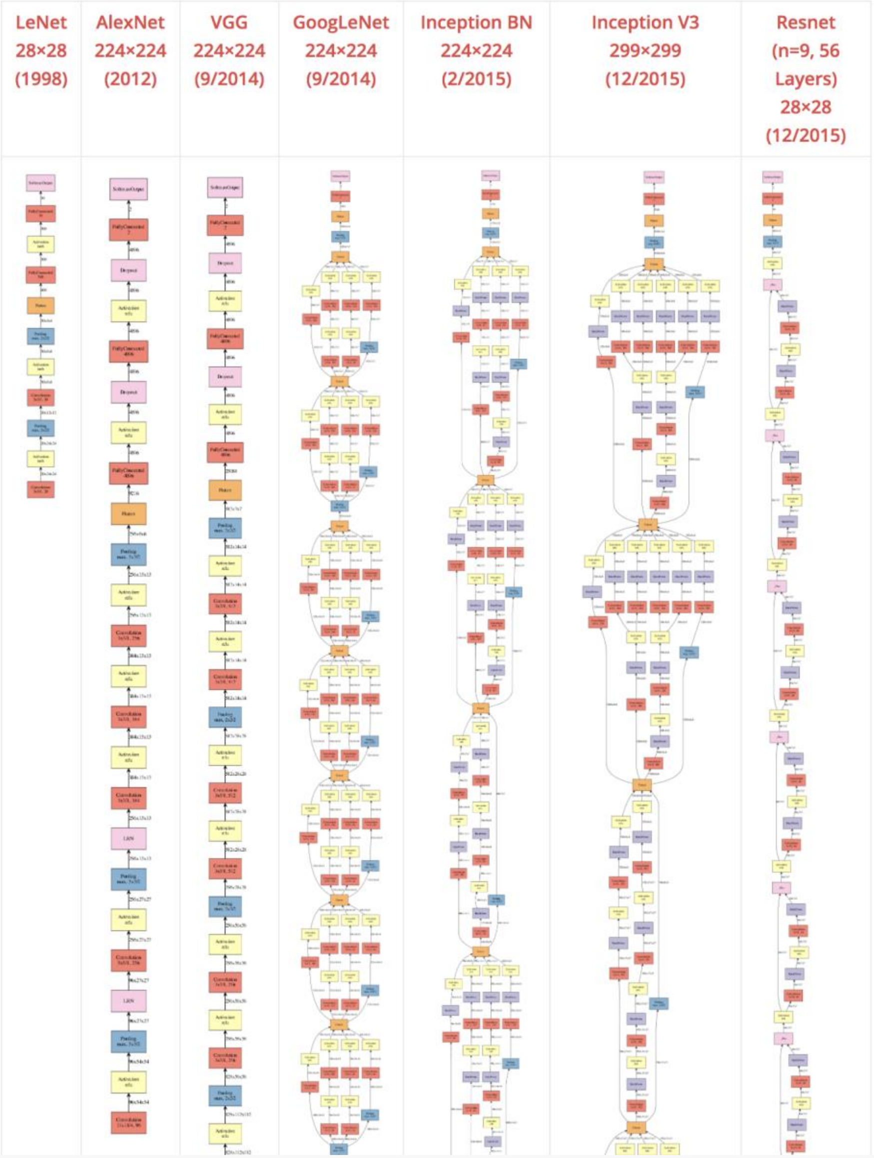
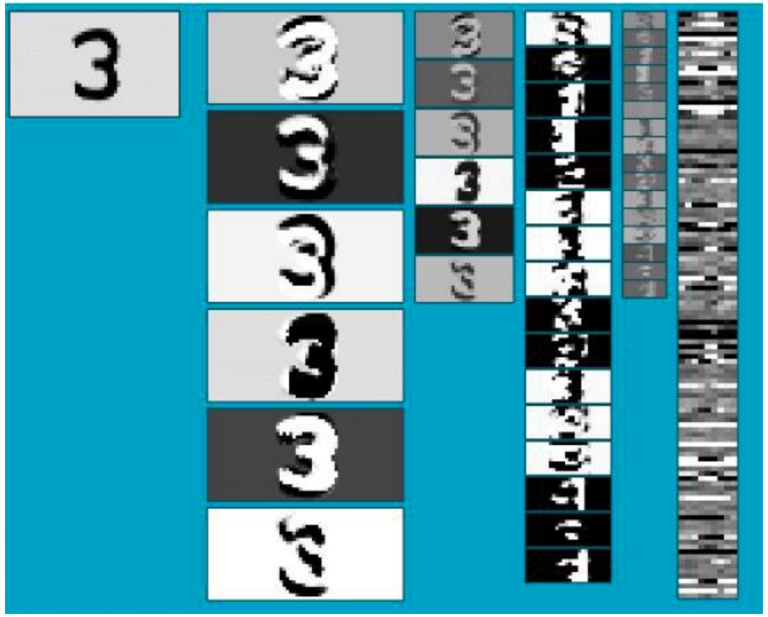
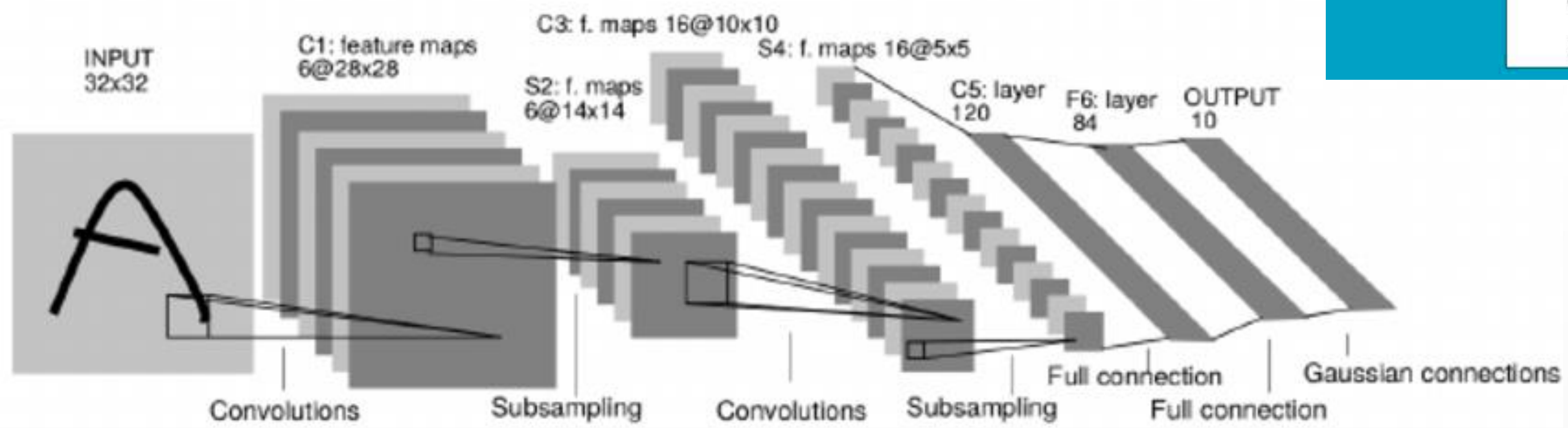


Image credit: http://josephpcohen.com/w/visualizing-cnn-architectures-side-by-side-with-mxnet/

