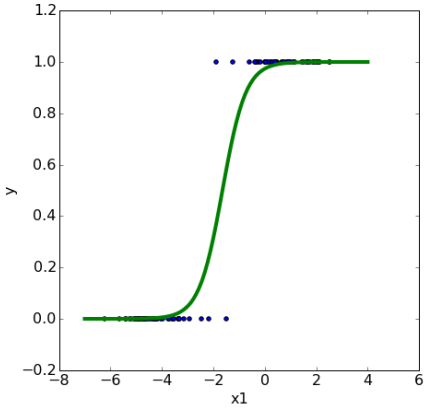
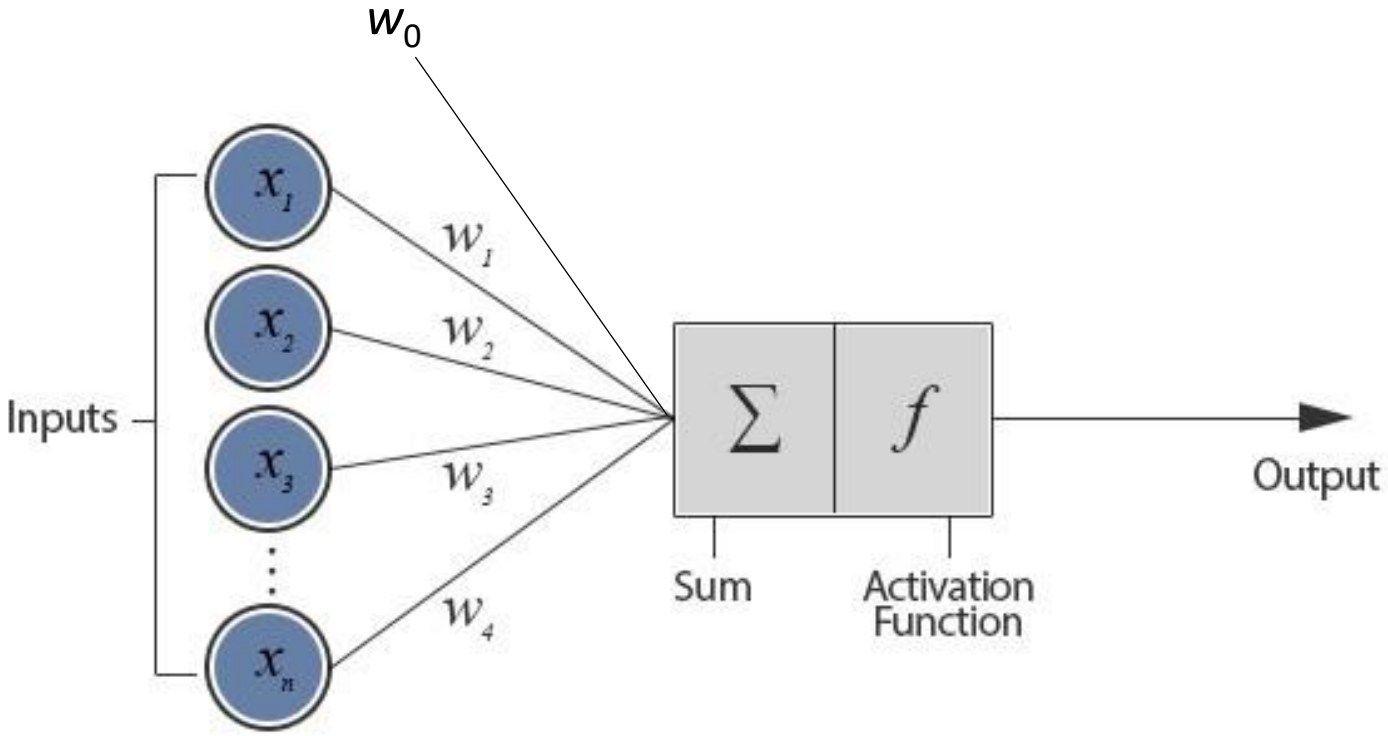
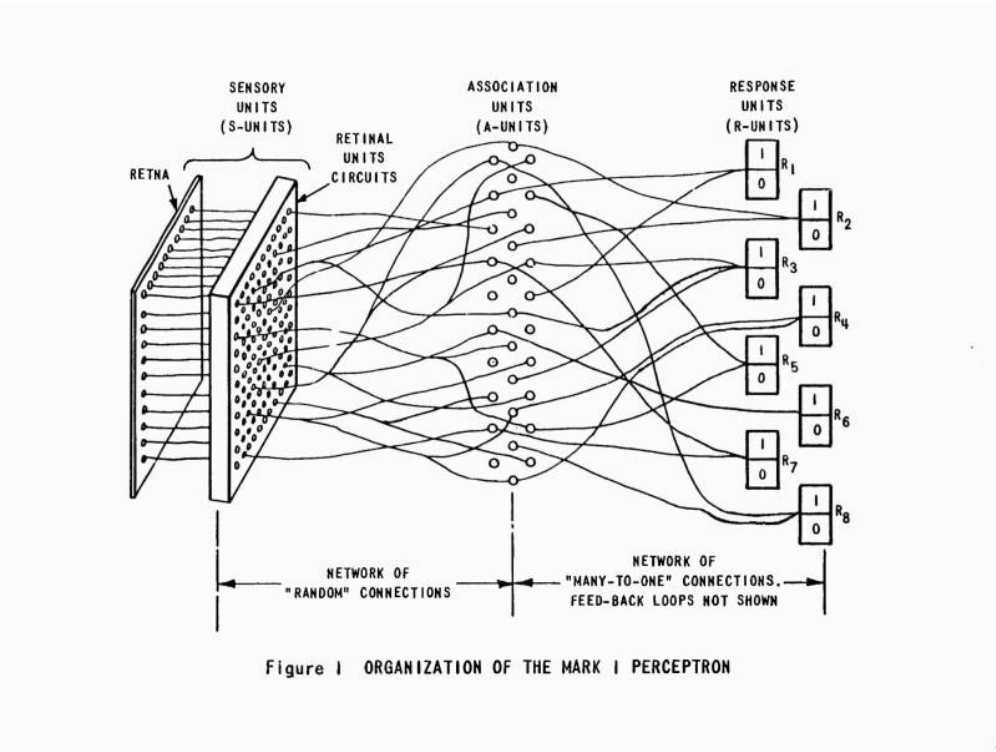
$$f(x,\theta) = g(\theta_0 x_0 + \theta_1 x_1 + \theta_2 x_2 + \ldots + \theta_m x_m) = g(\theta' x)$$







