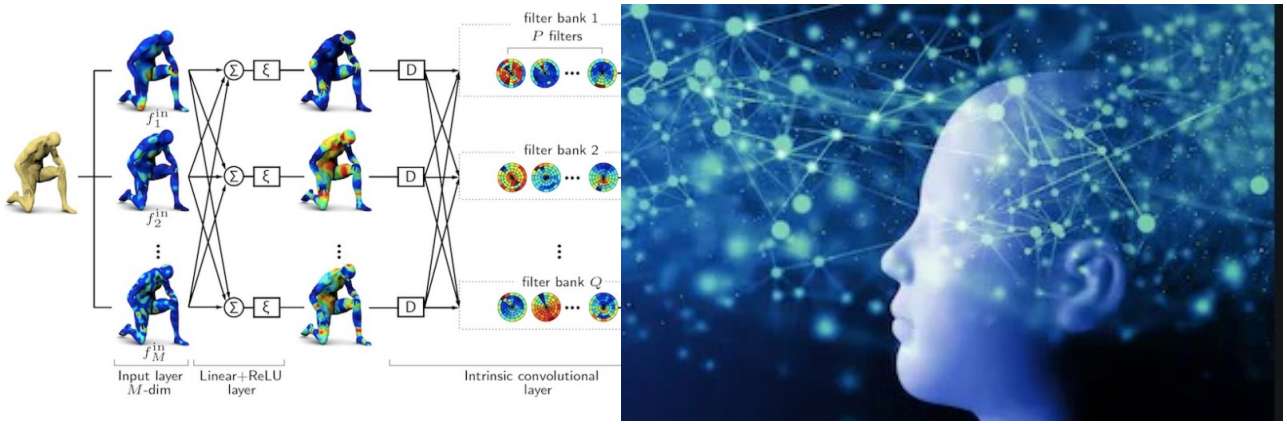
FACULTY OF ENGINEERING AND ARCHITECTURE

E016712: Computer Graphics

Deep Learning in Computer Graphics



Lecturers: Aleksandra Pizurica and Danilo Babin

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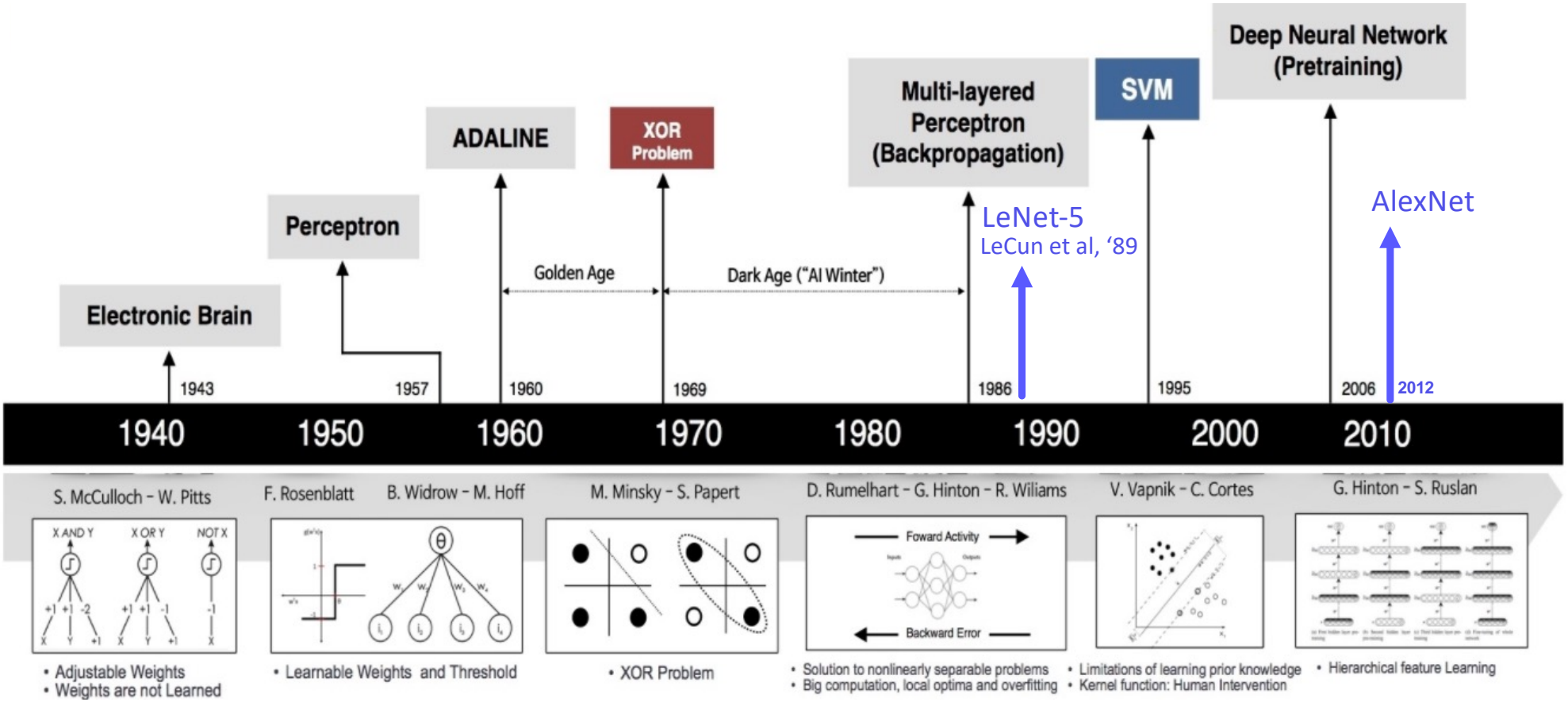
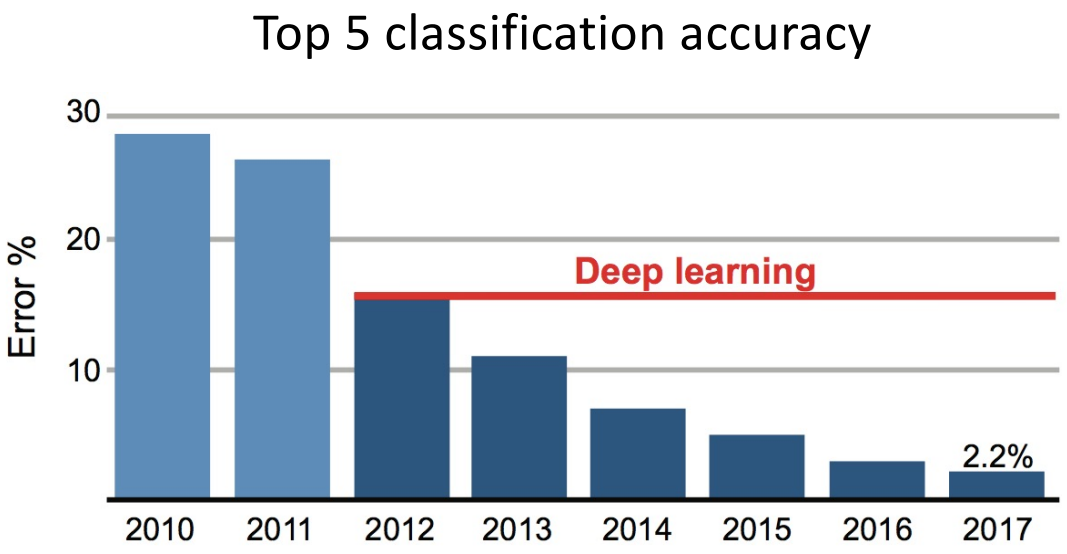
Some milestones in the history of deep learning