CNN Achievements

- LeNet: handwritten digit recognition

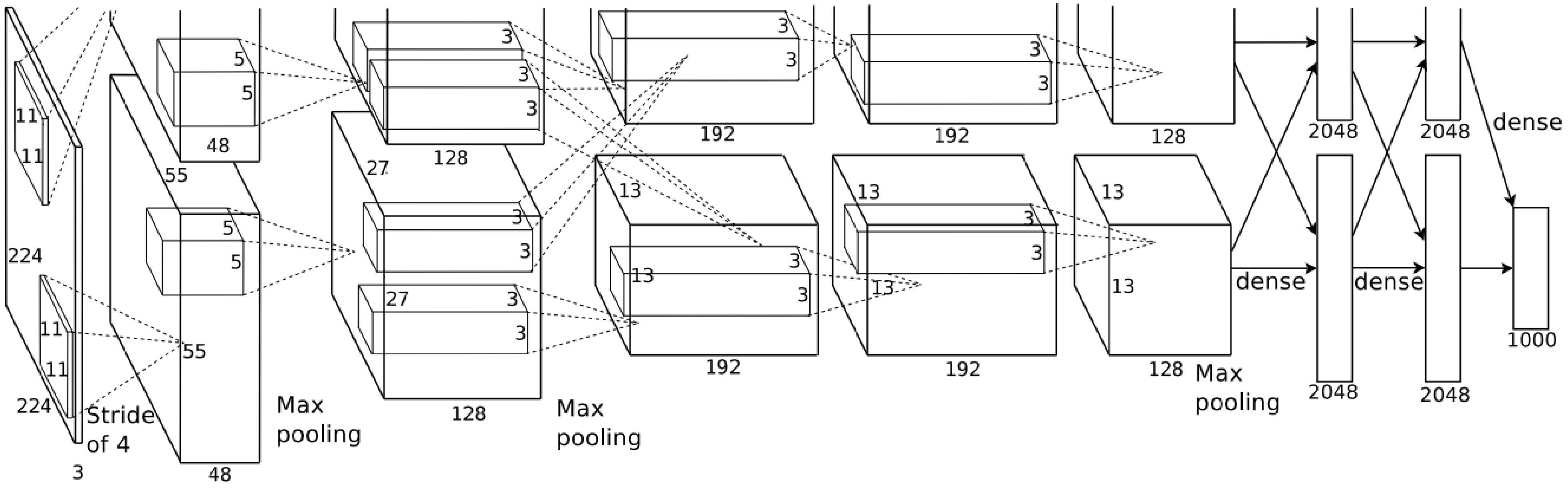




1. Y. LeCun, L. Bottou, Y. Bengio, and P. Haffner. “Gradient-based learning applied to document recognition”, *Proceedings of the IEEE*, 1998

CNN Achievements

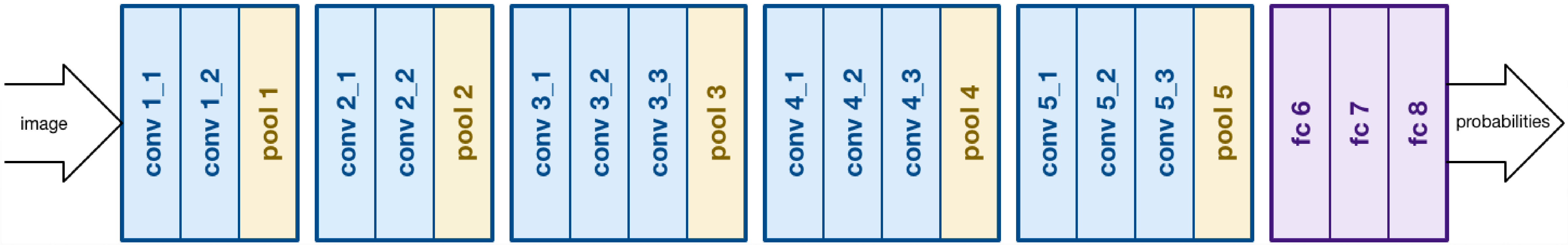
- AlexNet: image classification
- Winner of ImageNet ILSVRC 2012: top-5 error is **15.3% (8 layers).**
- Second place: top-5 error is **26.2%.**



1. A. Krizhevsky et al.,. "ImageNet Classification with Deep Convolutional Neural Networks", *NIPS*, 2012

CNN Achievements

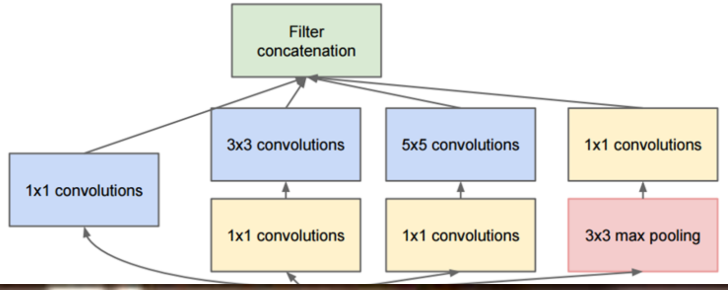
- VGGNet: image classification
- Simple and deep: only 3 x 3 kernels
- Top-5 error: 7.3% (19 layers)

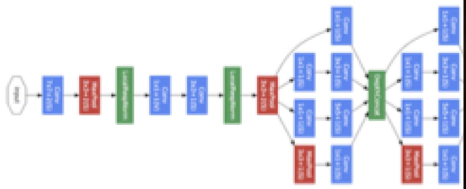


1. K. Simonyan, A. Zisserman, "Very Deep Convolutional Networks for Large-Scale Image Recognition", *arXiv*, 2014
2. Image credit: http://machinethink.net/blog/convolutional-neural-networks-on-the-iphone-with-vggnet/

CNN Achievements

- GoogLeNet: image classification
- Winner of ILSVRC 2014
- Top-5 error: 6.7% (22 layers)