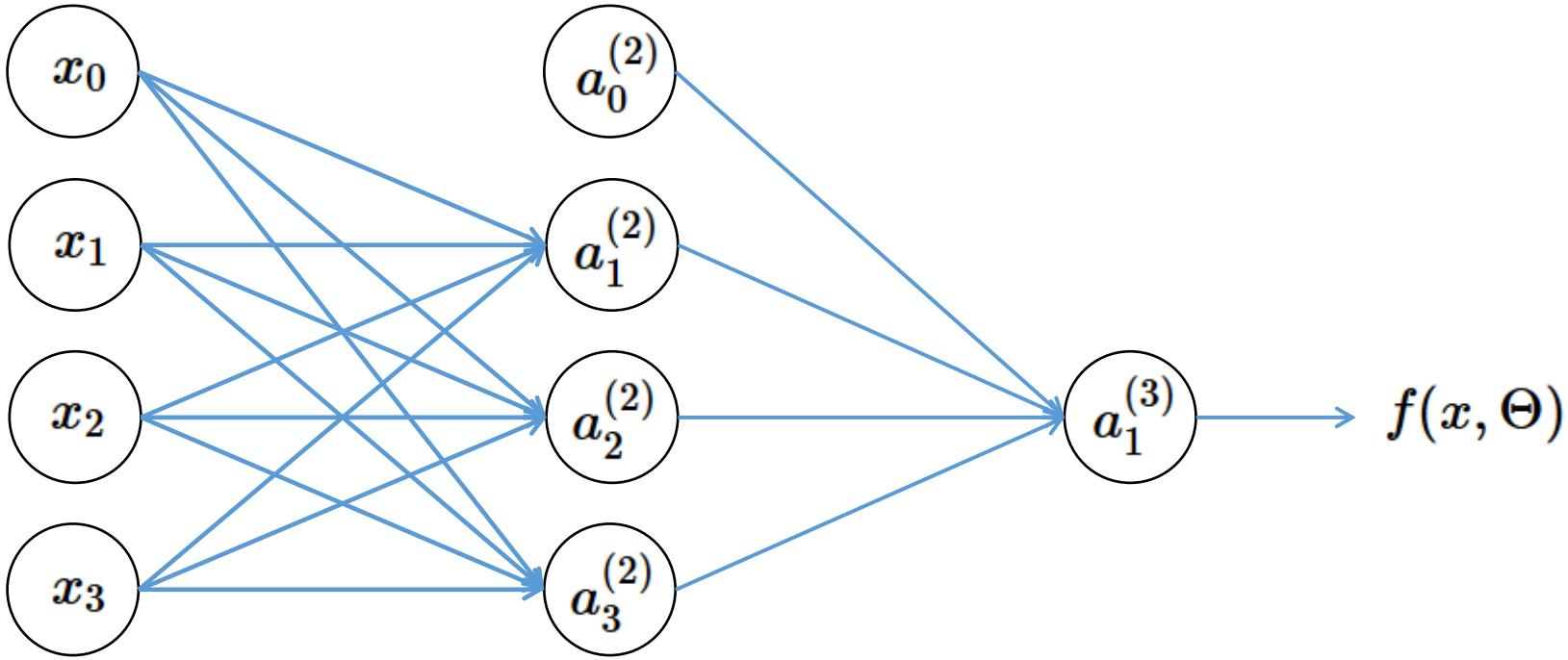
Frank Rosenblatt, Mark I Perceptron Operators' Manual. Buffalo, NY: Cornell Aeronautical Laboratory, 1960

Model: $f(x,\Theta) = g(\Theta_{10}^{(2)} a_0 + \Theta_{11}^{(2)} a_1^{(2)} + \Theta_{12}^{(2)} a_2^{(2)} + \Theta_{13}^{(2)} a_3^{(2)})$

$$a_1^{(2)} = g(\Theta_{10}^{(1)} x_0 + \Theta_{11}^{(1)} x_1 + \Theta_{12}^{(1)} x_2 + \Theta_{13}^{(1)} x_3)$$

$$a_2^{(2)} = g(\Theta_{20}^{(1)} x_0 + \Theta_{21}^{(1)} x_1 + \Theta_{32}^{(1)} x_2 + \Theta_{23}^{(1)} x_3)$$

$$a_3^{(2)} = g(\Theta_{30}^{(1)} x_0 + \Theta_{31}^{(1)} x_1 + \Theta_{32}^{(1)} x_2 + \Theta_{33}^{(1)} x_3)$$



Model: $f(x,\Theta) = g(\Theta_{10}^{(2)} a_0 + \Theta_{11}^{(2)} a_1^{(2)} + \Theta_{12}^{(2)} a_2^{(2)} + \Theta_{13}^{(2)} a_3^{(2)})$

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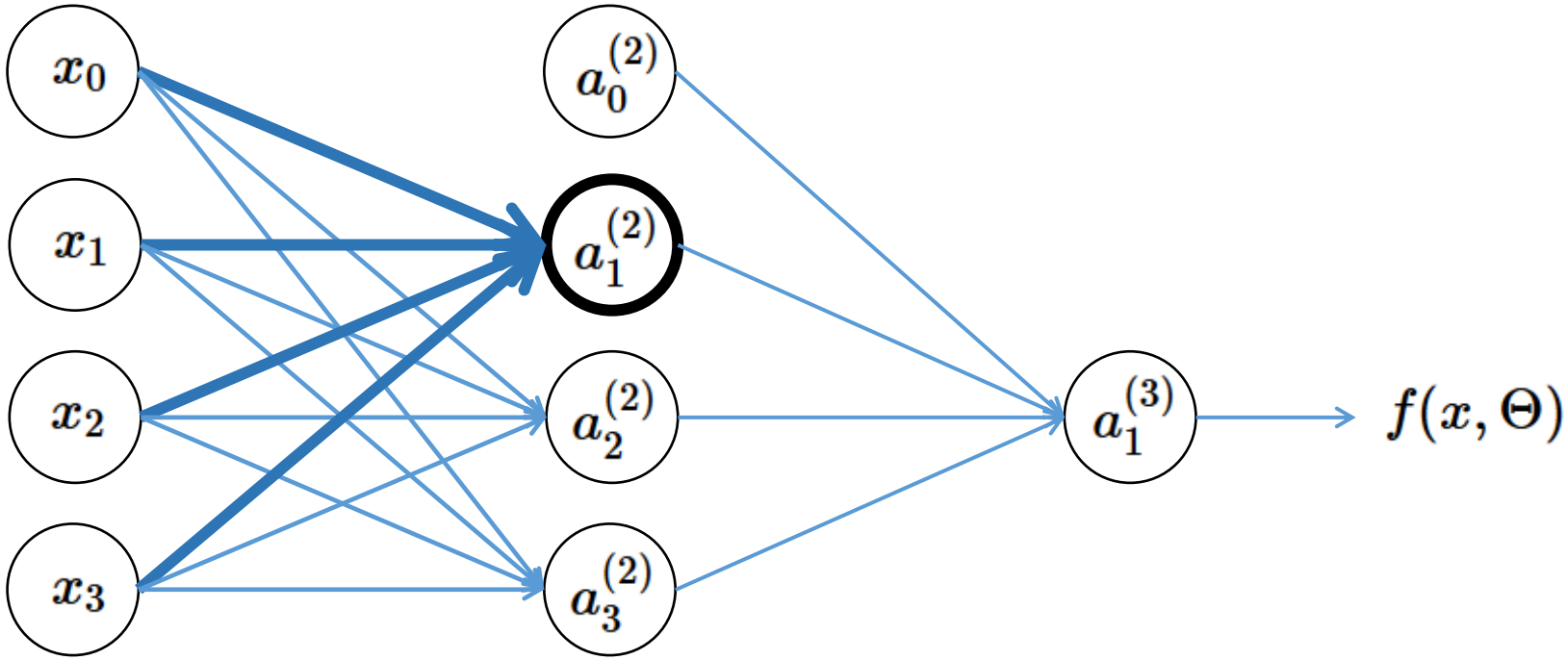
$$a_3^{(2)} = g(\Theta_{30}^{(1)} x_0 + \Theta_{31}^{(1)} x_1 + \Theta_{32}^{(1)} x_2 + \Theta_{33}^{(1)} x_3)$$



Model: $f(x,\Theta) = g(\Theta_{10}^{(2)} a_0 + \Theta_{11}^{(2)} a_1^{(2)} + \Theta_{12}^{(2)} a_2^{(2)} + \Theta_{13}^{(2)} a_3^{(2)})$

$$a_1^{(2)} = g(\Theta_{10}^{(1)} x_0 + \Theta_{11}^{(1)} x_1 + \Theta_{12}^{(1)} x_2 + \Theta_{13}^{(1)} x_3)$$