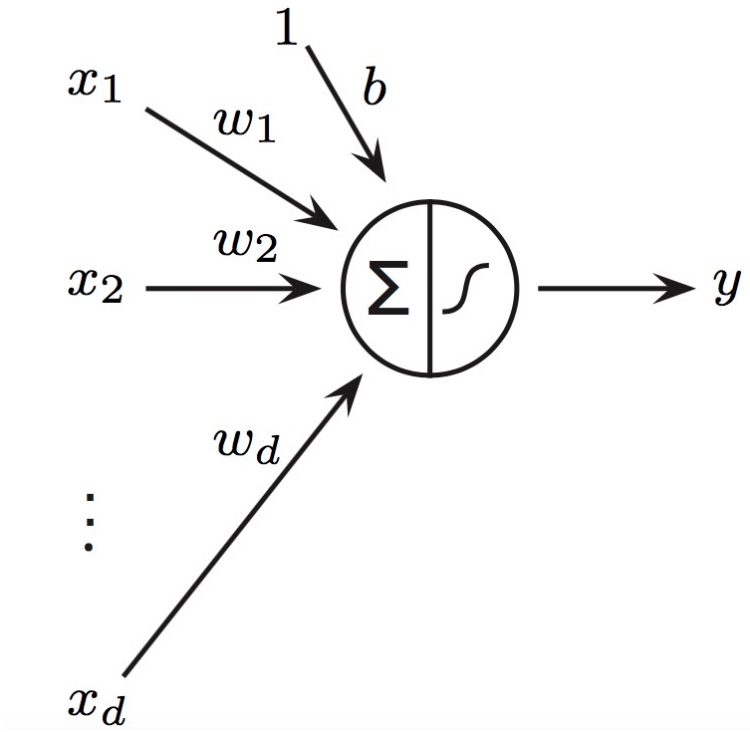
Progress of deep learning

…

…

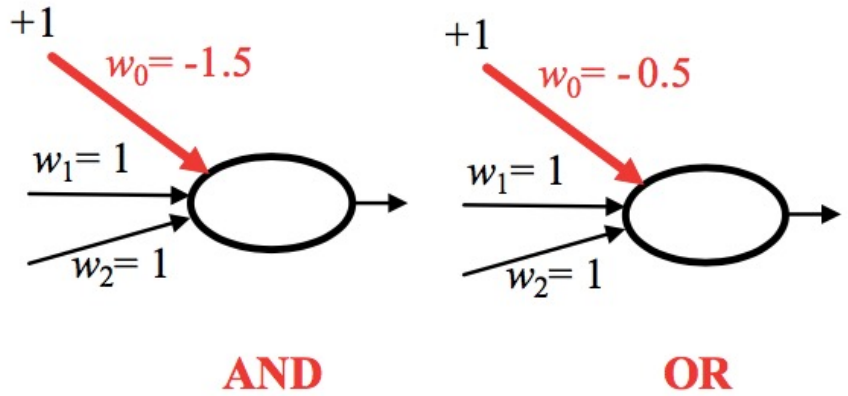


Beginnings of artificial neural networks



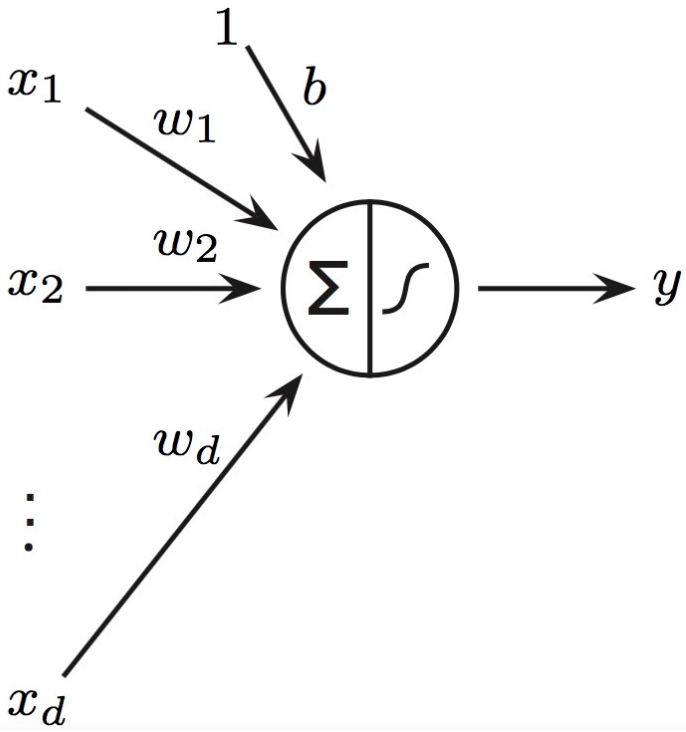
McCulloch-Pits neuron, 1943

Adjustable weights lead to different operations



Any Boolean function can be implemented as a network of these elements

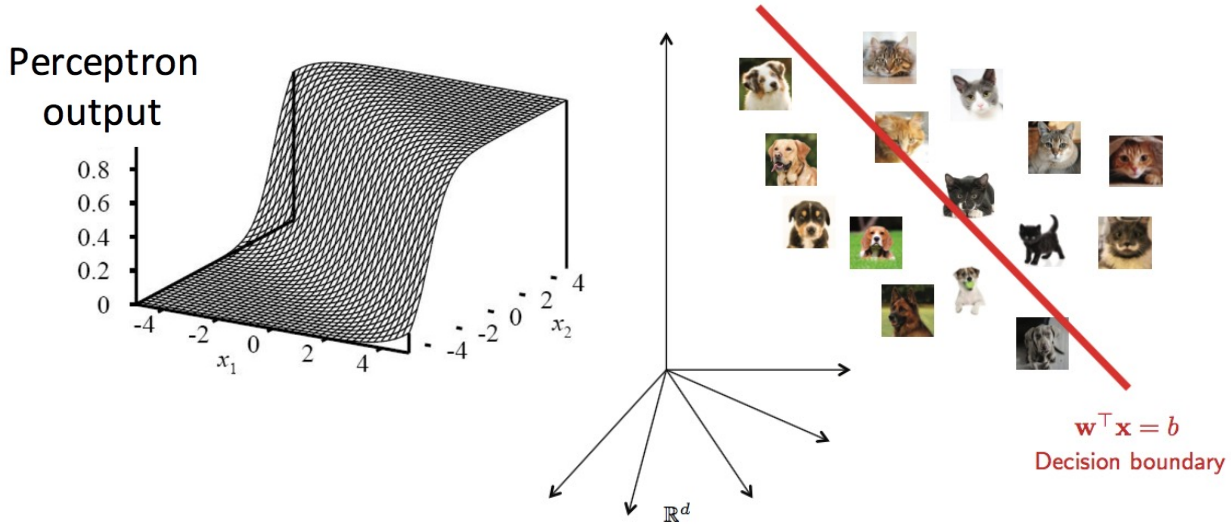
Perceptron



McCulloch-Pits neuron, 1943

Rosenblatt, 1958

Learning weights (from samples of linearly separable classes)

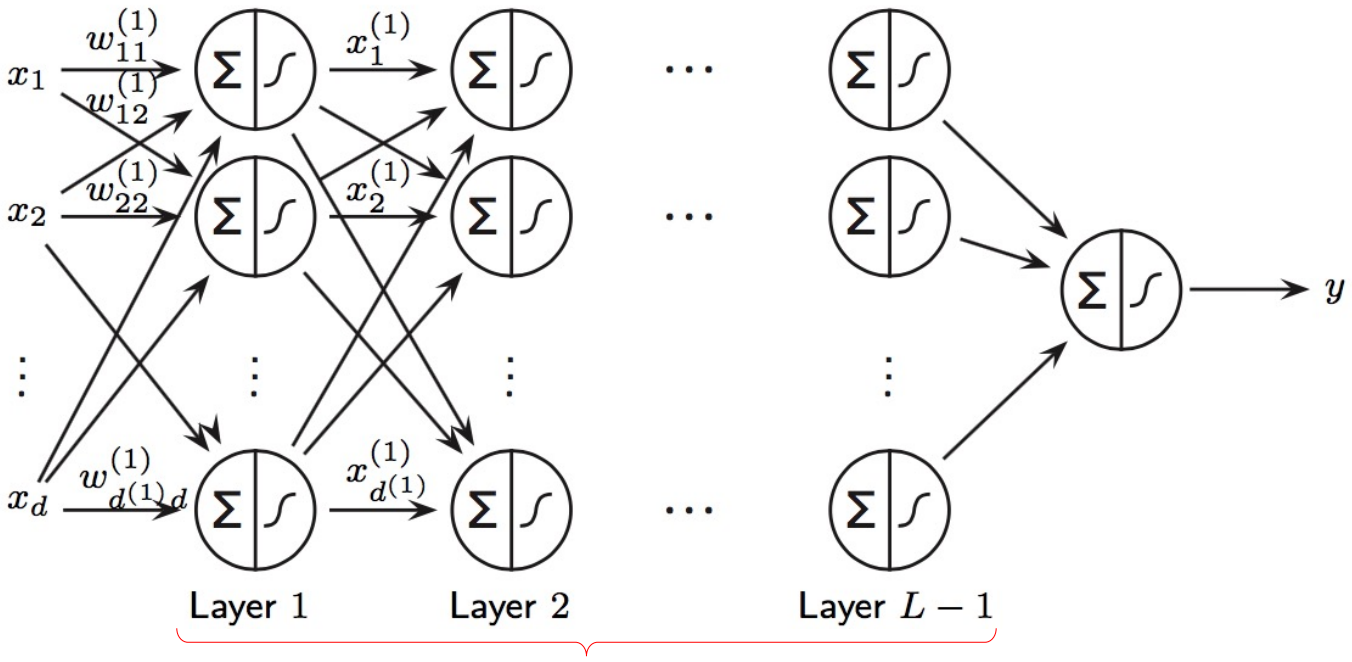


Linear layer $y = \xi\left(\sum_{\ell=0}^{d} w_\ell x_\ell\right)$

Activation, e.g. $\xi(x) = \tanh(x)$

Parameters layer weights $\mathbf{w} = (b, w_1, \ldots, w_d)$, including bias

Multilayer neural networks



Hidden layers

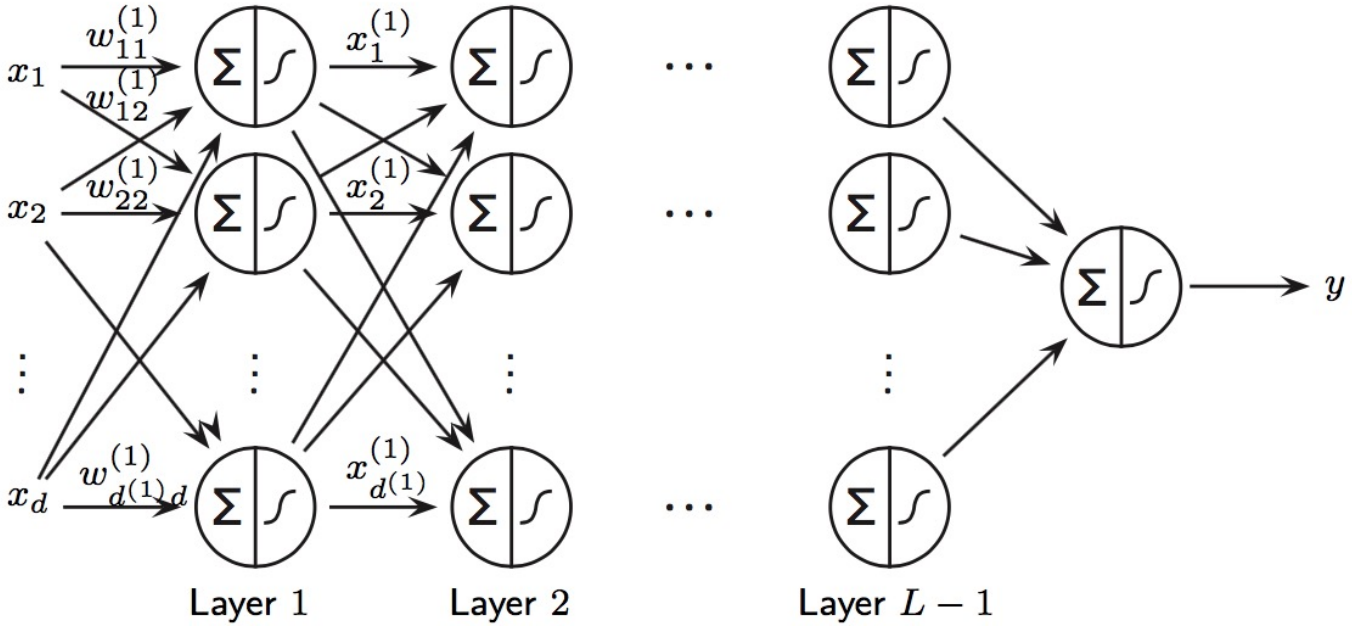
Linear layer $$x_{\ell'}^{(l+1)} = \xi\left(\sum_{\ell=0}^{d^{(l)}} w_{\ell'\ell}^{(l+1)} x_\ell^{(l)}\right)$$

Activation, e.g. $$\xi(x) = \tanh(x)$$

Parameters layer weights $\mathbf{W}^{(l+1)} \in \mathbb{R}^{d^{(l+1)} \times d^{(l)}}$

M. Bronstein et al, SIAM 2018

Multilayer neural networks



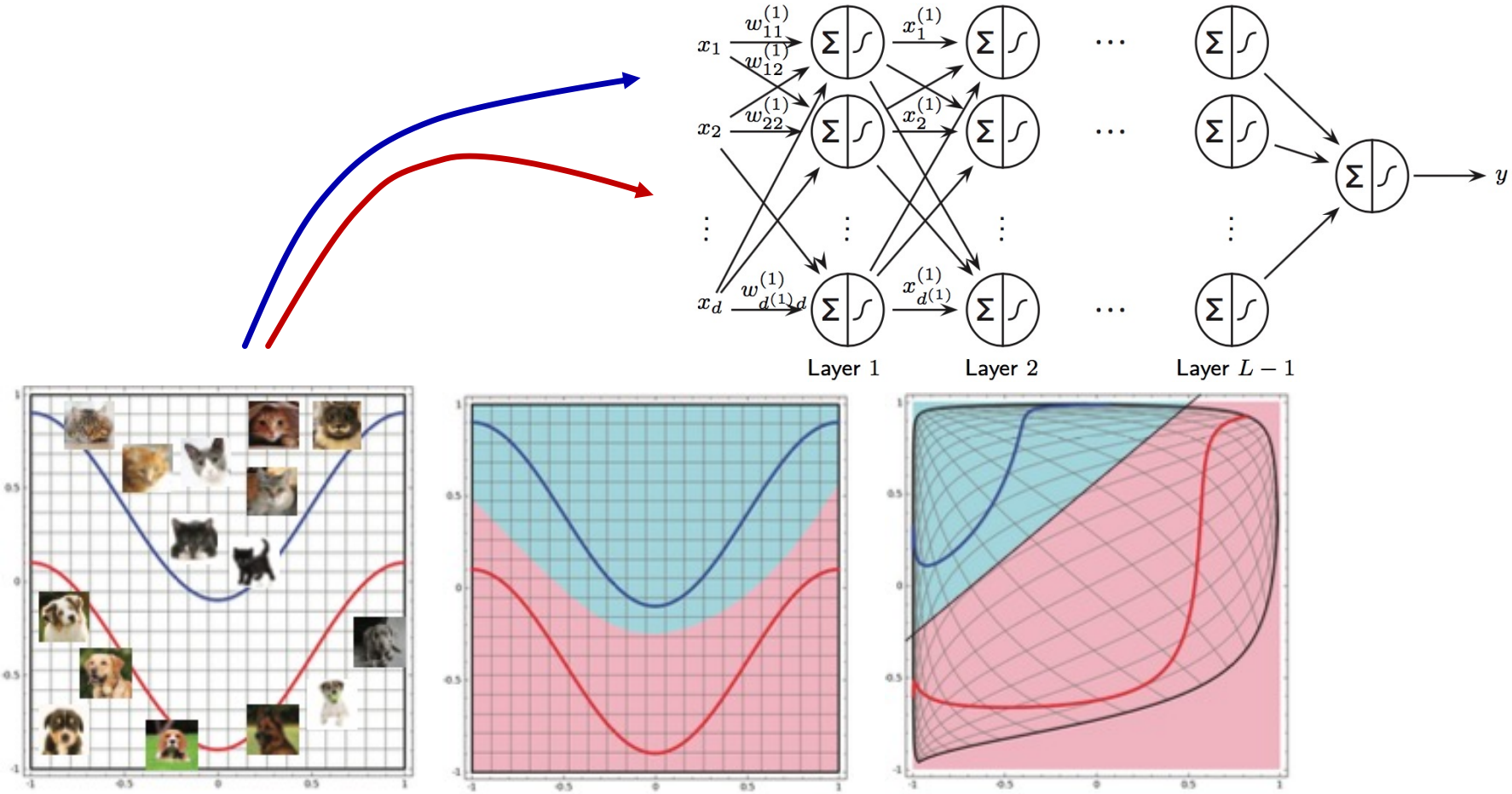
Linear layer $\mathbf{x}^{(l+1)} = \xi\left(\mathbf{W}^{(l+1)}\mathbf{x}^{(l)}\right)$