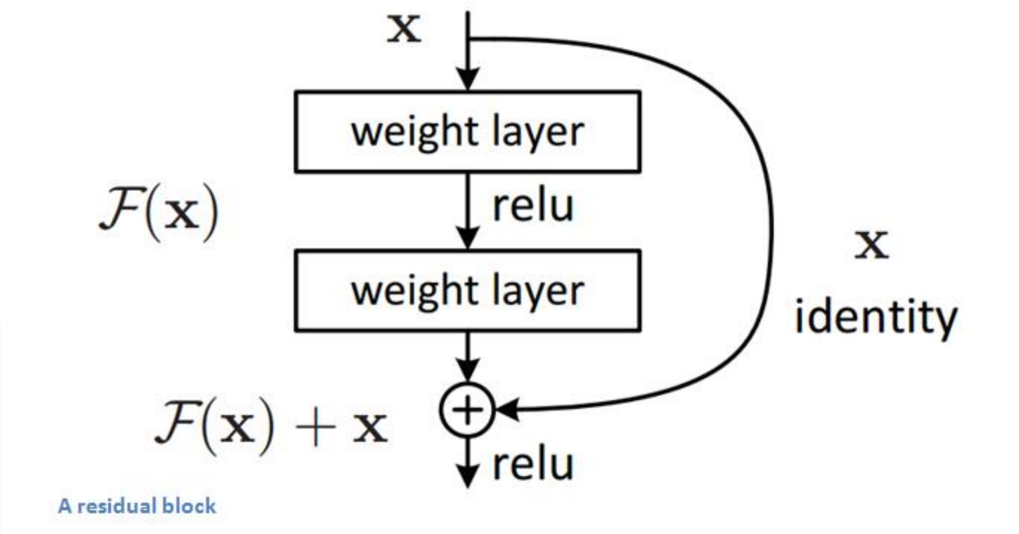


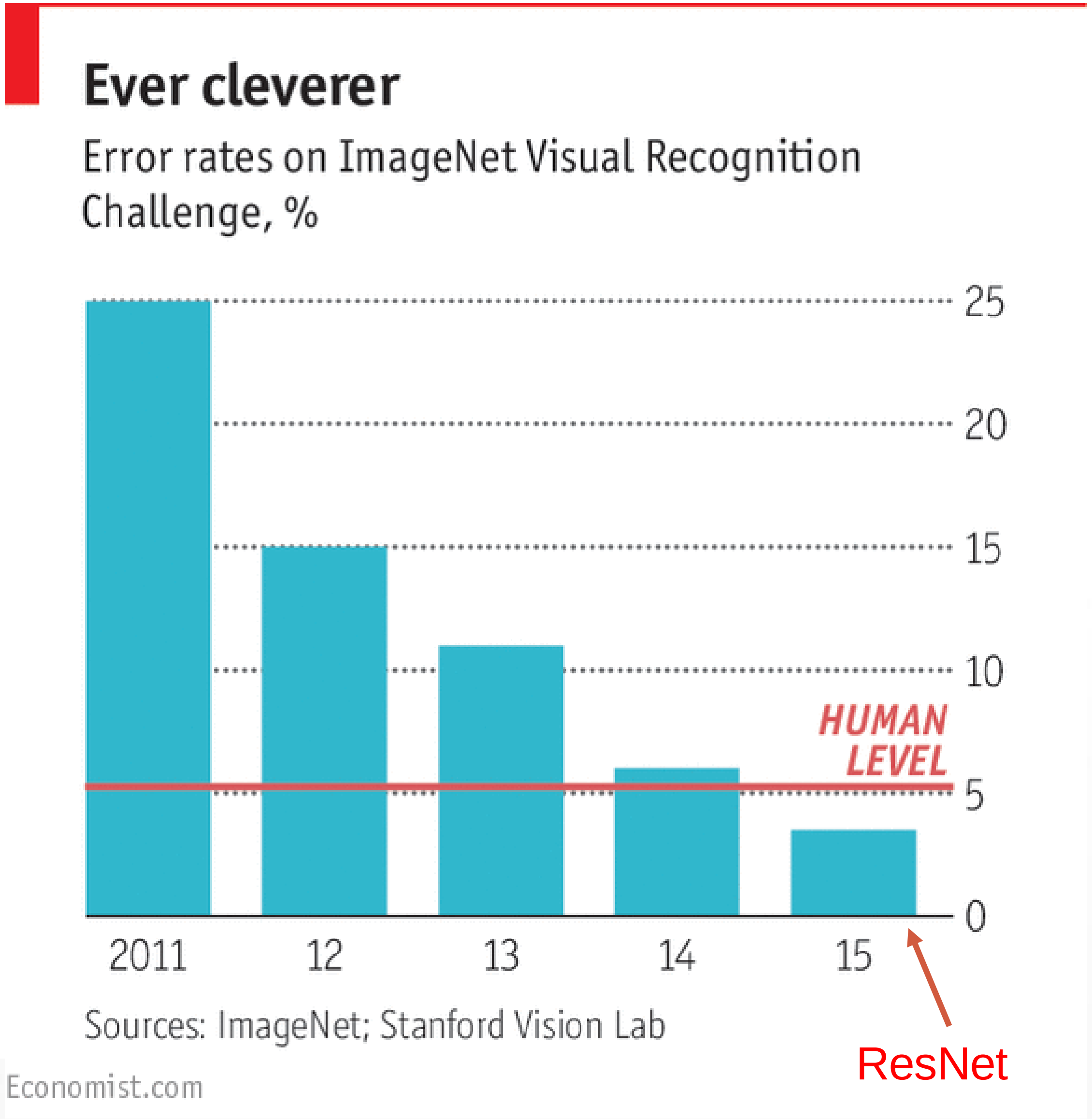


1. C. Szegedy et al., “Going Deeper with Convolutions”, *CVPR*, 2015
2. http://knowyourmeme.com/memes/we-need-to-go-deeper

CNN Achievements

- ResNet: image classification
- Winner of ILSVRC 2015
- Best Paper Award in CVPR 2016
- Top-5 error: 3.6% (152 layers)





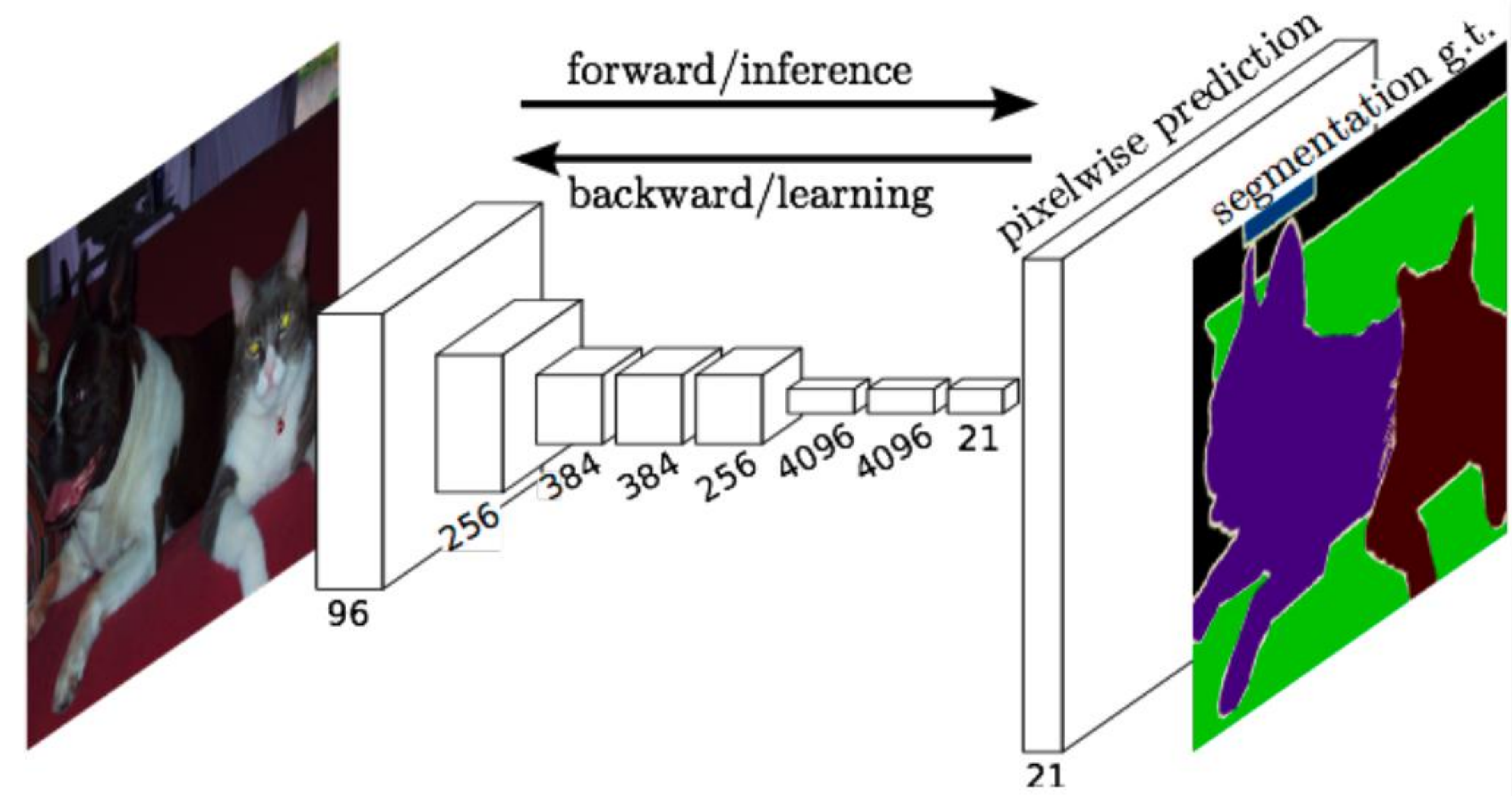
1. K. He, et al., "Deep Residual Learning for Image Recognition", *CVPR*, 2016

Deep Learning Segmentation

- Image Segmentation: pixel-wise labeling.

Fully Convolutional Network (FCN)

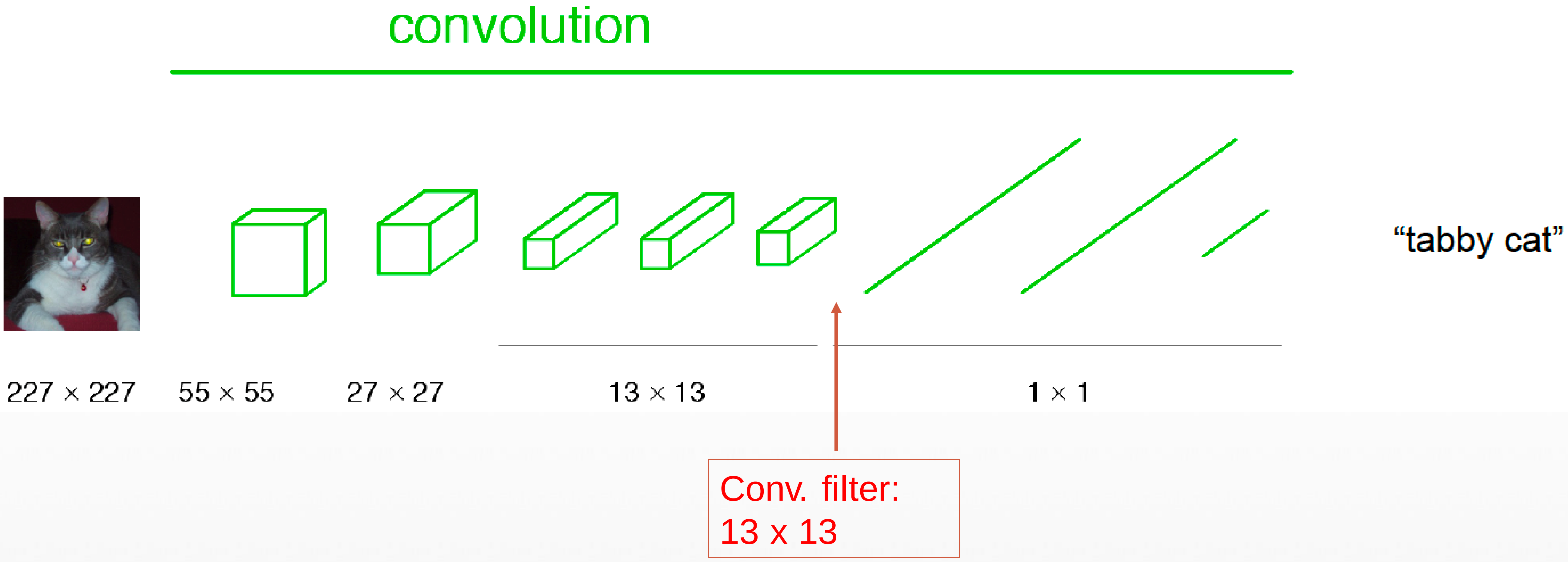
- FCN: end-to-end, pixels-to-pixels modeling.