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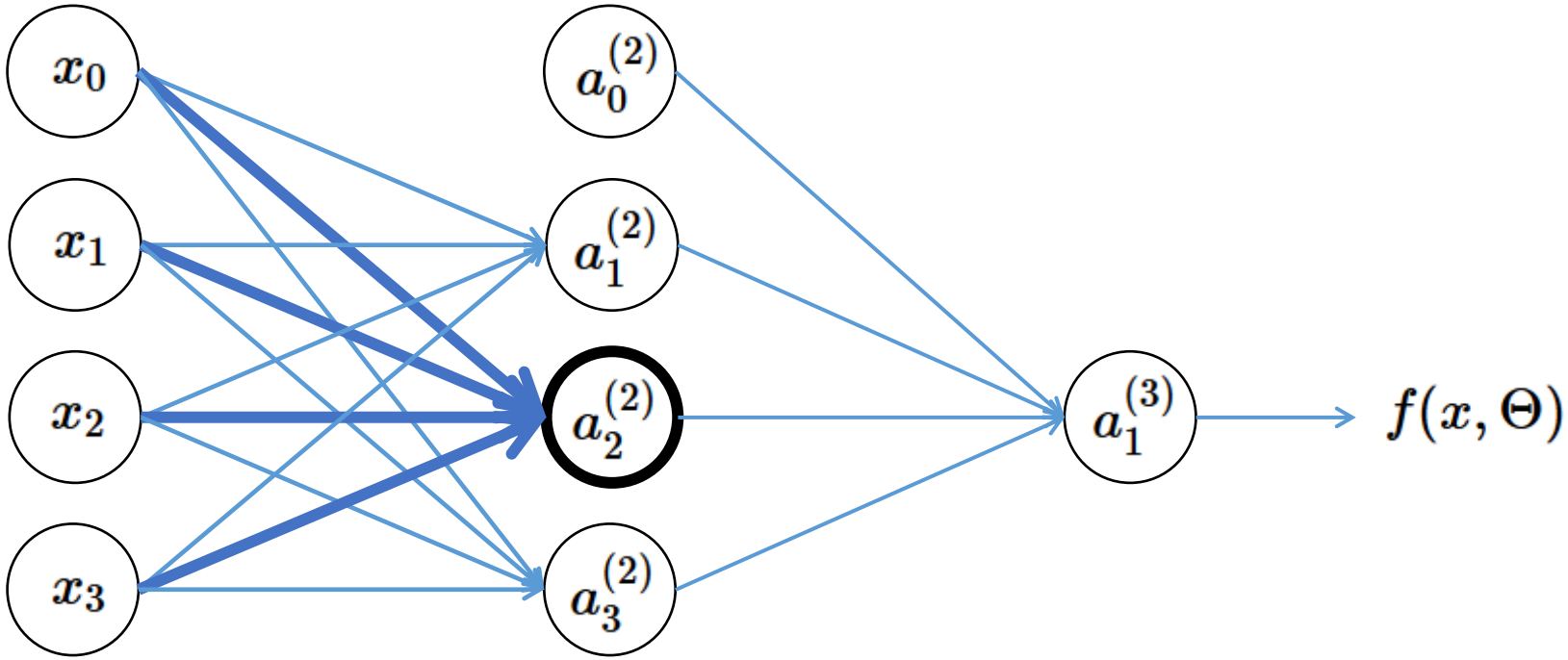
$$a_3^{(2)} = g(\Theta_{30}^{(1)} x_0 + \Theta_{31}^{(1)} x_1 + \Theta_{32}^{(1)} x_2 + \Theta_{33}^{(1)} x_3)$$



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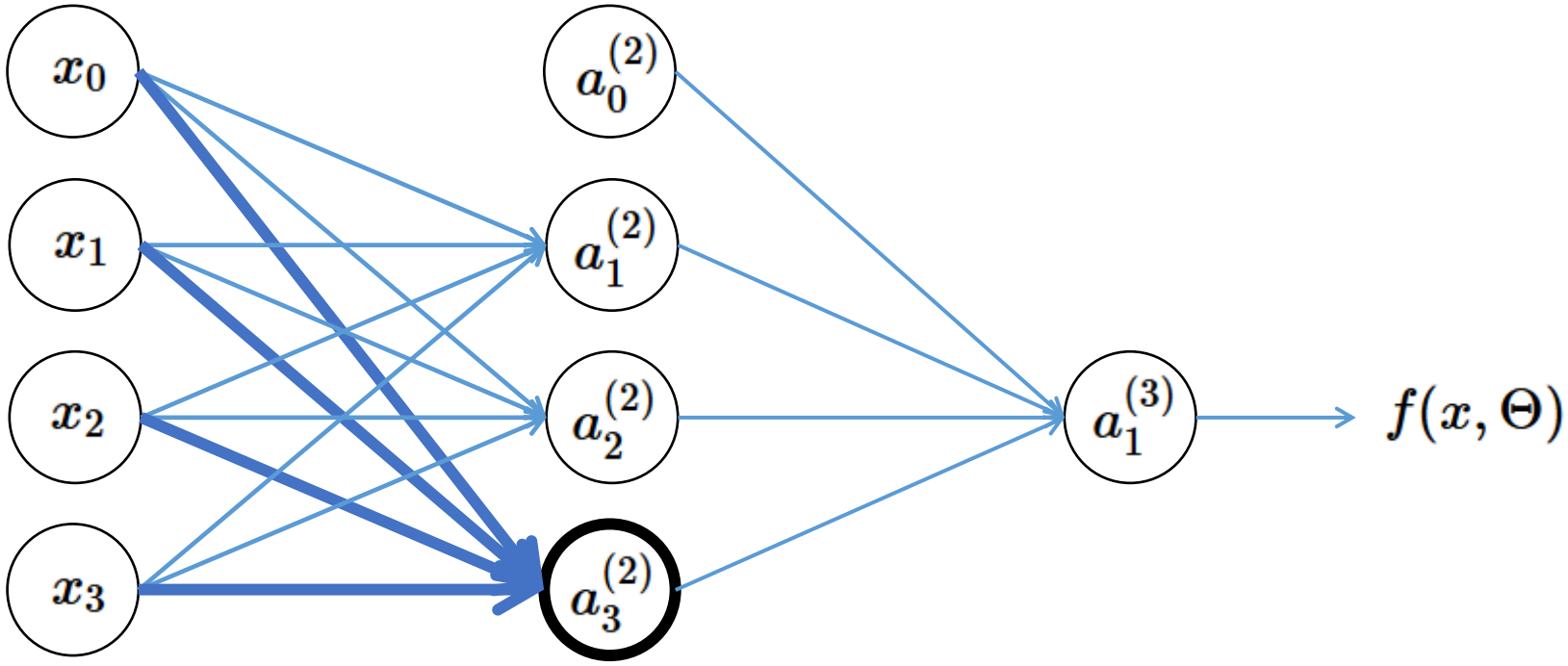
$$a_1^{(2)} = g(\Theta_{10}^{(1)} x_0 + \Theta_{11}^{(1)} x_1 + \Theta_{12}^{(1)} x_2 + \Theta_{13}^{(1)} x_3)$$

$$a_2^{(2)} = g(\Theta_{20}^{(1)} x_0 + \Theta_{21}^{(1)} x_1 + \Theta_{32}^{(1)} x_2 + \Theta_{23}^{(1)} x_3)$$

$$a_3^{(2)} = g(\Theta_{30}^{(1)} x_0 + \Theta_{31}^{(1)} x_1 + \Theta_{32}^{(1)} x_2 + \Theta_{33}^{(1)} x_3)$$