Activation, e.g. $\xi(x) = \tanh(x)$

Parameters layer weights $\mathbf{W}^{(l+1)} \in \mathbb{R}^{d^{(l+1)} \times d^{(l)}}$

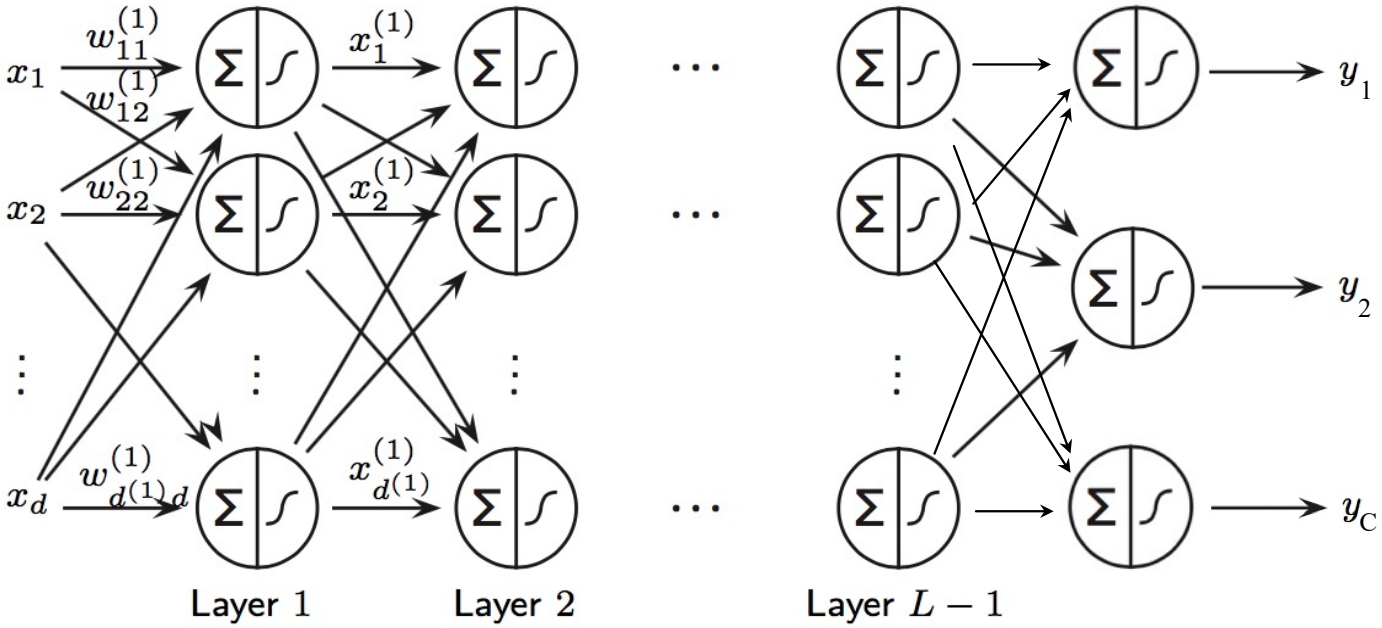
M. Bronstein et al, SIAM 2018

Multilayer neural networks



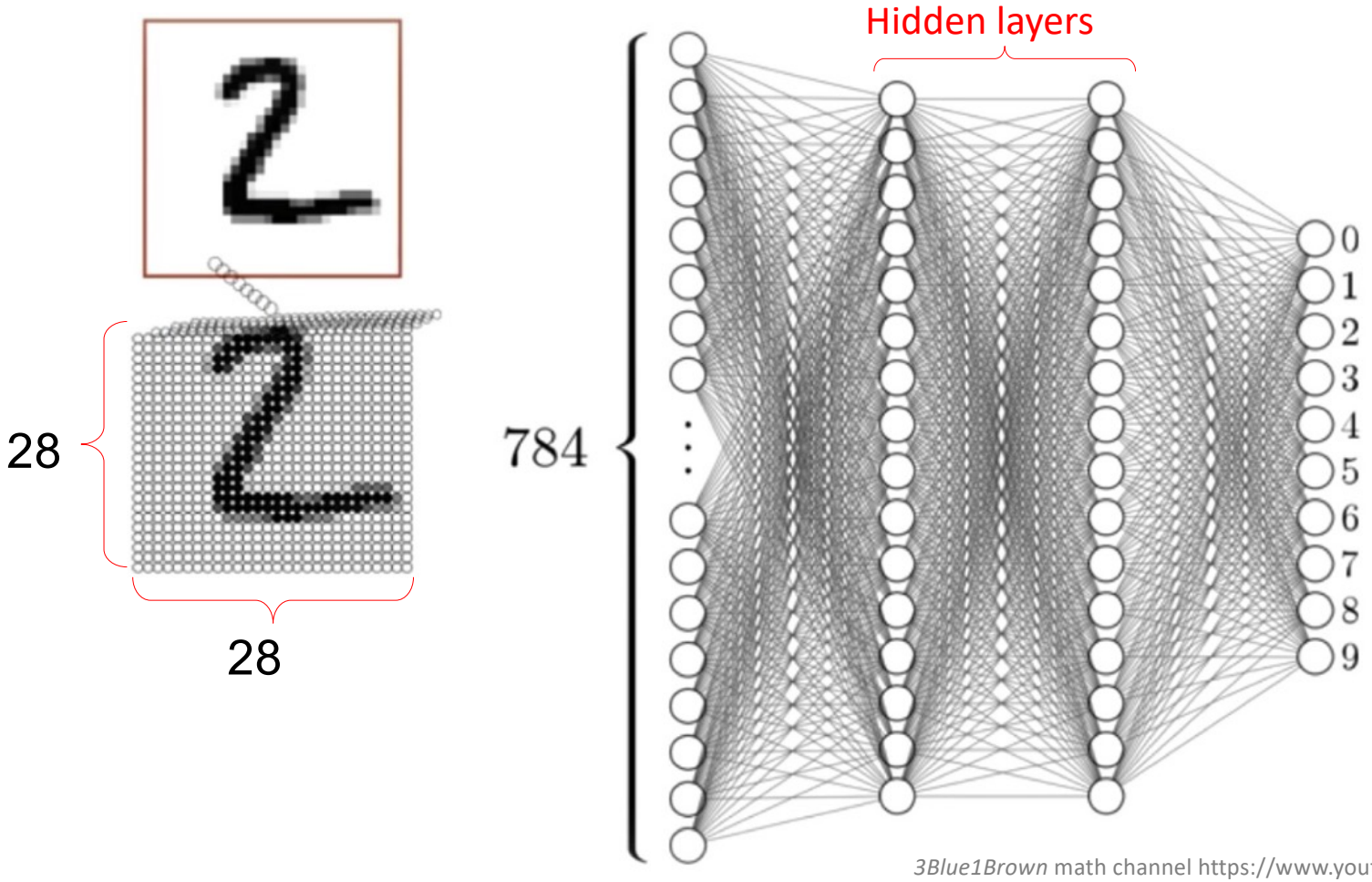
A multi-layer neural net can distort the input space to make the classes of data linearly separable.

In general: multiple outputs



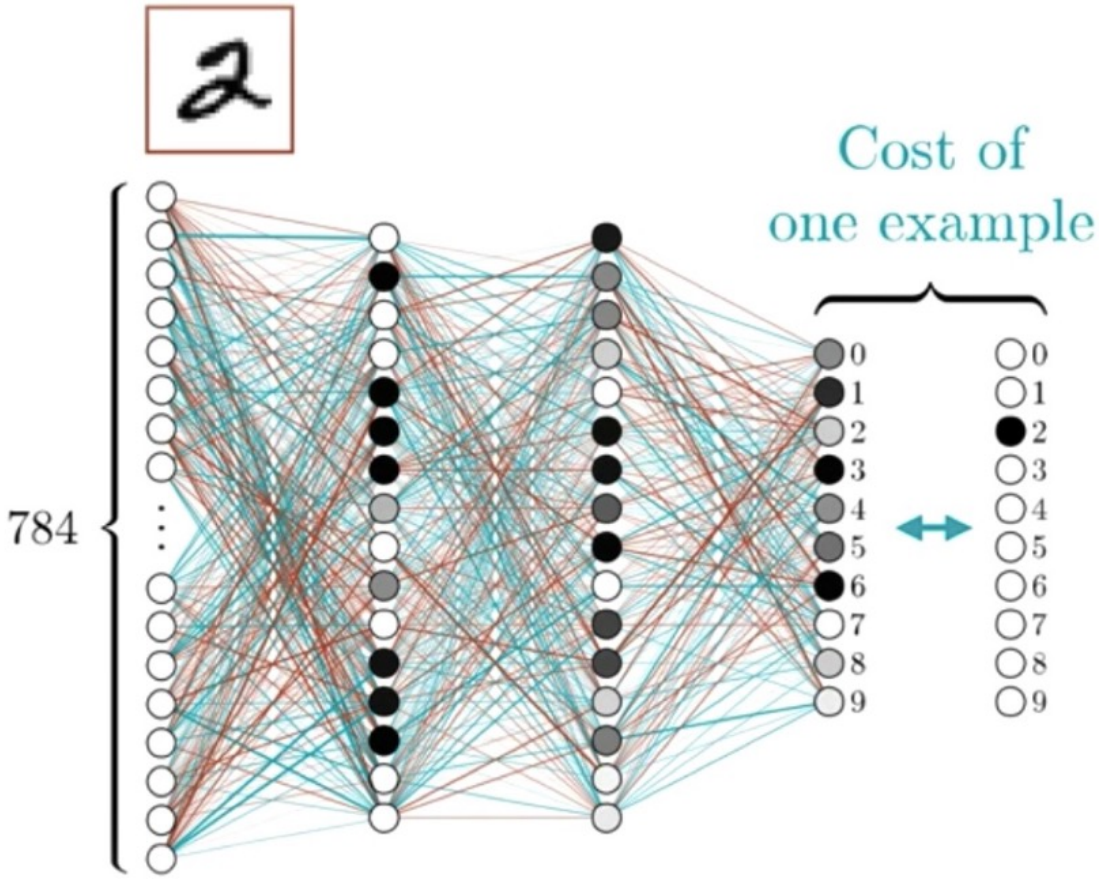
Multi-class classification: each output gives a score indicating confidence that the input $[x_1 \ldots . x_d]$ belongs to a particular class $c \in \{1 \ldots C\}$.