1. J. Long, et al., "Fully Convolutional Networks for Semantic Segmentation", *CVPR*, 2015

Fully Convolutional Network (FCN)

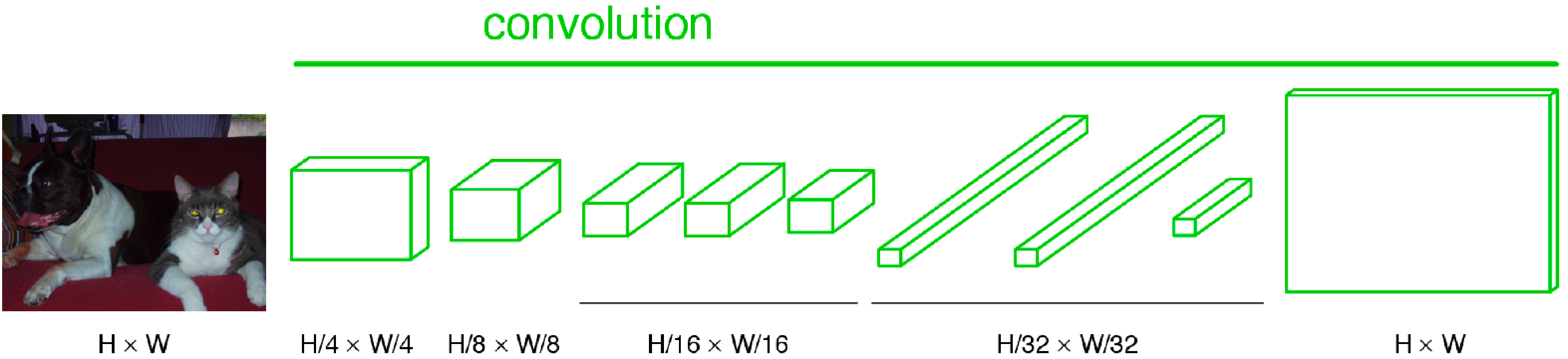
- CNN ⟶ FCN.



1. J. Long, et al., "Fully Convolutional Networks for Semantic Segmentation", *CVPR*, 2015

Fully Convolutional Network (FCN)

- FCN: arbitrary-sized input.



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Fully Convolutional Network (FCN)

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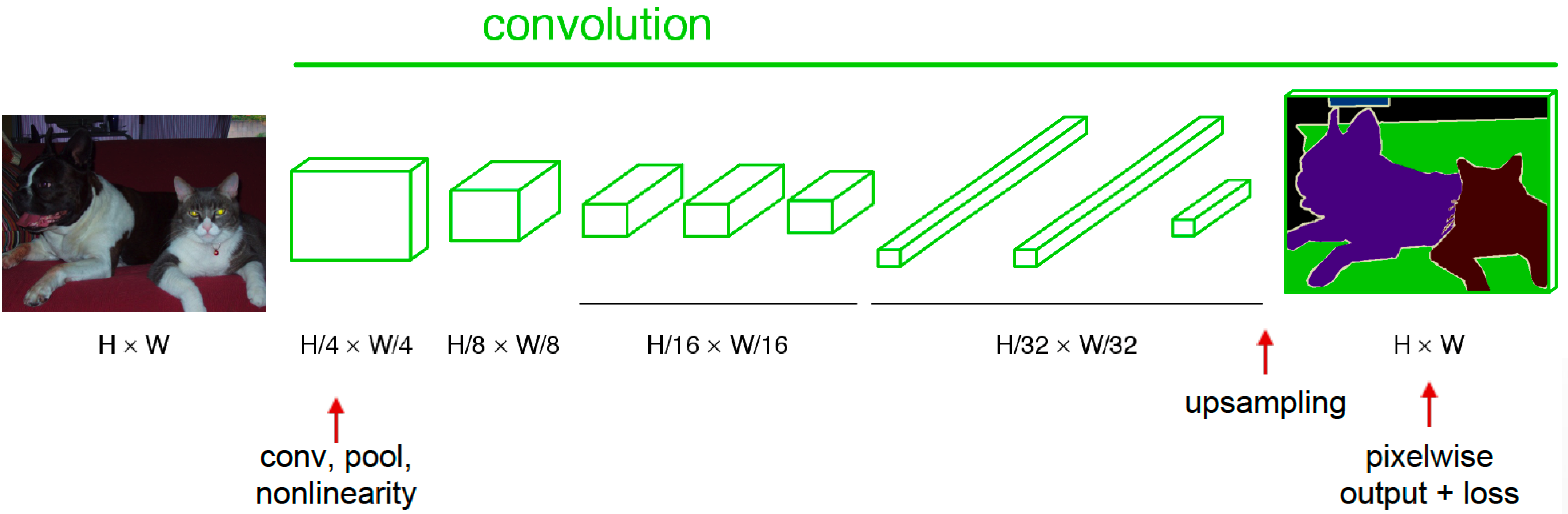


1. J. Long, et al., "Fully Convolutional Networks for Semantic Segmentation", *CVPR*, 2015

Deep Learning in Biomedical Image Computing

- Deep learning has improved biomedical image analysis in many tasks.

Original Investigation | Innovations in Health Care Delivery FREE

December 13, 2016

Development and Validation of a Deep Learning Algorithm for Detection of Diabetic Retinopathy in Retinal Fundus Photographs