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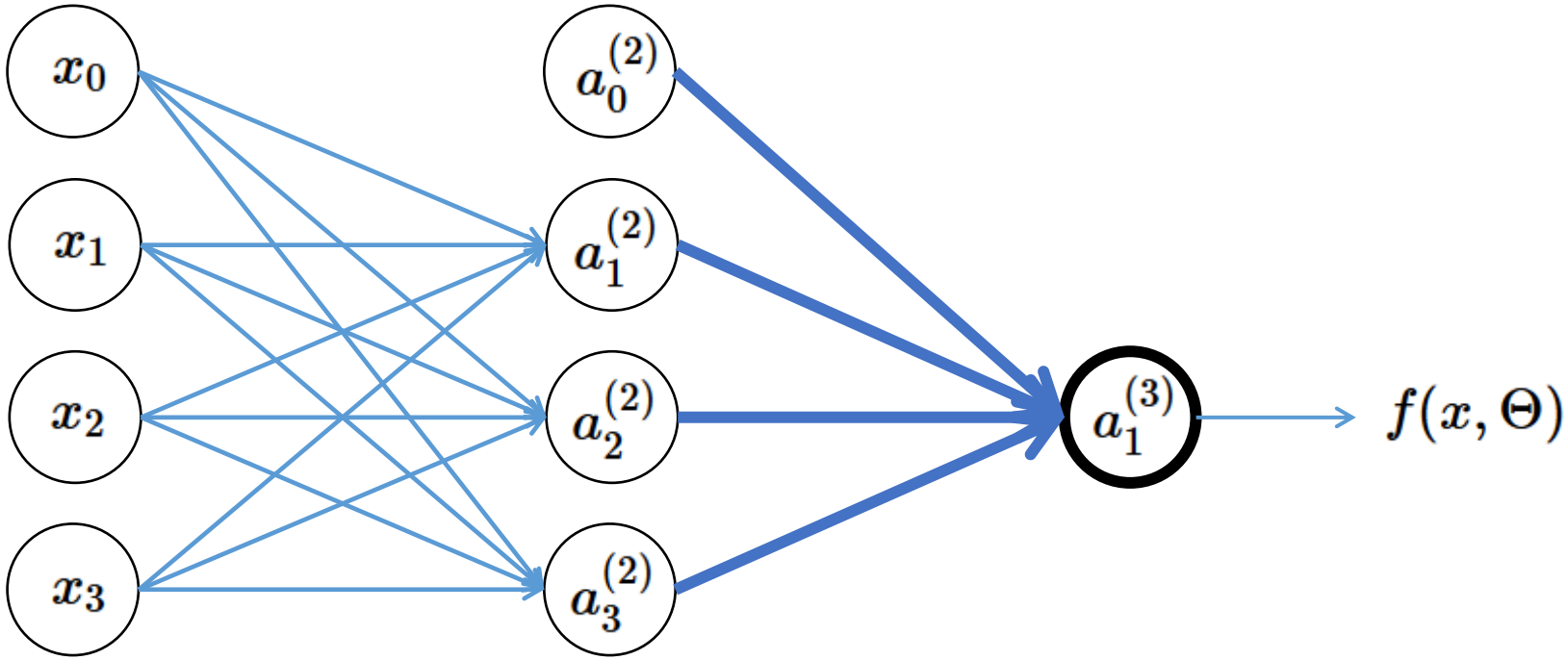
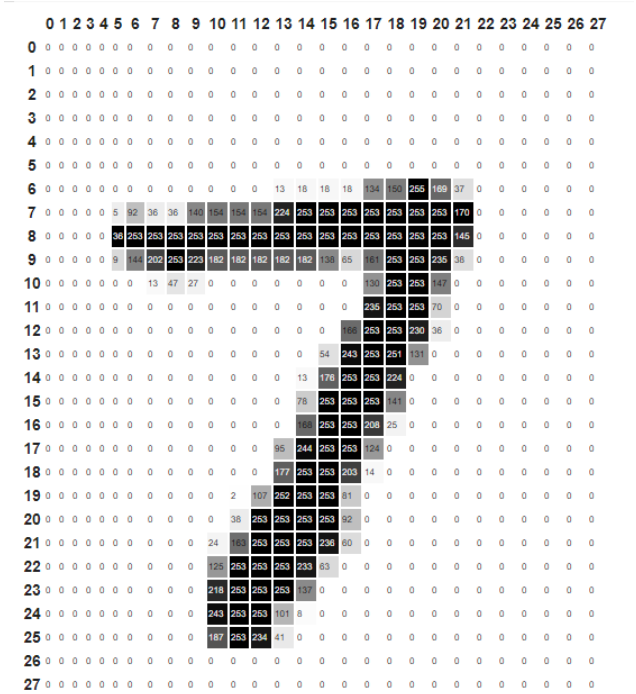
$$a_3^{(2)} = g(\Theta_{30}^{(1)} x_0 + \Theta_{31}^{(1)} x_1 + \Theta_{32}^{(1)} x_2 + \Theta_{33}^{(1)} x_3)$$



Neural networks



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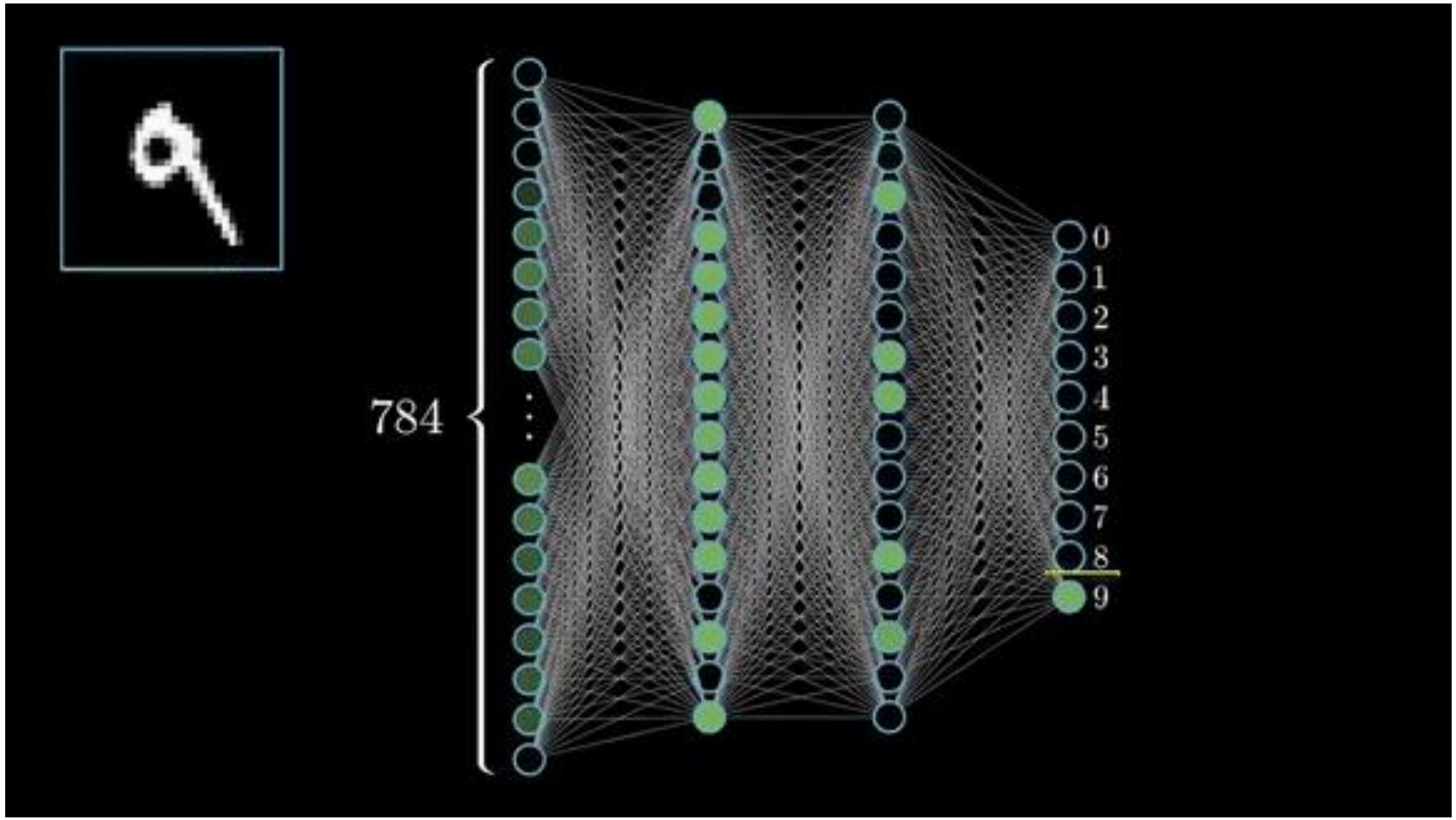