Example: Digit classification



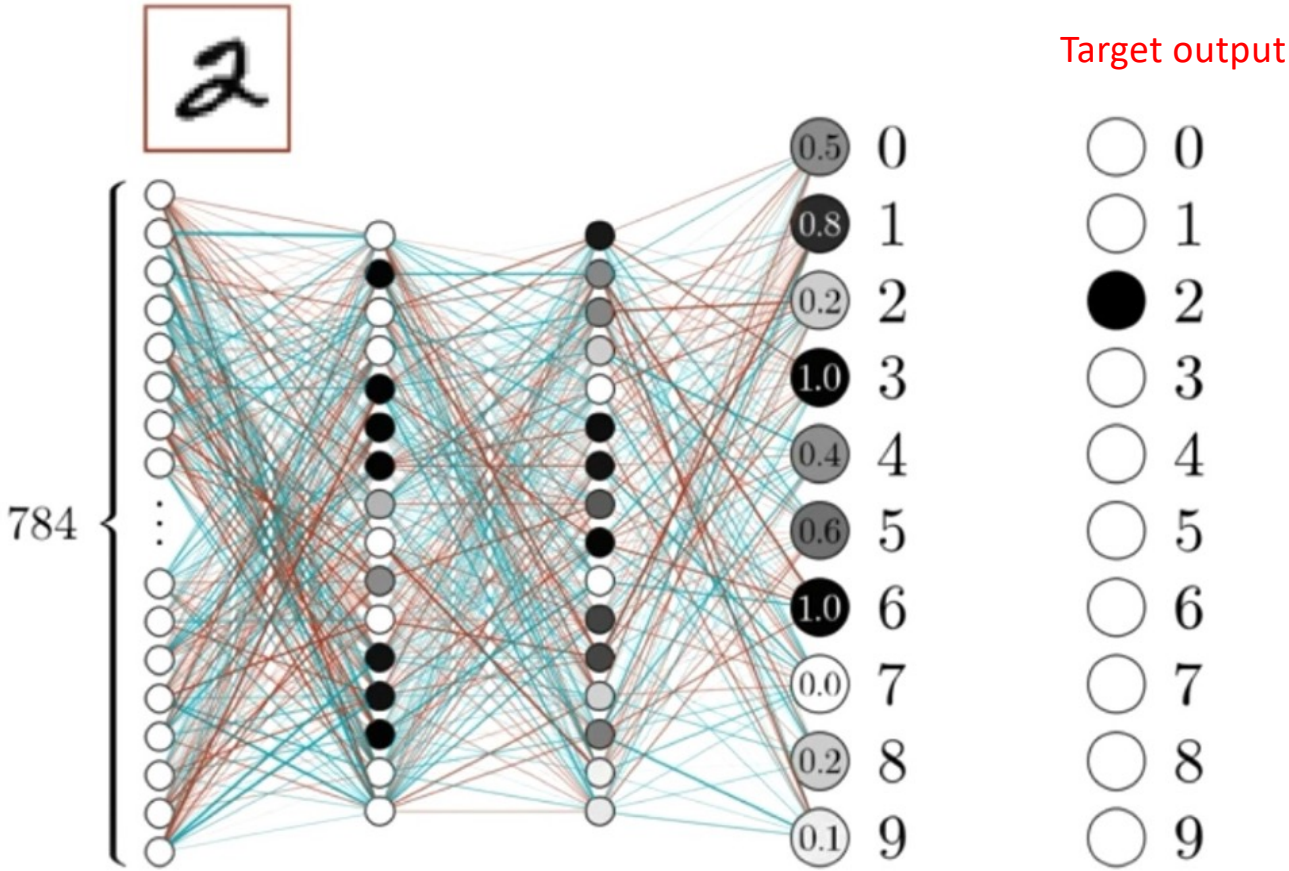
3Blue1Brown math channel https://www.youtube.com/watch?v=Ilg3gGewQ5U

Example: Example: Digit classification



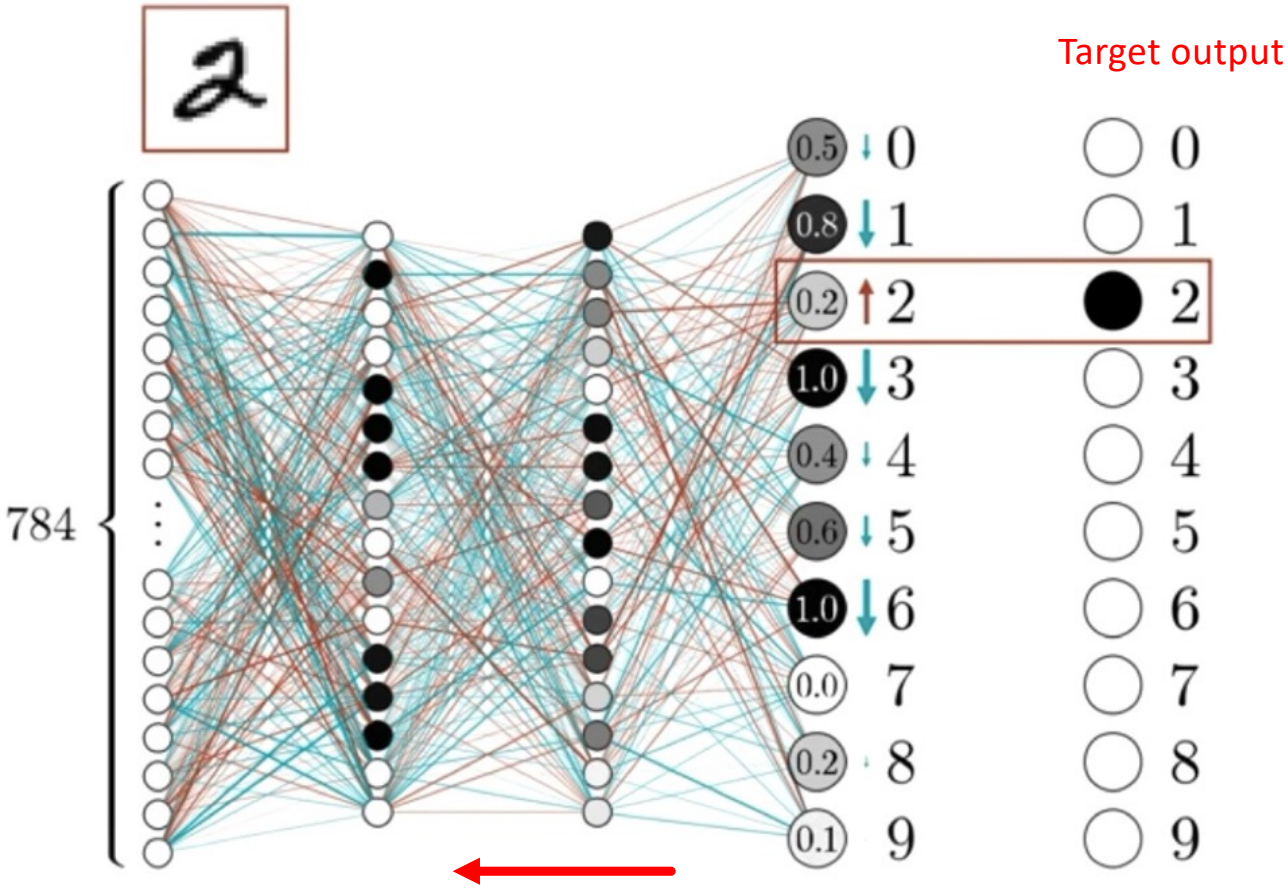
3Blue1Brown math channel https://www.youtube.com/watch?v=Ilg3gGewQ5U

Example: Example: Digit classification



3Blue1Brown math channel https://www.youtube.com/watch?v=Ilg3gGewQ5U

Example: Example: Digit classification



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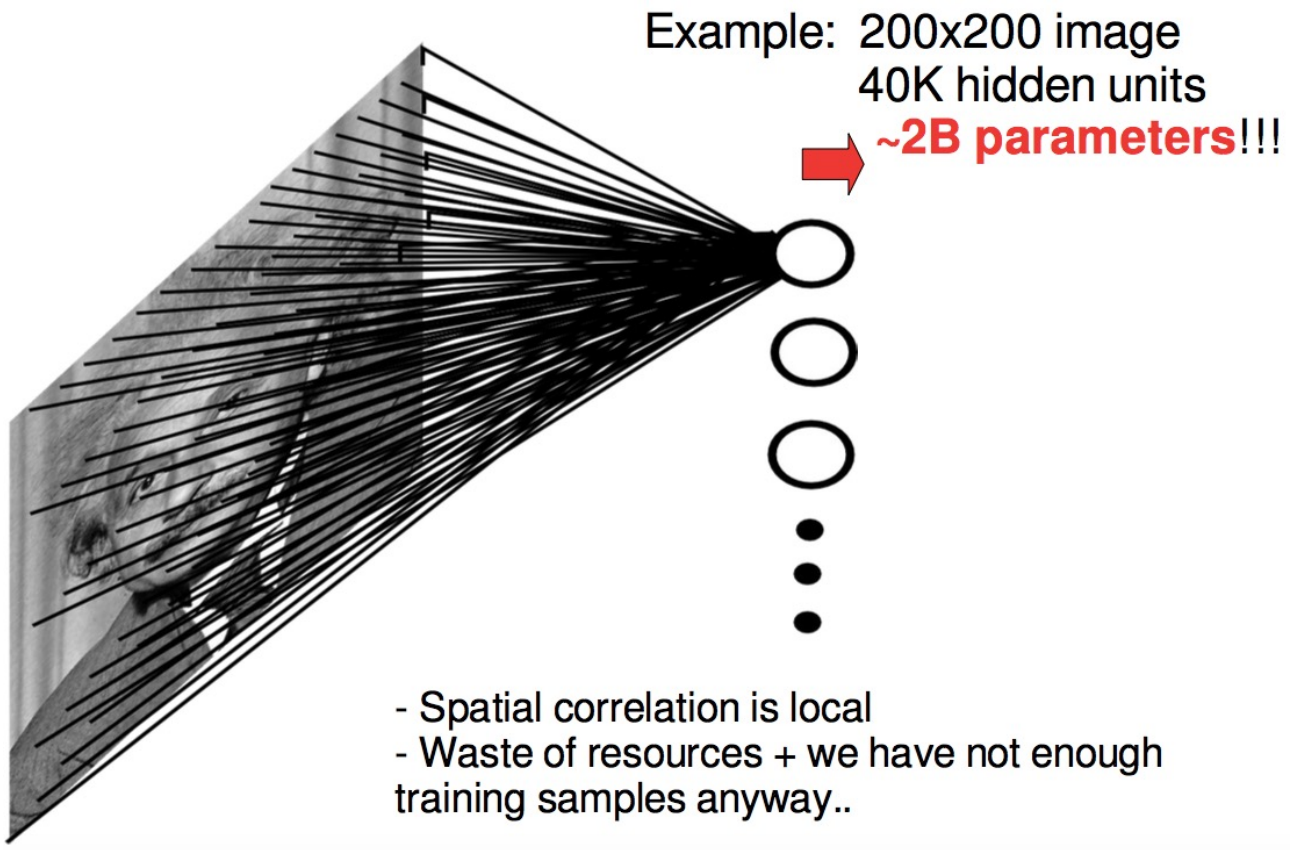
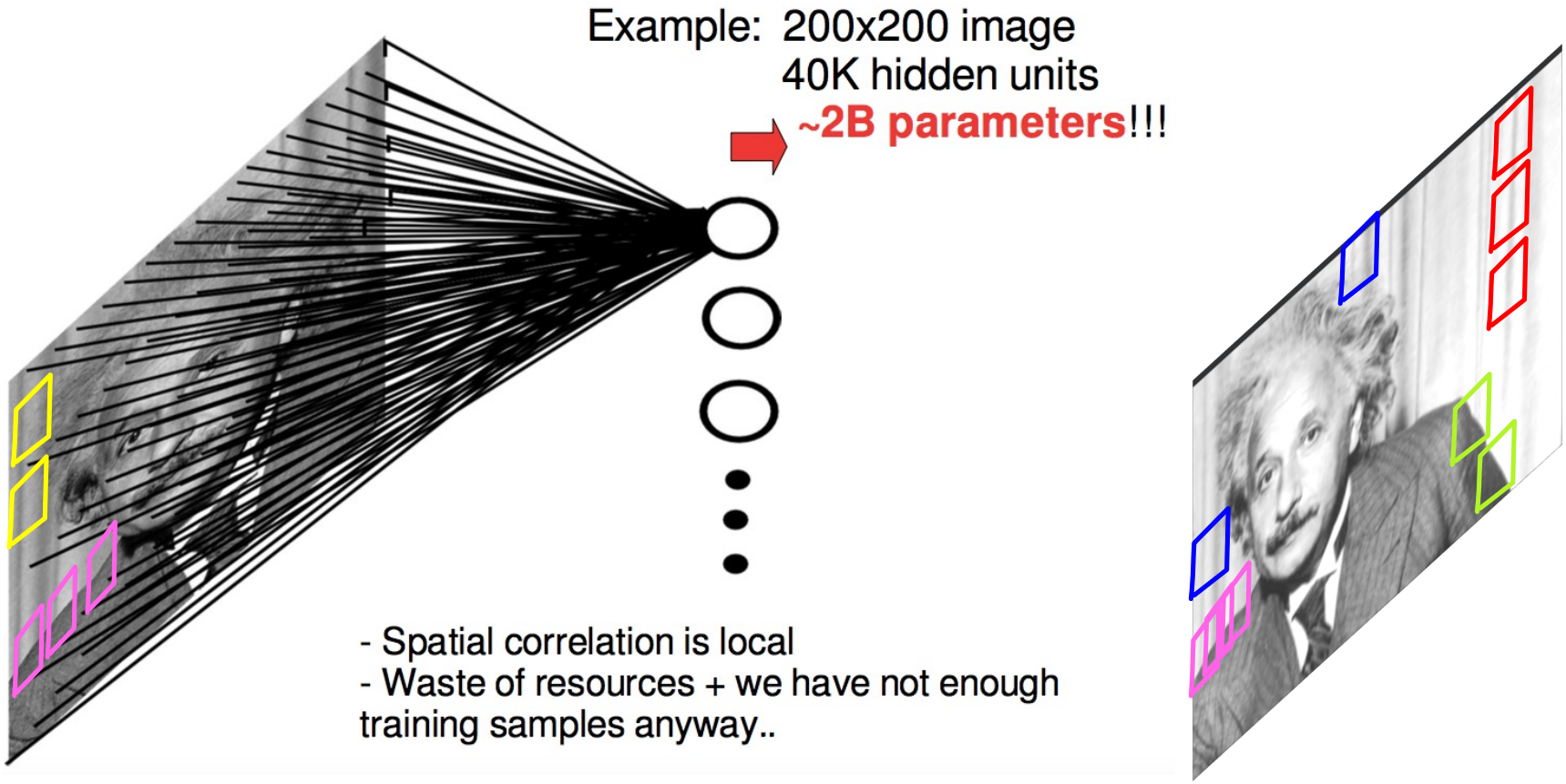
Fully connected layer