Varun Gulshan, PhD[1]; Lily Peng, MD, PhD[1]; Marc Coram, PhD[1]; et al

» Author Affiliations | Article Information

JAMA. 2016;316(22):2402-2410. doi:10.1001/jama.2016.17216

Editorial Comment

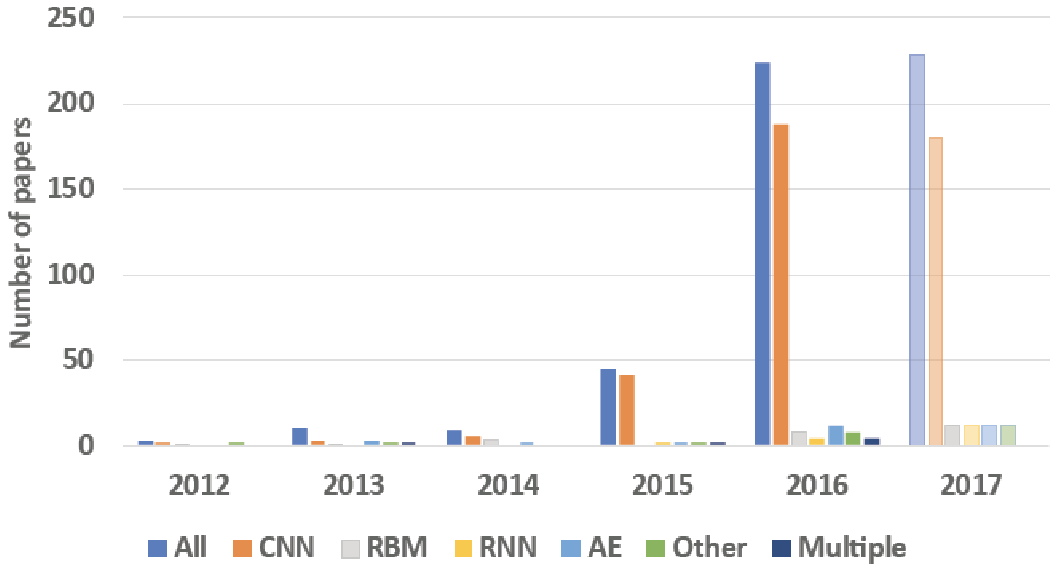
Key Points

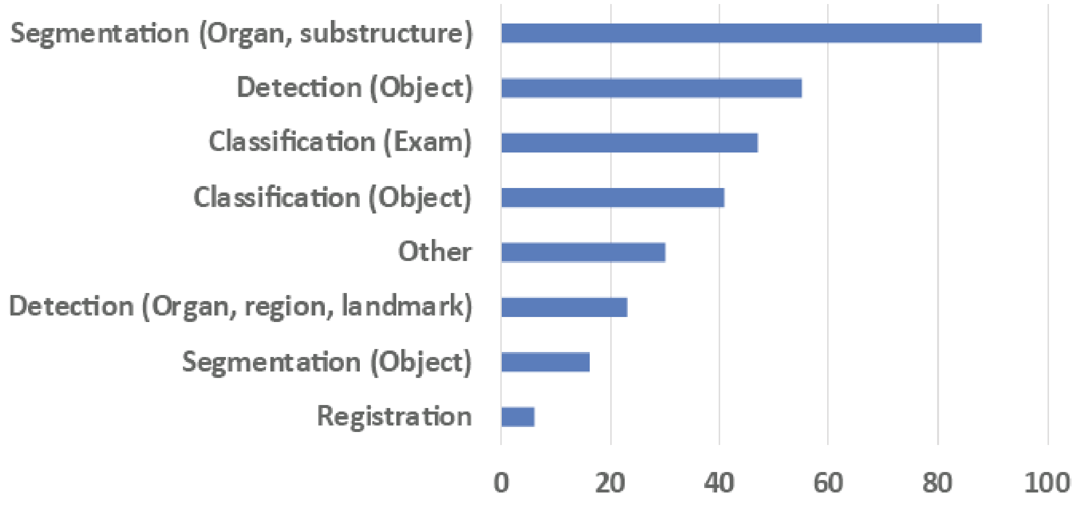
Question How does the performance of an automated deep learning algorithm compare with manual grading by ophthalmologists for identifying diabetic retinopathy in retinal fundus photographs?

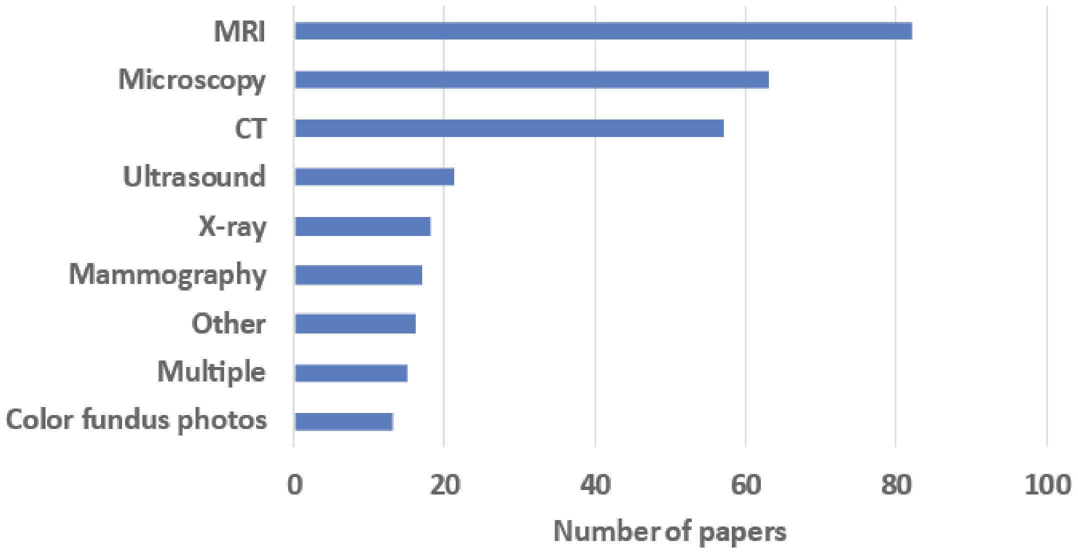
Finding In 2 validation sets of 9963 images and 1748 images, at the operating point selected for high specificity, the algorithm had 90.3% and 87.0% sensitivity and 98.1% and 98.5% specificity for detecting referable diabetic retinopathy, defined as moderate or worse diabetic retinopathy or referable macular edema by the majority decision of a panel of at least 7 US board-certified ophthalmologists. At the operating point selected for high sensitivity, the algorithm had 97.5% and 96.1% sensitivity and 93.4% and 93.9% specificity in the 2 validation sets.

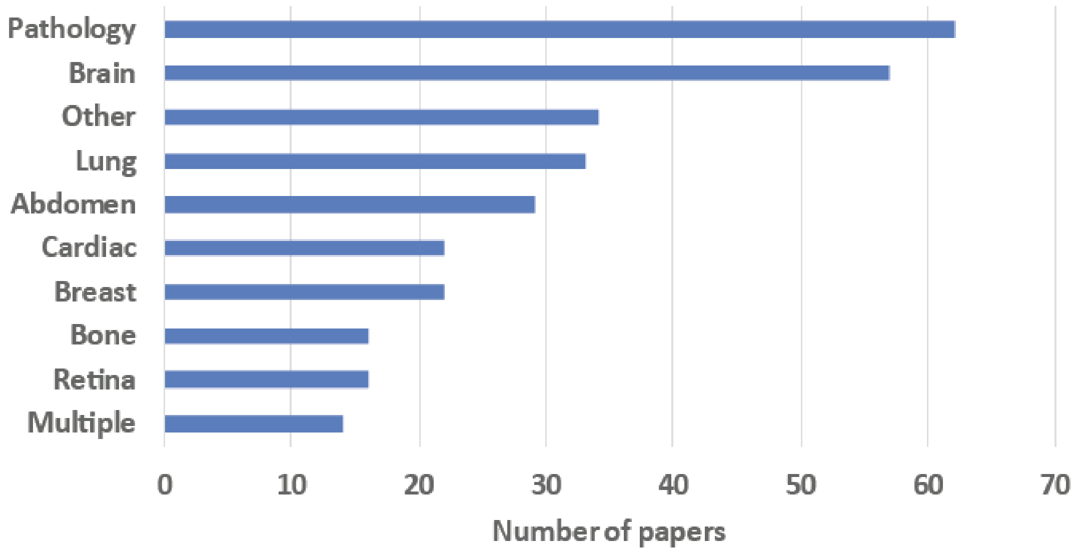
Meaning Deep learning algorithms had high sensitivity and specificity for detecting diabetic retinopathy and macular edema in retinal fundus photographs.