Cost function

Logistic regression:

$$J(\theta) = -\frac{1}{m}\left[\sum_{i=1}^{m} y^{(i)} \log h_\theta(x^{(i)}) + (1-y^{(i)}) \log(1-h_\theta(x^{(i)}))\right] + \frac{\lambda}{2m}\sum_{j=1}^{n}\theta_j^2$$

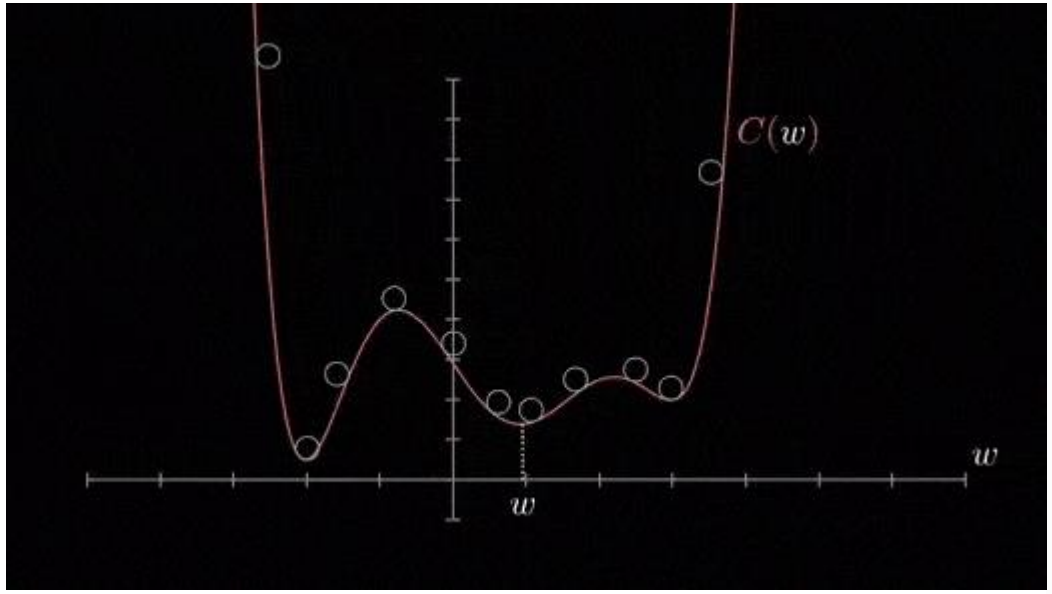
Neural network:

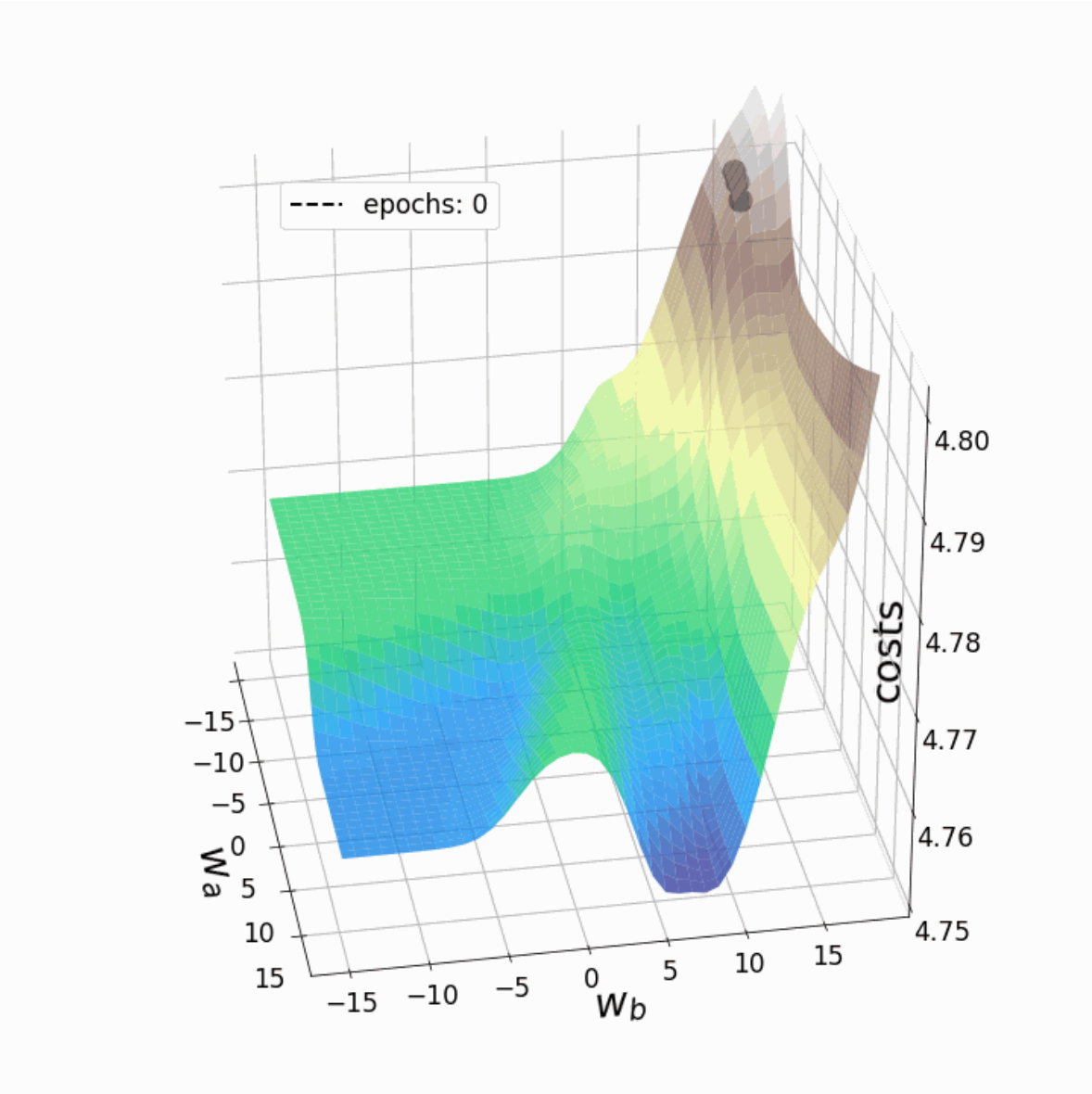
$$h_\Theta(x) \in \mathbb{R}^K \quad (h_\Theta(x))_i = i^{th} \text{ output}$$