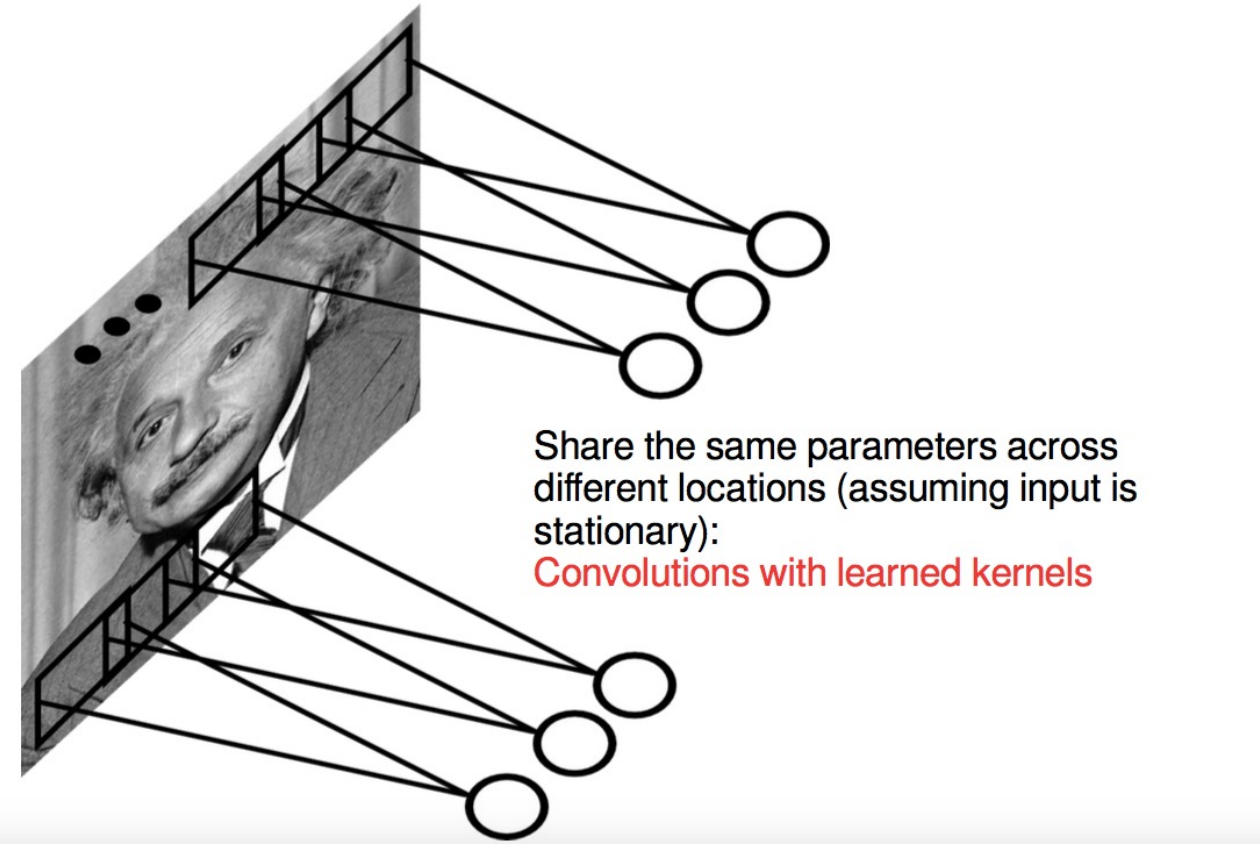
M. Ranzato (Facebook A.I. research): Image Classification with Deep Learning, 2015.

Alternatives to fully connected layer?



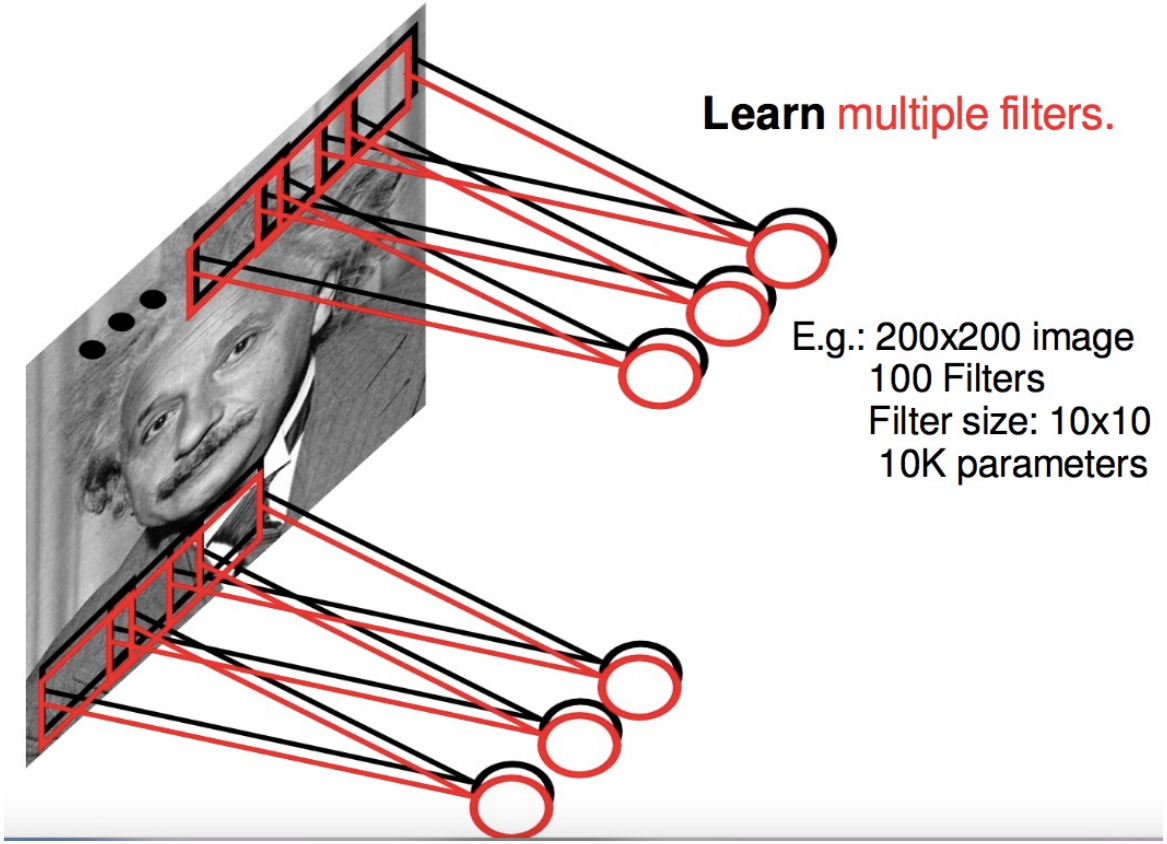
Observe re-appearing spatial structures

Convolutional Neural Networks (CNN) - idea



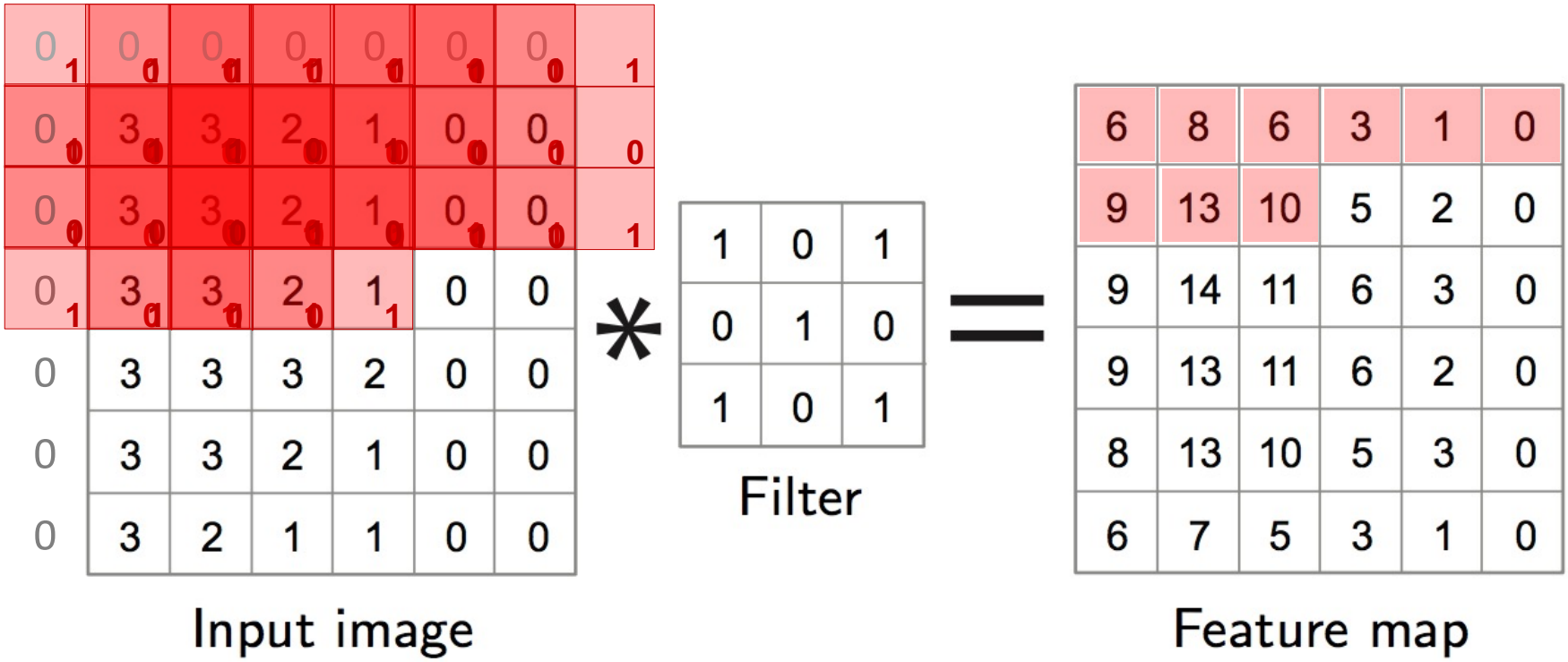
M. Ranzato (Facebook A.I. research): Image Classification with Deep Learning, 2015.