Deep Learning in Biomedical Image Computing





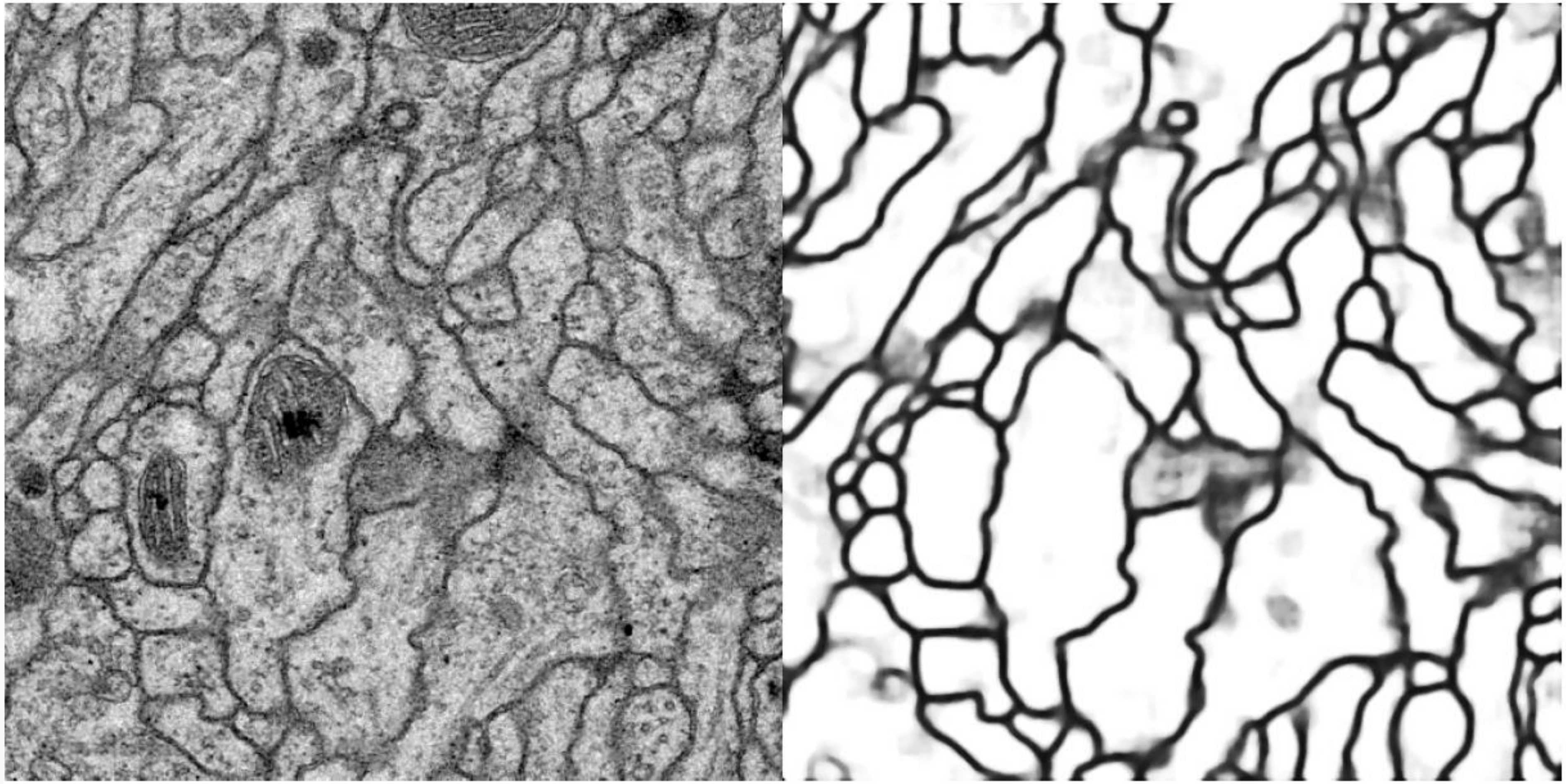




1. G. Litjens, et al., “A survey on deep learning in medical image analysis”, *Medical Image Analysis*, 2017

Biomedical Image Segmentation

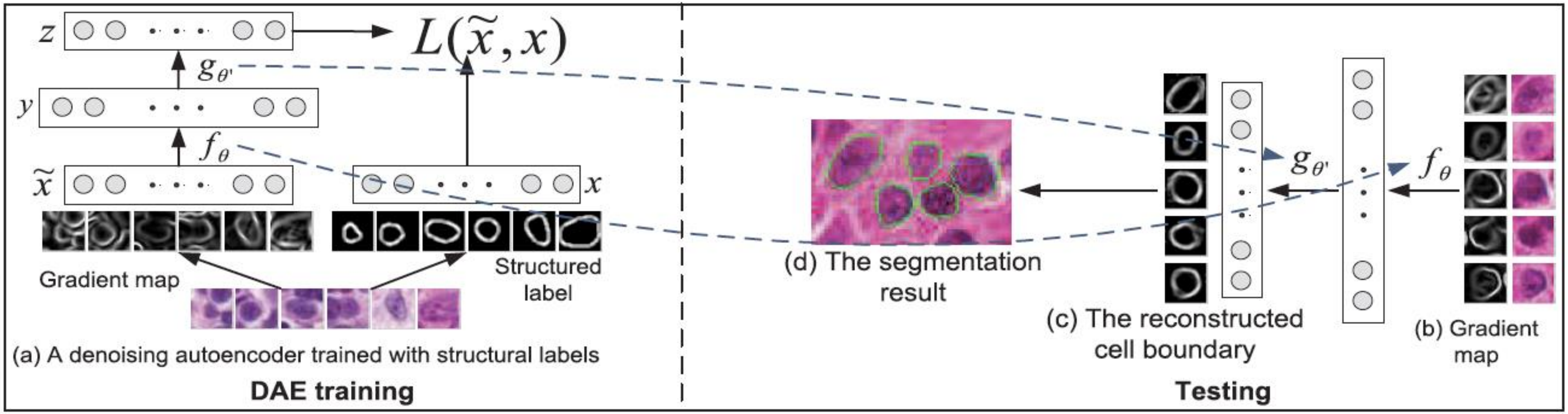
- CNN: neuronal membrane segmentation of 3D volumetric images.
- Winner of ISBI 2012 electron microscopy image segmentation.



1. D.C. Ciresan, et al., “Deep Neural Networks Segment Neuronal Membranes in Electron Microscopy Images”, *NIPS,* 2012

Biomedical Image Segmentation

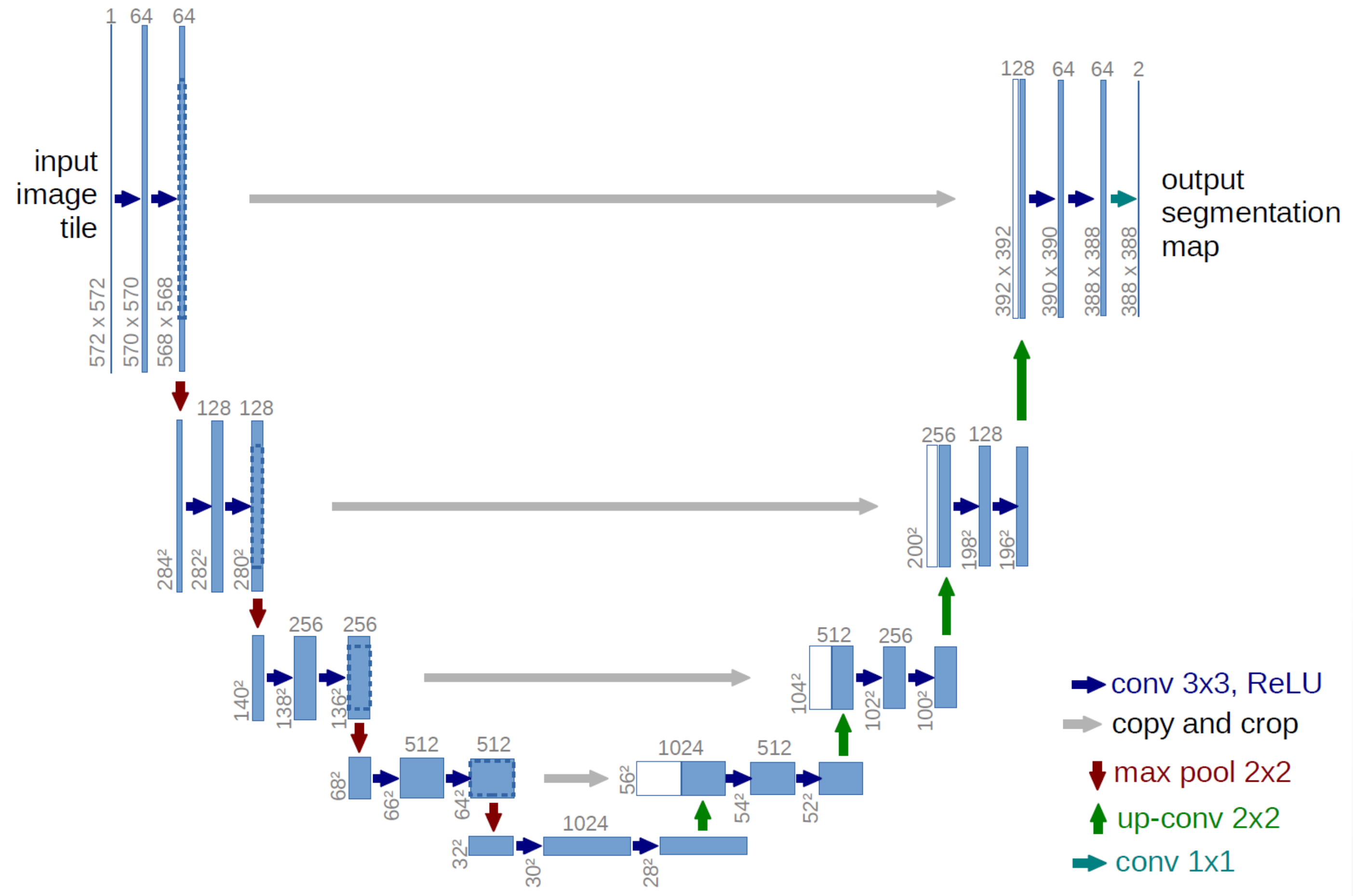
- Stacked denoising autoencoder (sDAE): nucleus segmentation in histopathology images.
- Runners Up for Young Scientist Awards in MICCAI 2015.