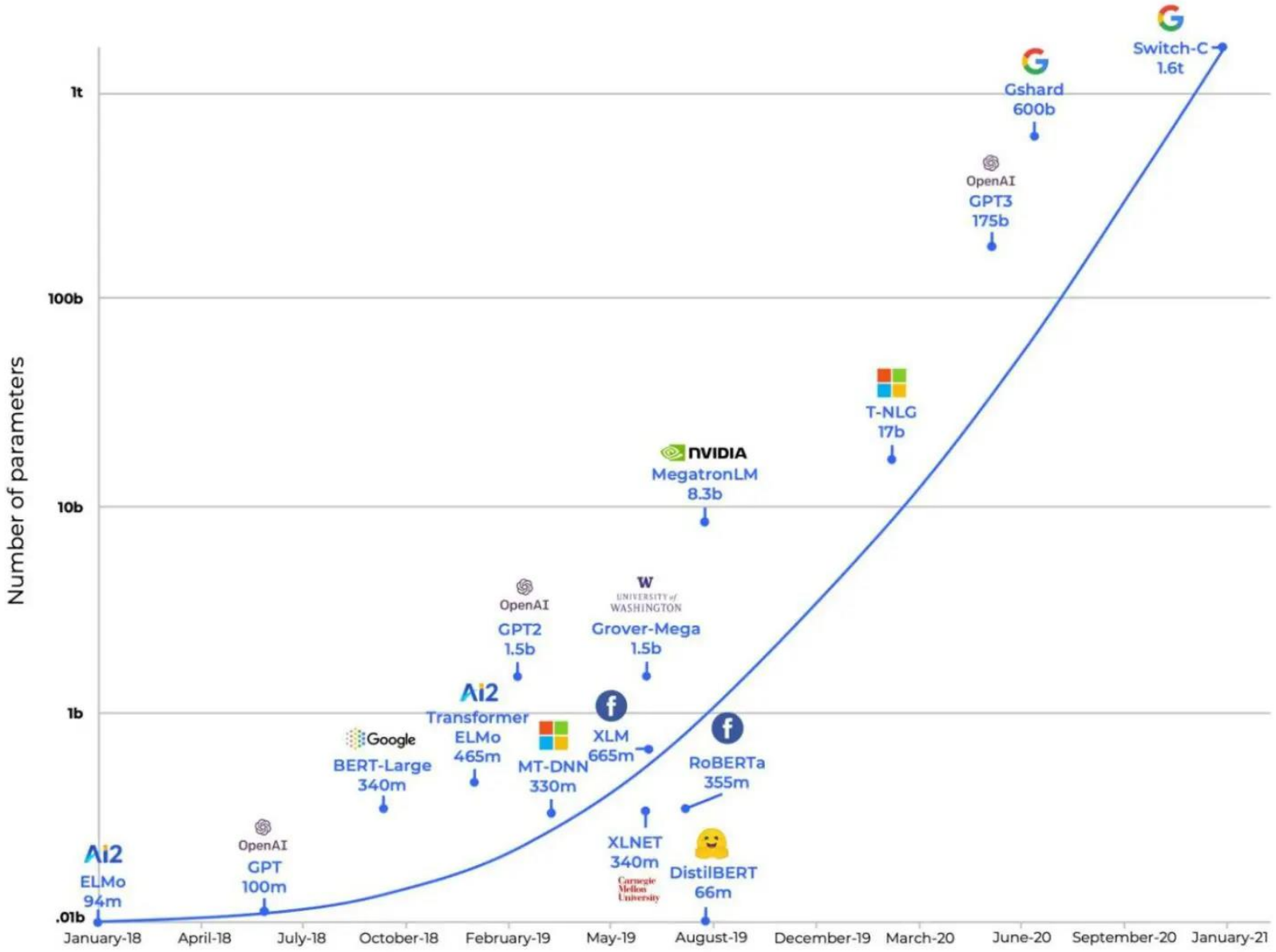
$$J(\Theta) = -\frac{1}{m}\left[\sum_{i=1}^{m}\sum_{k=1}^{K} y_k^{(i)} \log(h_\Theta(x^{(i)}))_k + (1-y_k^{(i)}) \log(1-(h_\Theta(x^{(i)}))_k)\right]$$

$$+\frac{\lambda}{2m}\sum_{l=1}^{L-1}\sum_{i=1}^{s_l}\sum_{j=1}^{s_{l+1}}(\Theta_{ji}^{(l)})^2$$

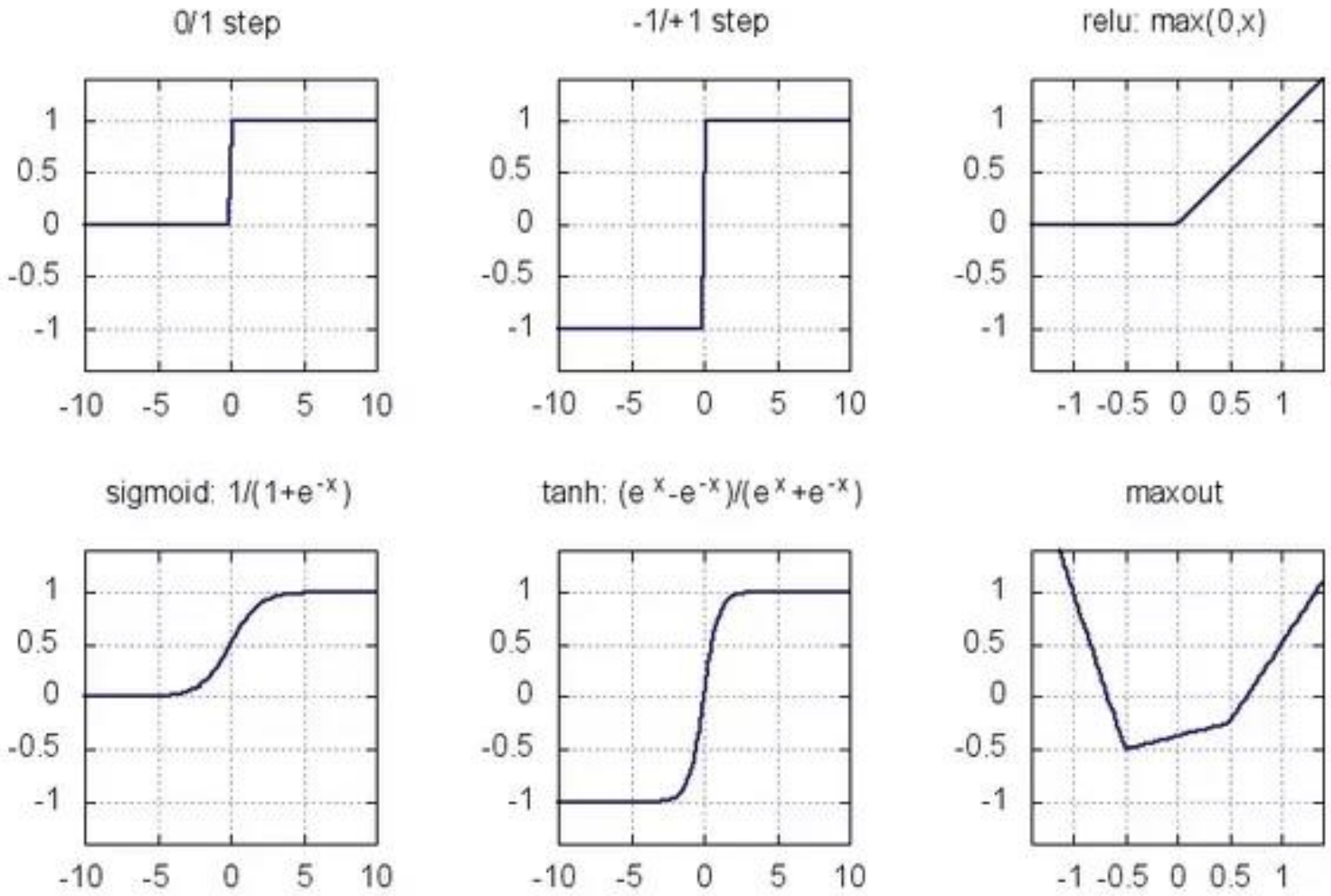
Gradient descent (back-propagation)