Convolutional Neural Networks (CNN) - idea

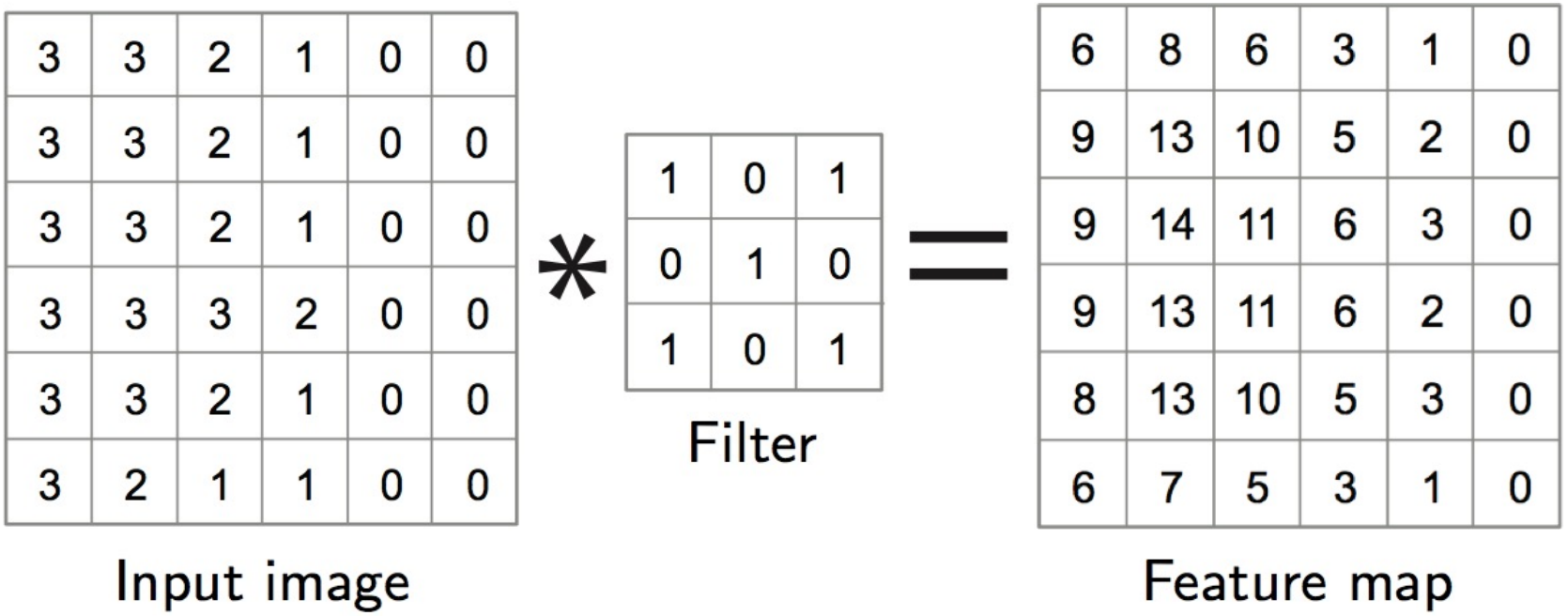


M. Ranzato (Facebook A.I. research): Image Classification with Deep Learning, 2015.

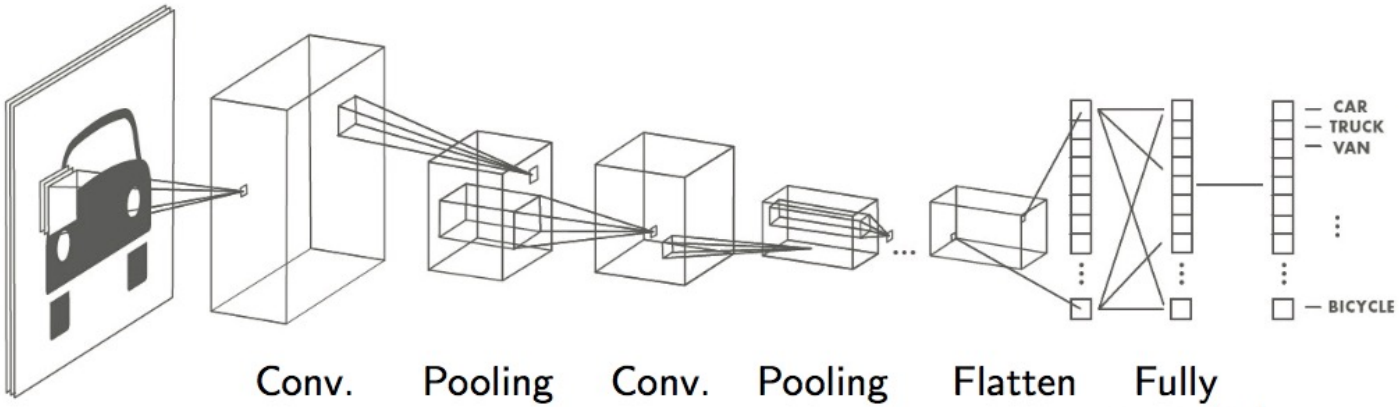
Convolutional layer



Pooling operation



Convolutional Neural Networks (CNN)



Conv. layer $$x_{\ell'}^{(l+1)}(\mathbf{u}) = \xi\left(\sum_{\ell=1}^{d^{(l)}}(w_{\ell'\ell}^{(l+1)} \star x_{\ell}^{(l)})(\mathbf{u})\right)$$

Activation, e.g. $\xi(x) = \max\{x, 0\}$ rectified linear unit (ReLU)

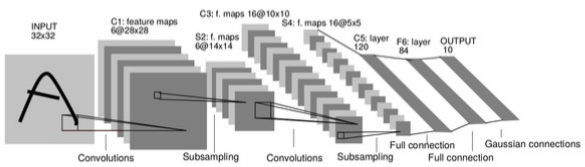
Parameters filters $W^{(1)}, \ldots, W^{(L)}$

Pooling $$x_{\ell}^{(l+1)}(\mathbf{u}) = \|x_{\ell}^{(l)}(\mathbf{u}') : \mathbf{u}' \in \mathcal{N}(\mathbf{u})\|_p \quad p = 1, 2, \text{ or } \infty$$

M. Bronstein et al, Geometric deep learning on graphs and manifolds, SIAM 2018

Convolutional Neural Networks

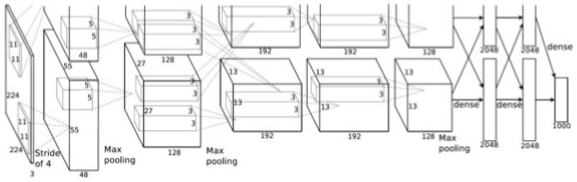
LeNet-5 **1989**



- 3 convolutional + 1 fully connected layer
- 1M parameters
- Trained on MNIST 70K
- CPU-based
- $\tanh$ non-linearity

LeCun et al. 1998

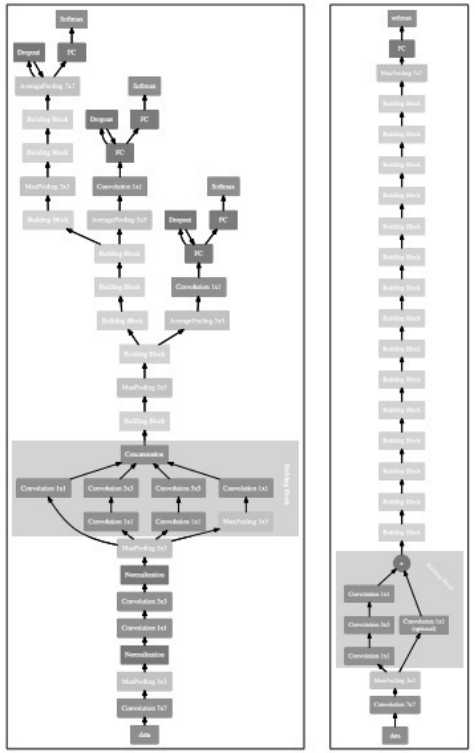
AlexNet **2012**



- 5 convolutional + 3 fully connected layers
- 60M parameters
- Trained on ImageNet 1.5M
- GPU-based
- ReLU, Dropout

Krizhevsky, Sutskever, Hinton 2012

2013 - 2017



Inception-V1
5M param.

VGG
138M param.

Resnet-50
23M param.

Inception-V3
24M param.

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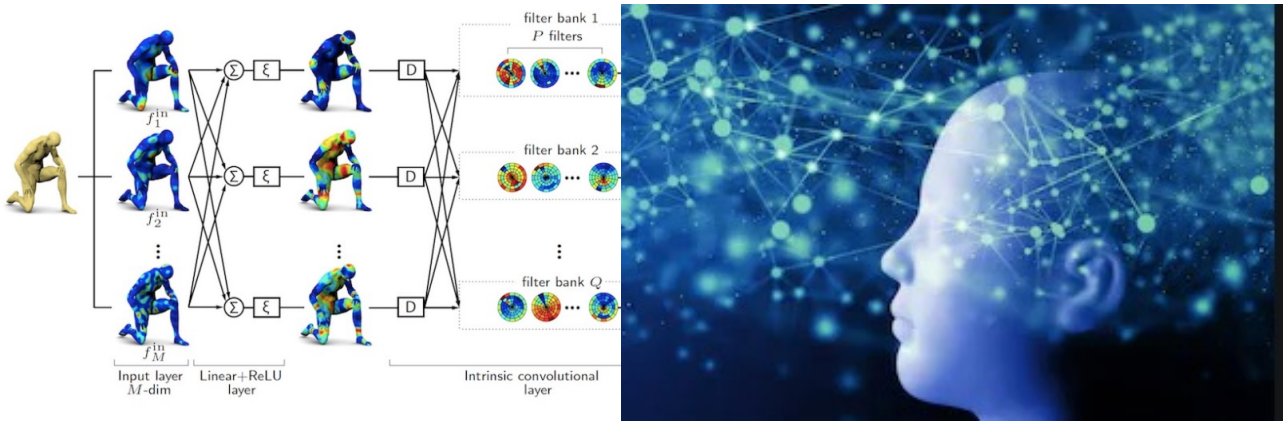
E016712: Computer Graphics

Deep Learning in Computer Graphics (Part 2)