1. H. Su, F. Xing, X. Kong, Y. Xie, S. Zhang, and L. Yang, "Robust cell detection and segmentation in histopathological images using sparse reconstruction and stacked denoising autoencoders", *MICCAI*, 2015

Biomedical Image Segmentation

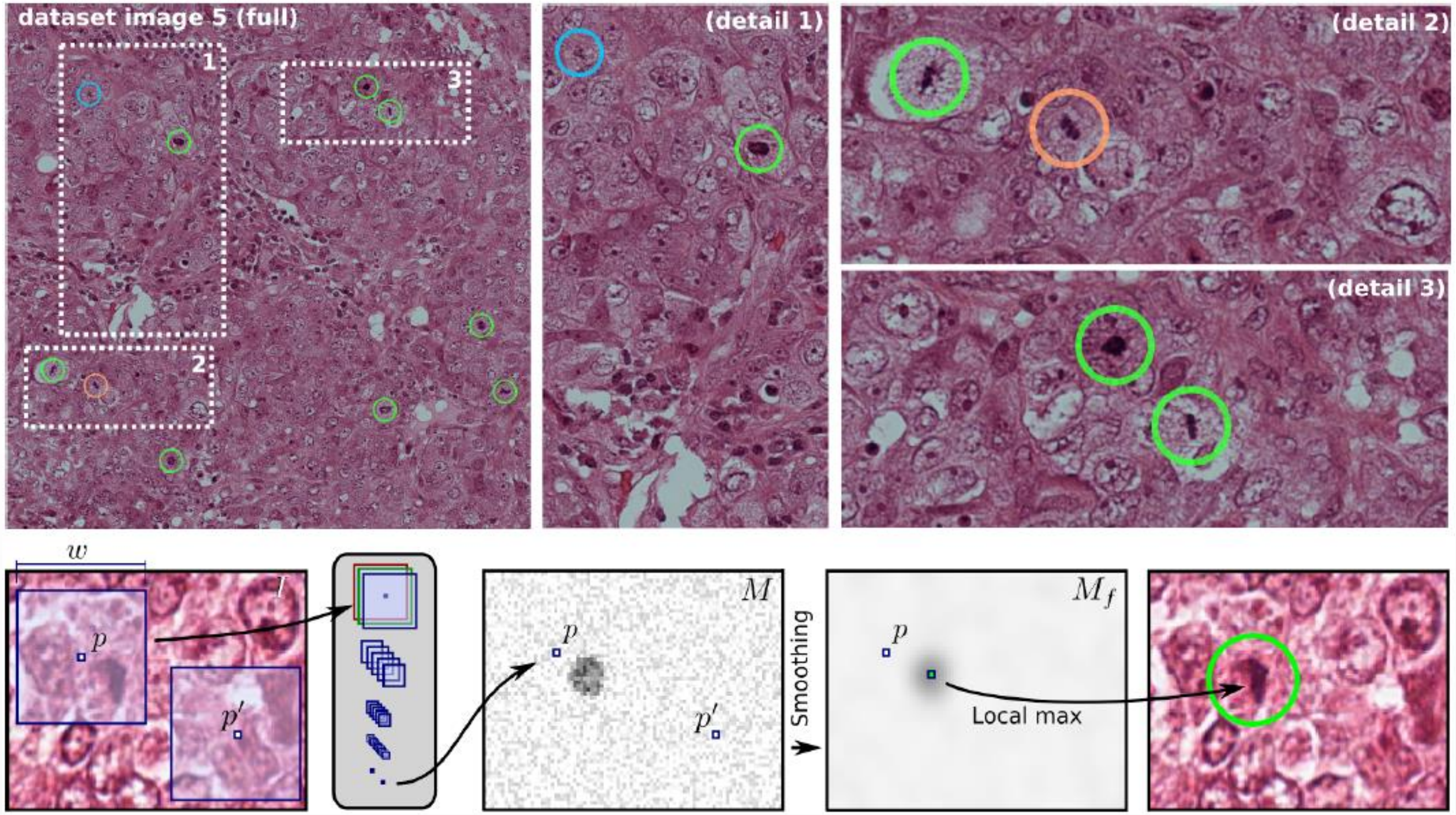
- U-Net: introduces an expansion path and concatenation connection.
- Winner of ISBI 2015 challenges (dental X-ray image segmentation and cell tracking).



1. O. Ronneberger, P. Fischer, T. Brox, “U-Net: Convolutional Networks for Biomedical Image Segmentation”, *MICCAI*, 2015

Detection in Biomedical Images

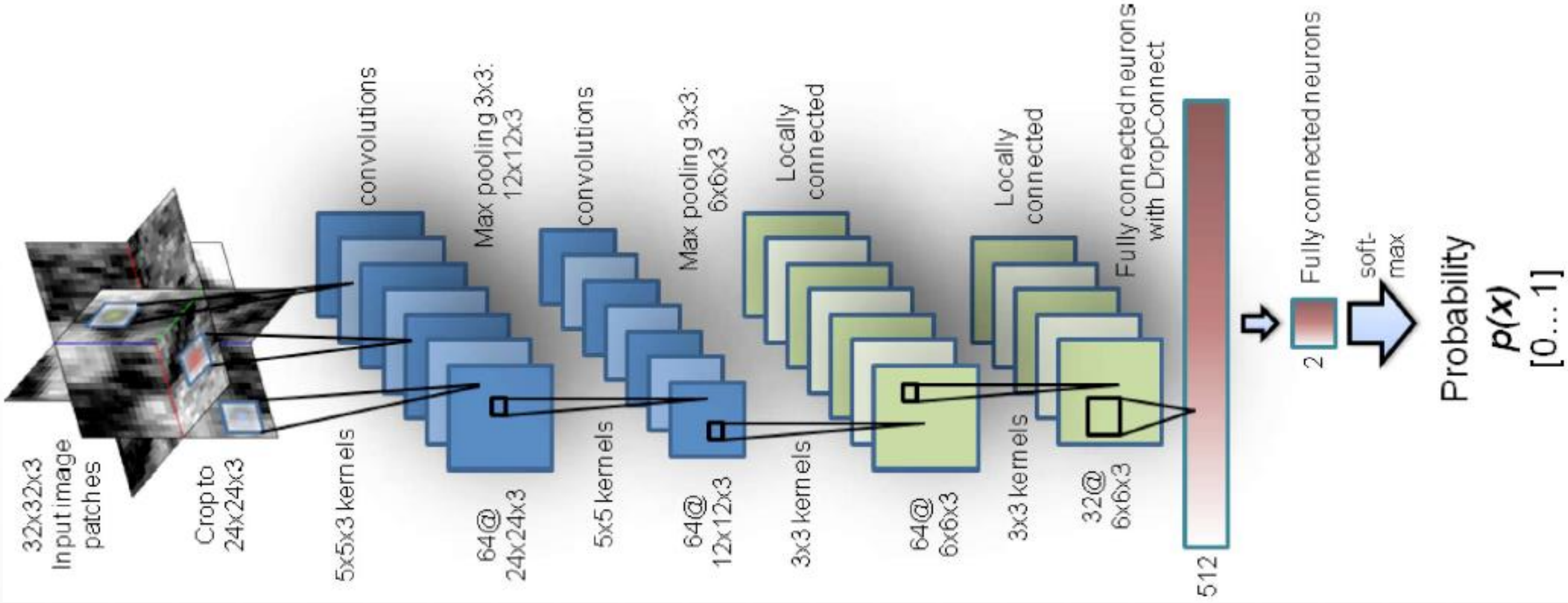
- CNN: mitosis detection in breast cancer histology images.
- Winner of MICCAI 2013 Grand Challenge.



1. D.C. Ciresan, et al., "Mitosis Detection in Breast Cancer Histology Images with Deep Neural Networks", *MICCAI*, 2013

Detection in Biomedical Images

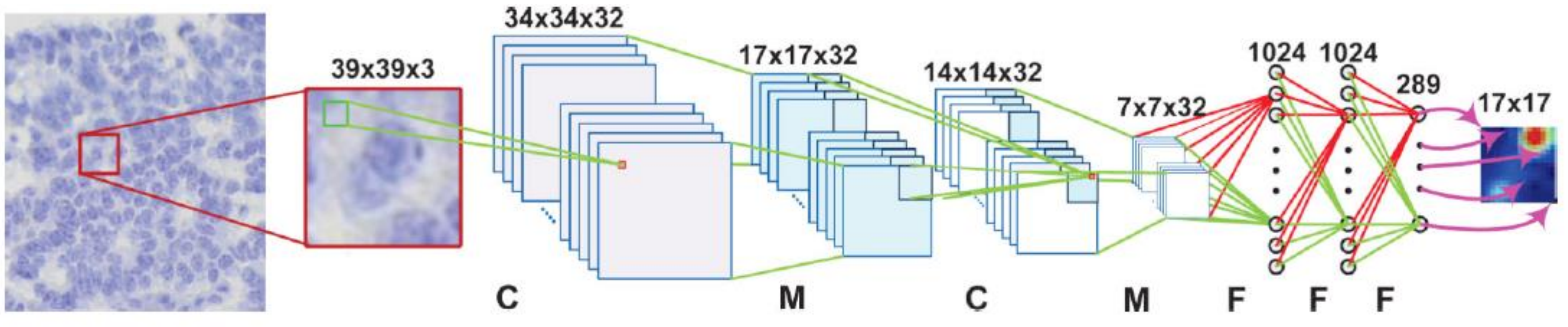
- CNN: lesion detection in CT images.