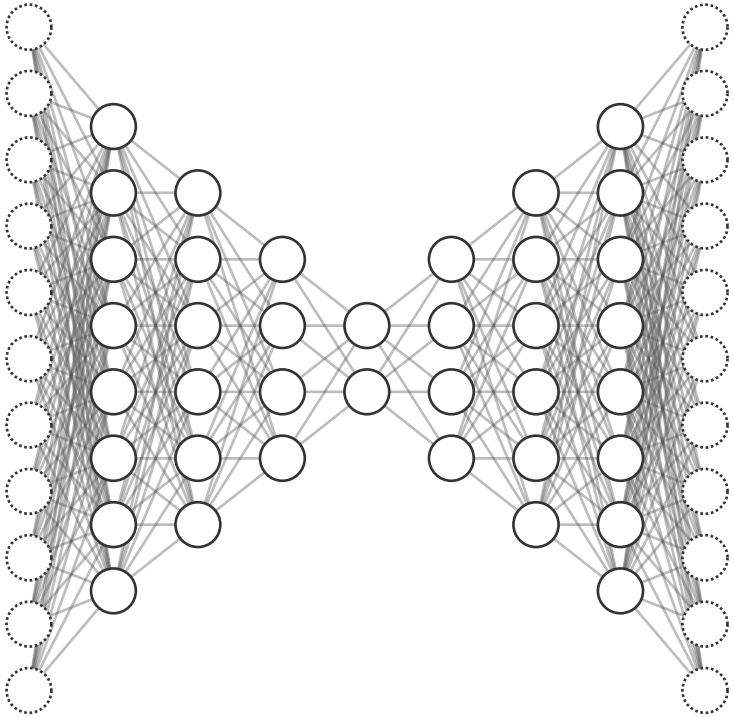




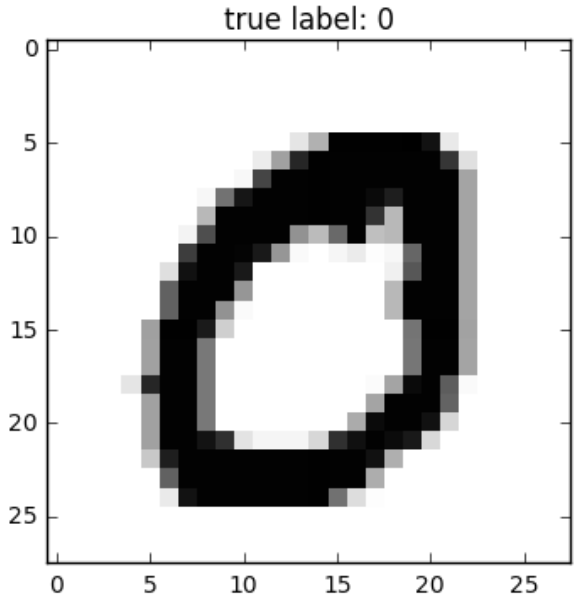
Source: https://deci.ai

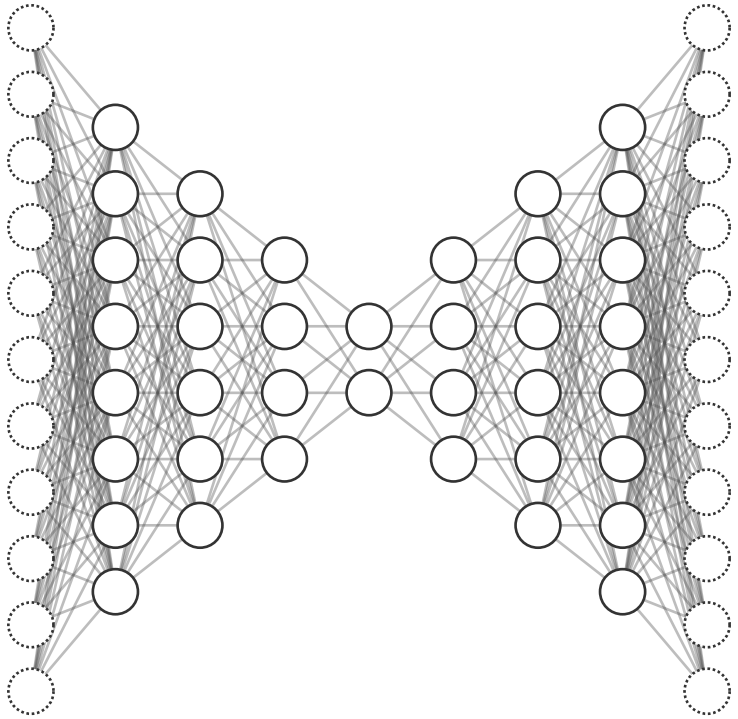


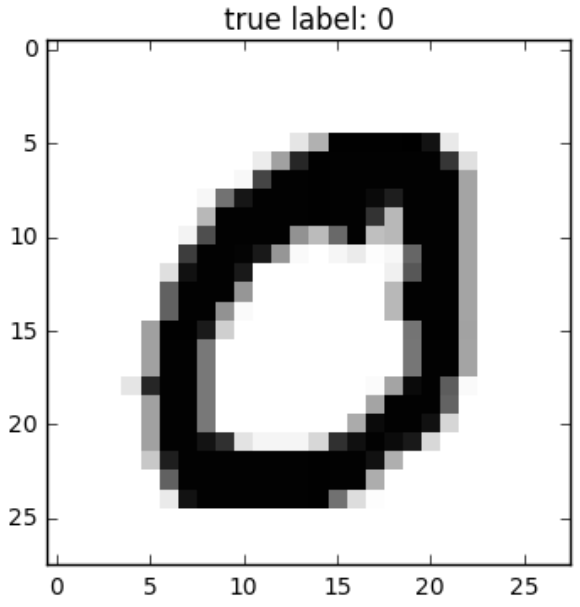
Activation functions



Auto-encoders







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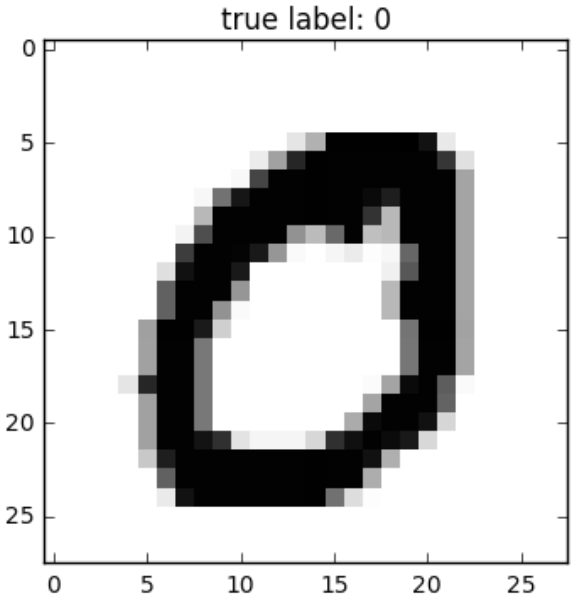
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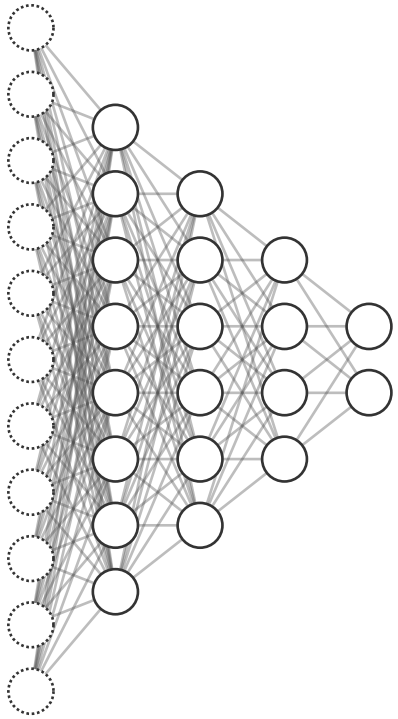