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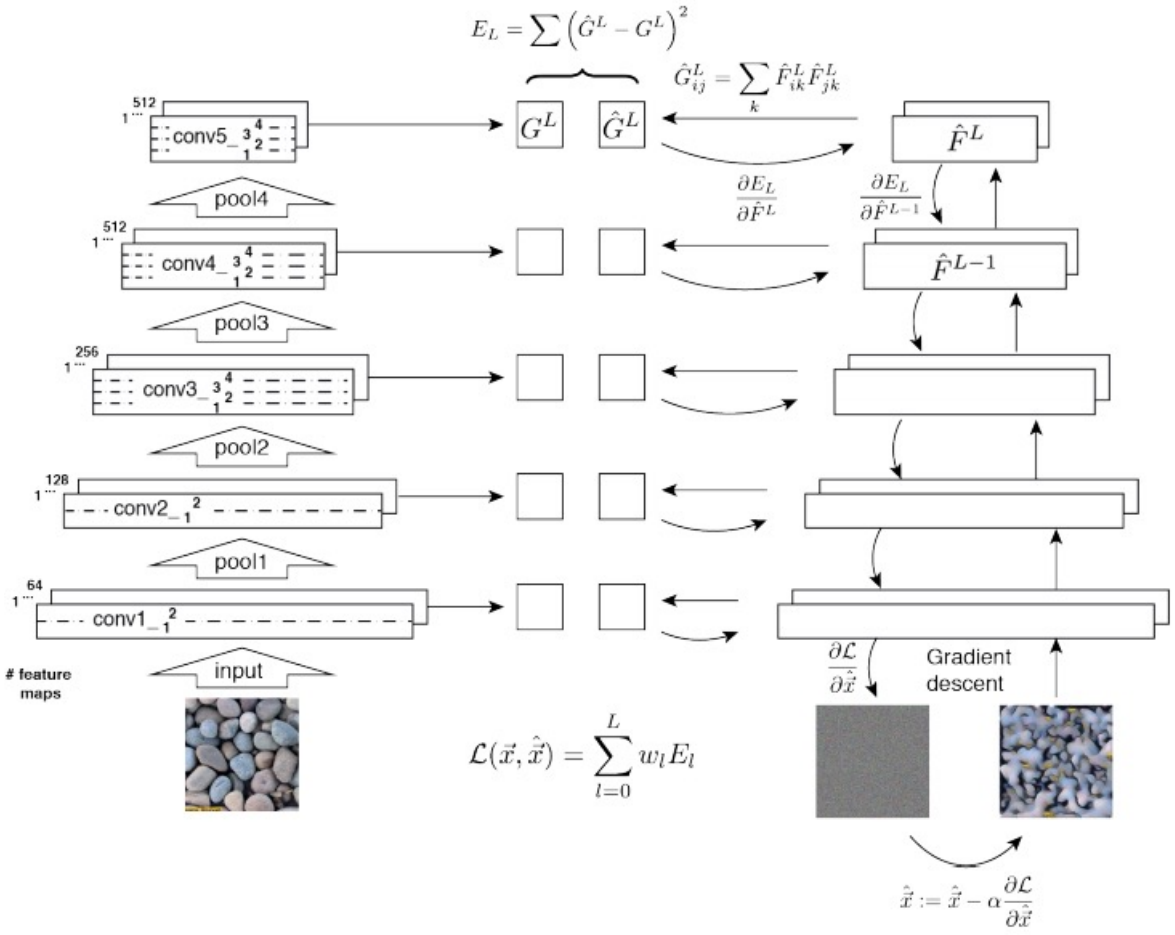
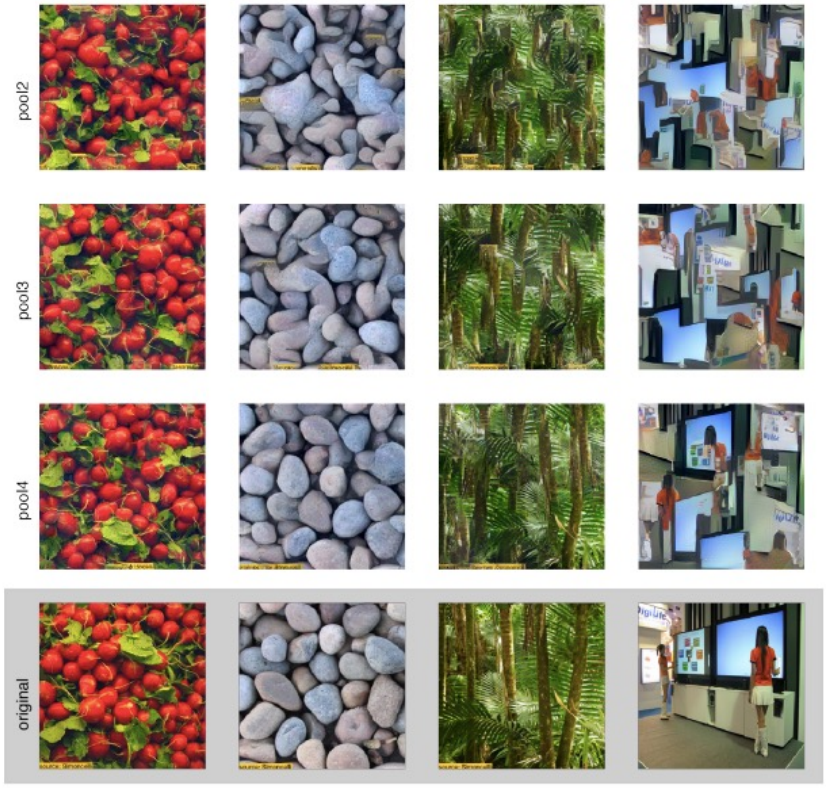
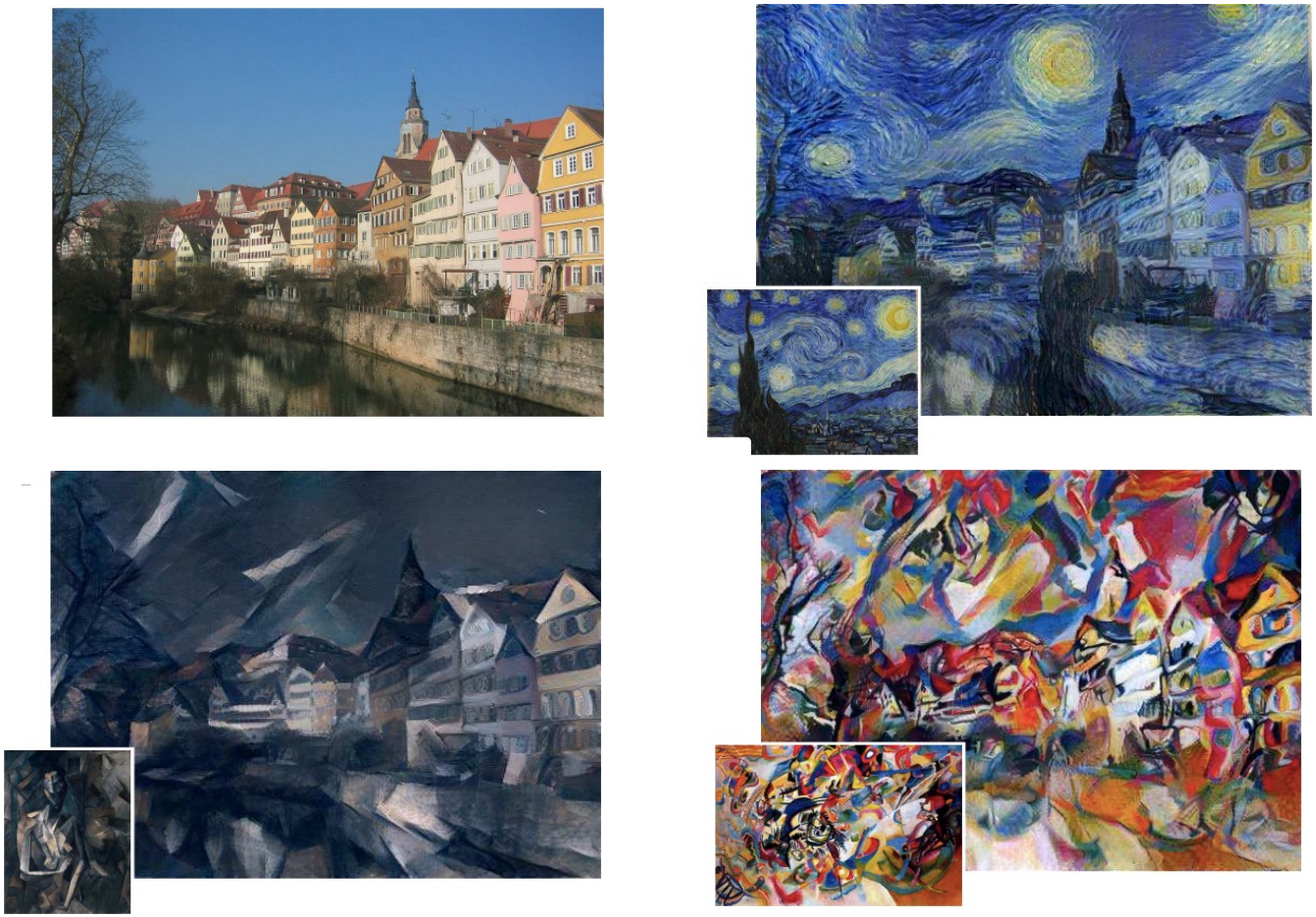
Texture synthesis using CNNs