1. H. R. Roth, et al., "Improving Computer-Aided Detection Using Convolutional Neural Networks and Random View Aggregation", *TMI,* 2016

Detection in Biomedical Images

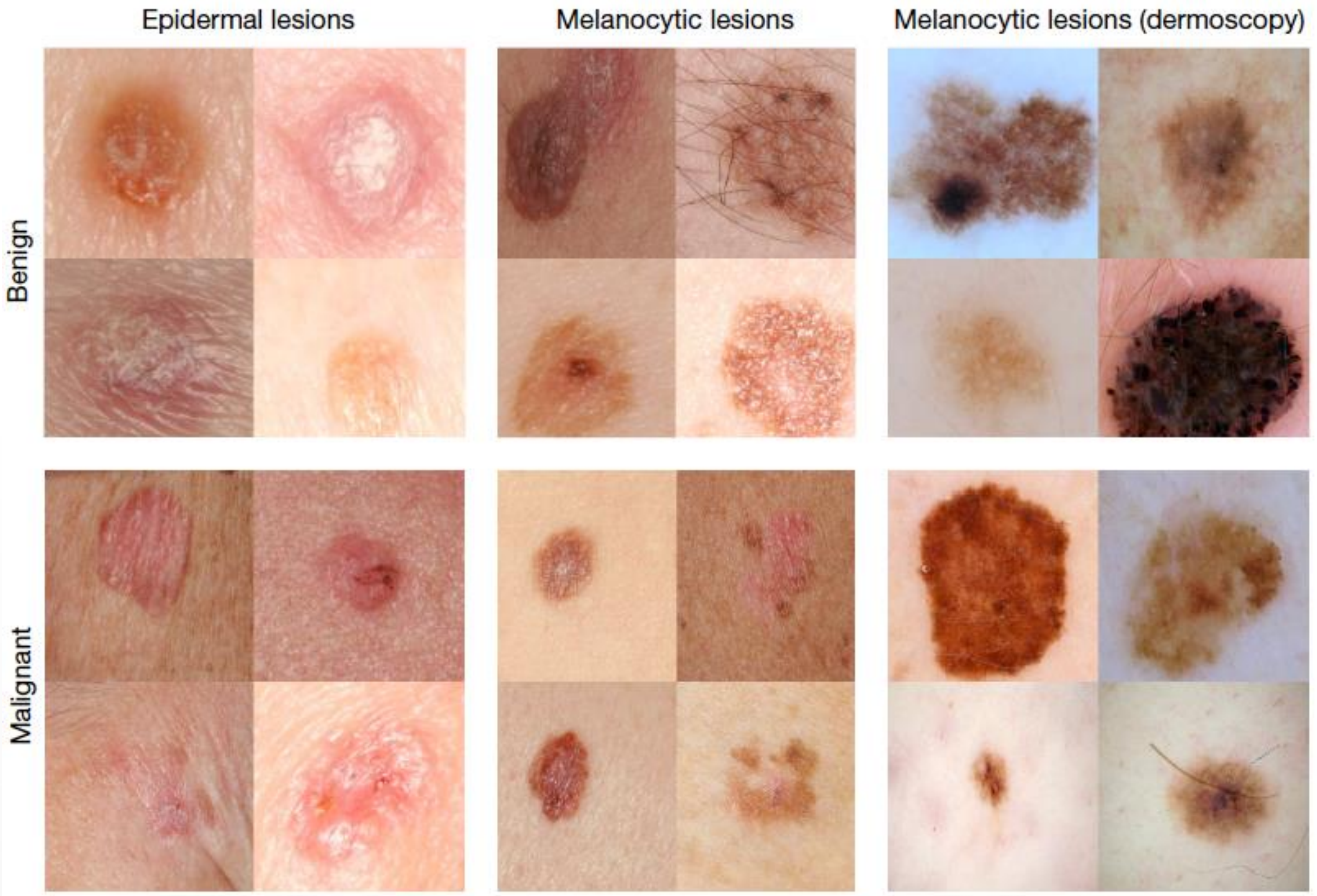
- CNN: structured regression for cell detection in microscopy images.
- Runners Up for Young Scientist Awards in MICCAI 2015



1. Y. Xie, F. Xing, X. Kong, H. Su, and L Yang., “Beyond Classification: Structured Regression for Robust Cell Detection Using Convolutional Neural Network”, *MICCAI,* 2015

Biomedical Image Classification

- CNN (GoogLeNet Inception-v3): skin cancer classification.

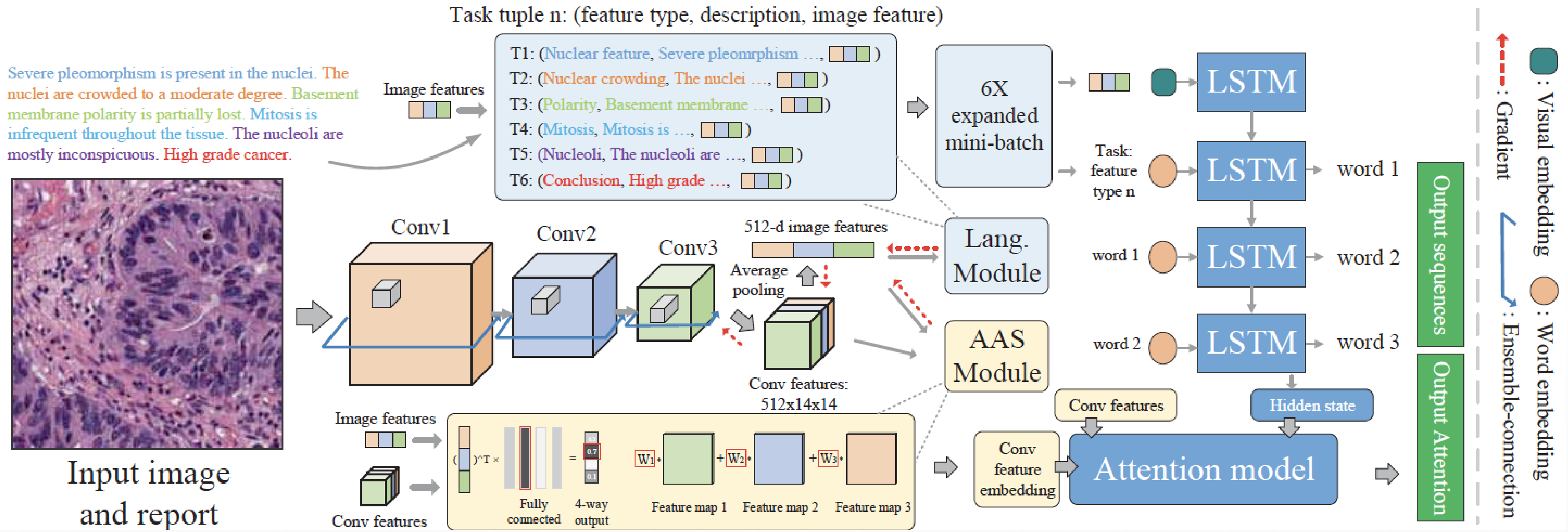


1. A. Esteva, et al., "Dermatologist-level classification of skin cancer with deep neural networks", *Nature,* 2017

Text Generation From Biomedical Images

- CNN + RNN: descriptive paragraph generation.

  Link: https://www.youtube.com/watch?v=yy7NUrc3KI0



1. Z. Zhao, et al., “MDNet: A Semantically and Visually Interpretable Medical Image Diagnosis Network”, *CVPR*, 2017

Deep Learning Frameworks

PYTORCH

mxnet

DEEPLEARNING4J

Microsoft CNTK

theano

Caffe

TensorFlow

Keras

MatConvNet

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