L. Gatys, A.S. Ecker and M. Bethge: Texture Synthesis Using Convolutional Neural Networks, NIPS 2015.

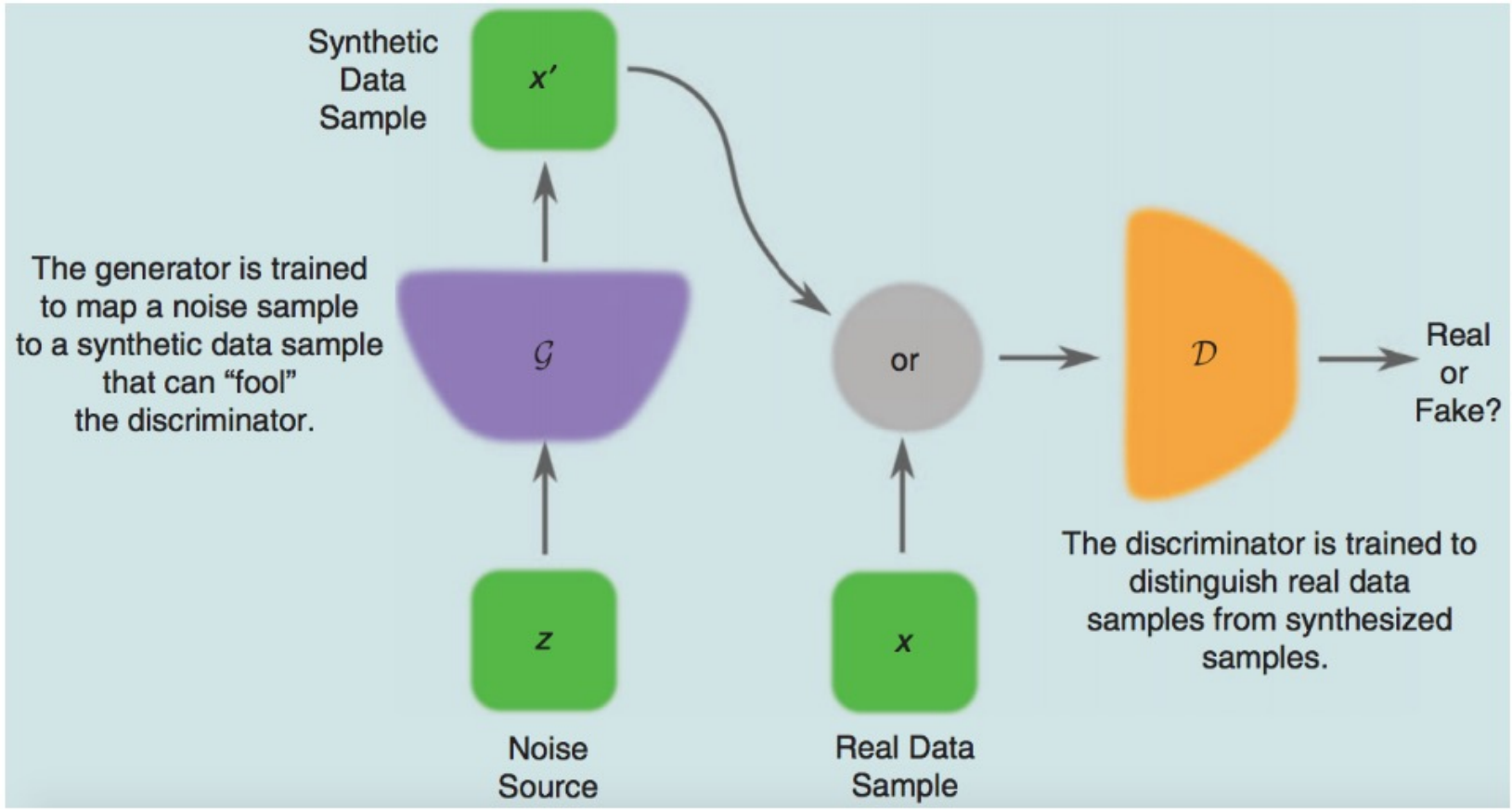
Style transfer using CNNs



L. Gatys, A.S. Ecker and M. Bethge: Image Style Transfer Using Convolutional Neural Networks, CVPR 2016.

Generative Adversarial Networks (GAN)

Goodfellow et al, 2014



A. Creswell. Generative Adversarial Networks. IEEE Signal Processing Magazine, Jan 2018.

StyleGAN for image synthesis

AI-generated images of people who don't exist, from https://thispersondoesnotexist.com

Karras et al, 2019

T. Karras, S. Laine and T. Aila (NVIDIA): A Style-Based Generator Architecture for Generative Adversarial Networks (2019)

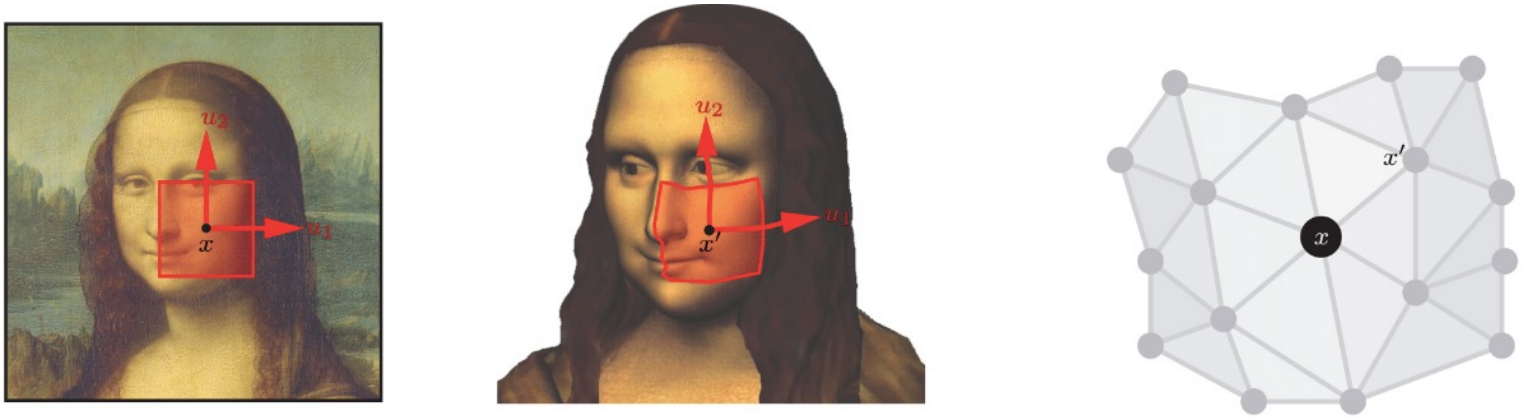
StyleGAN for image synthesis

T. Karras, S. Laine and T. Aila (NVIDIA): A Style-Based Generator Architecture for Generative Adversarial Networks (2019)

Extensions to non-Euclidean data

Deep learning research focused so far mainly on Euclidean data
i.e., data on regular grids, such as images

How to extend these approaches to data beyond such regular grids?
E.g., CNNs involve convolutions;
How to define convolution on manifolds or on graphs?

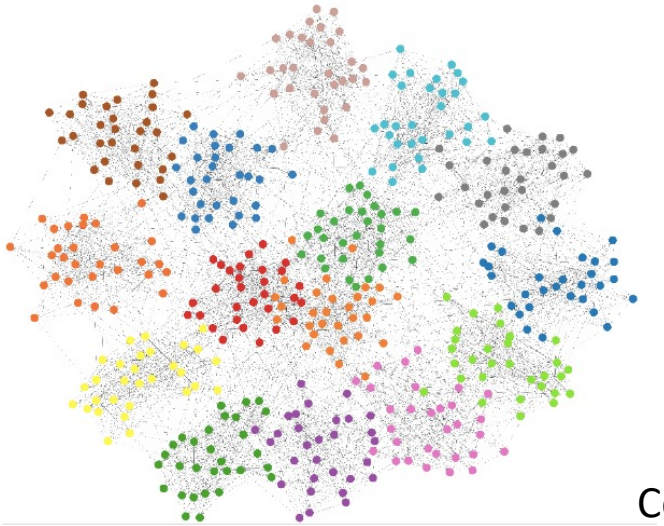


Example from: M. Bronstein et al. Geometric deep learning on graphs and manifolds. SIAM 2018.

Geometric deep learning

Geometric deep learning extends the deep learning framework to graphs and manifolds

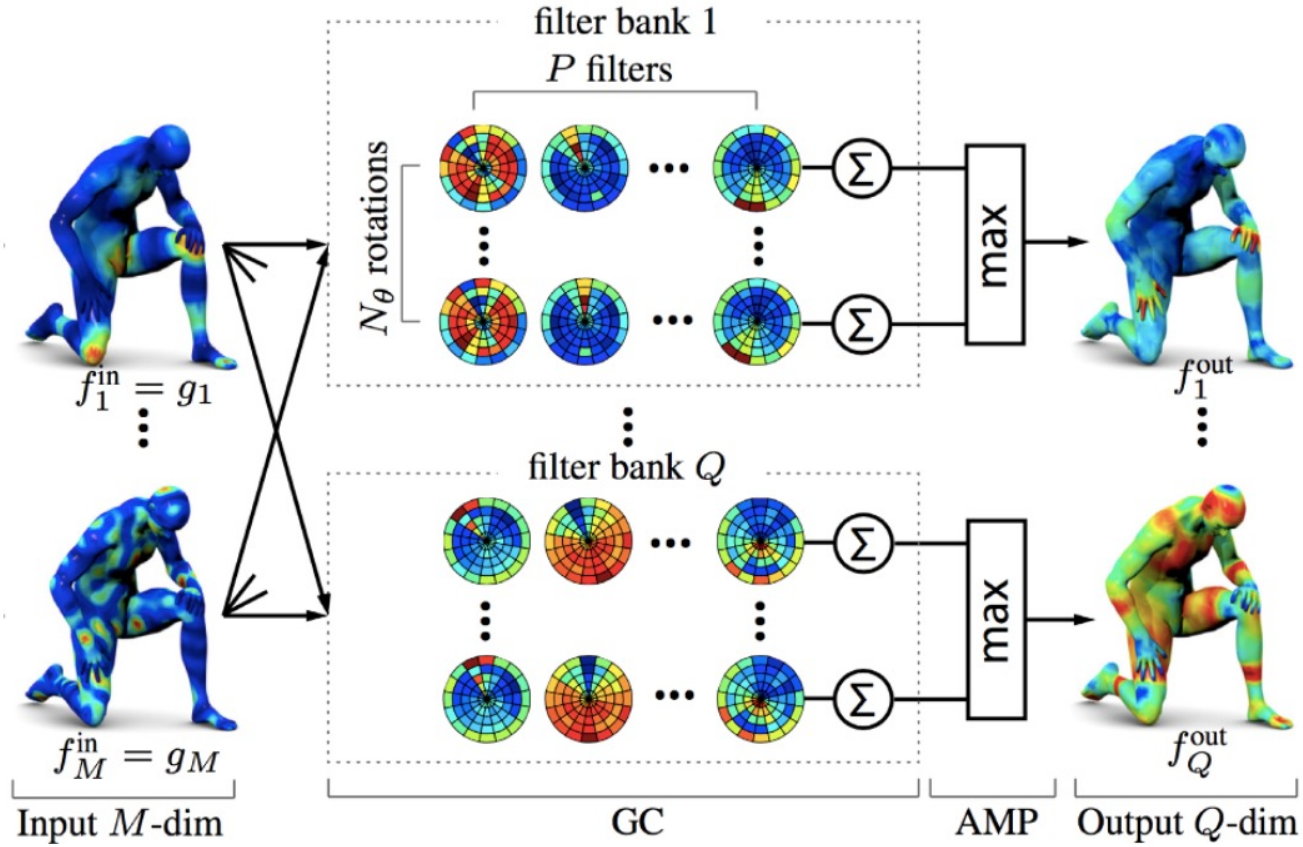
Classification of point cloud data



Learning on graphs (like social nets)

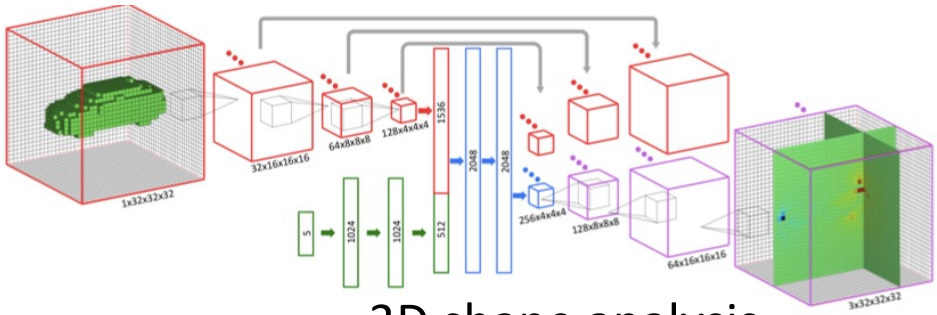
Correspondence learning on manifolds

Geometric deep learning example: Geodesic CNN



J. Masci et al, Geodesic convolutional neural networks on Riemannian manifolds, ICCV Workshops 2015.

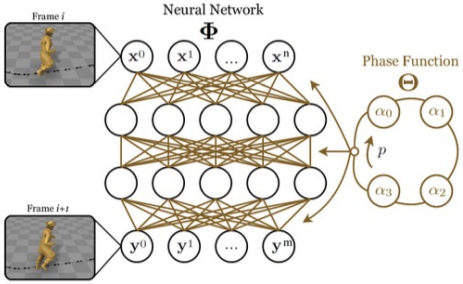
Seminar: Deep learning in computer graphics



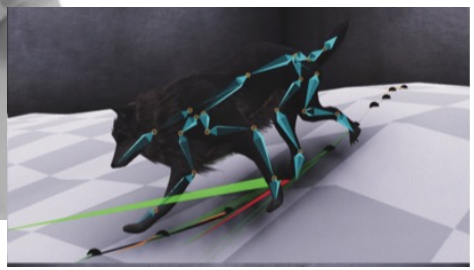
3D shape analysis

shading

style transfer



locomotion



motion capture

analysis of point clouds