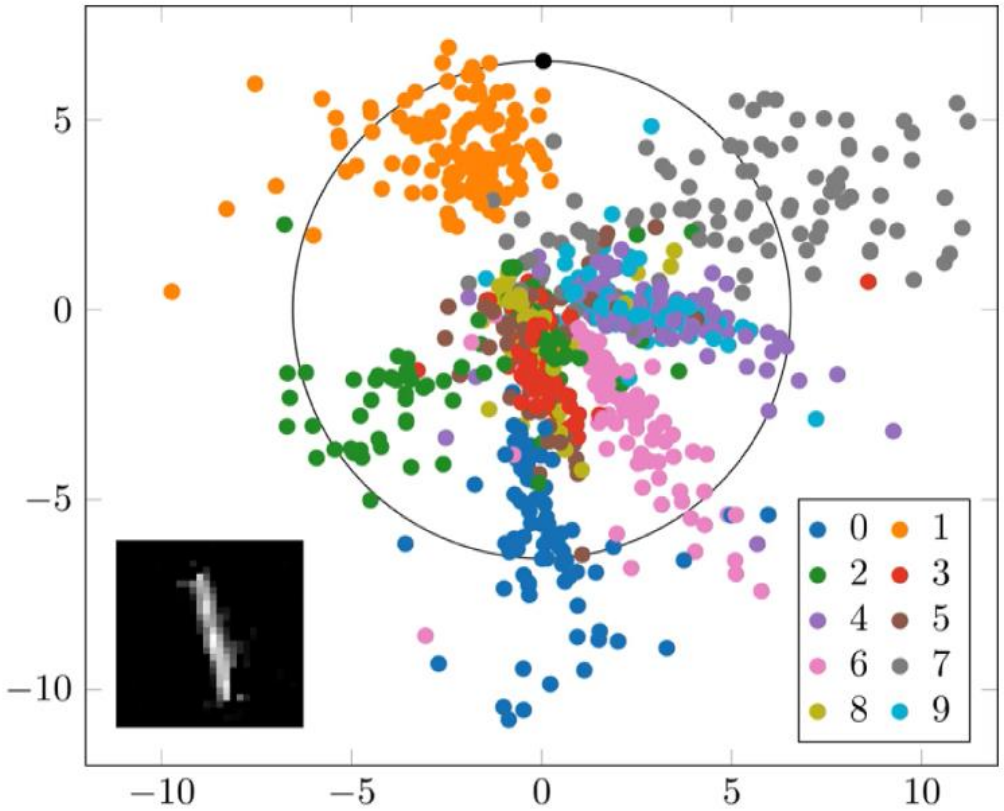
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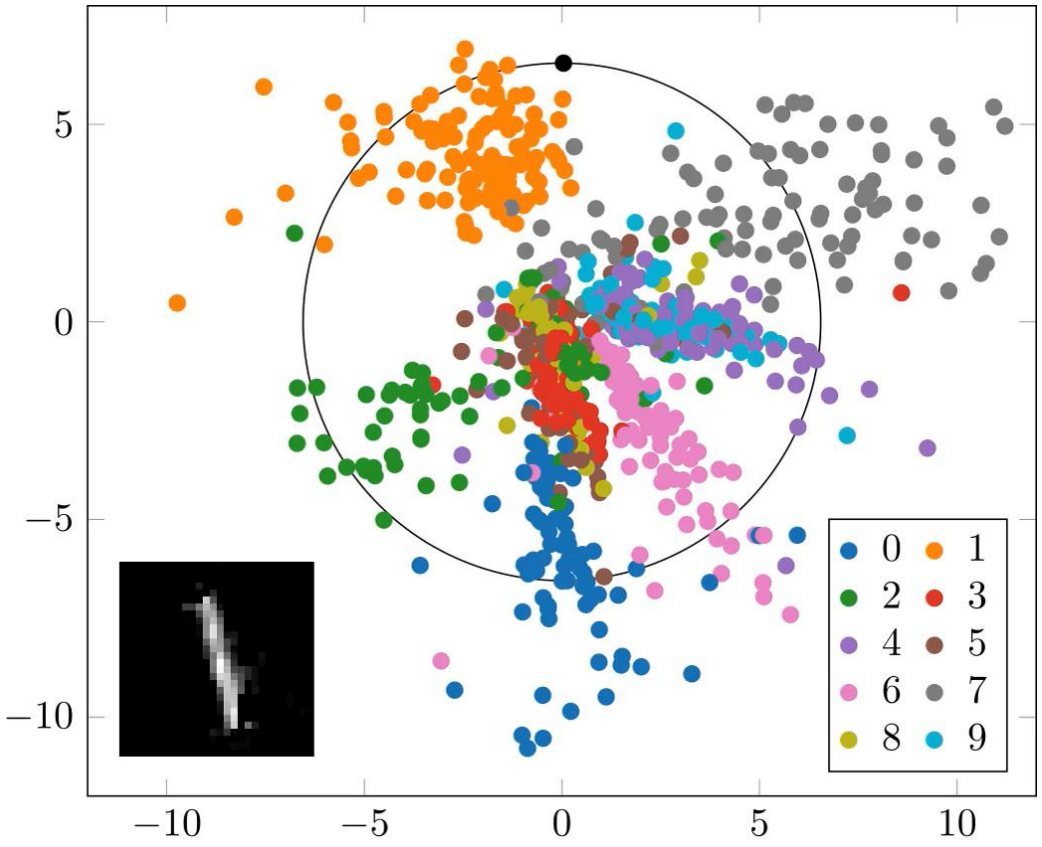
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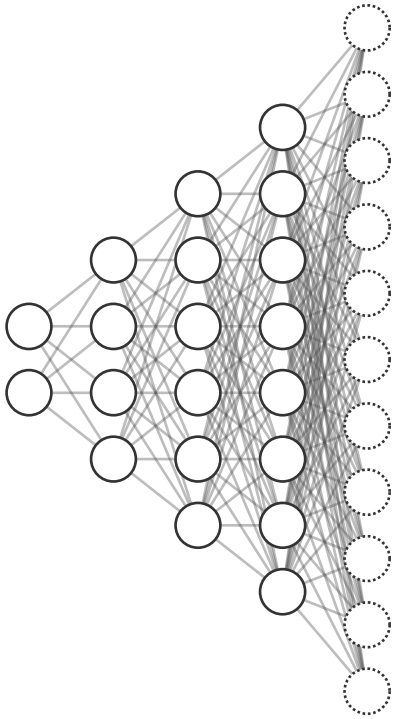

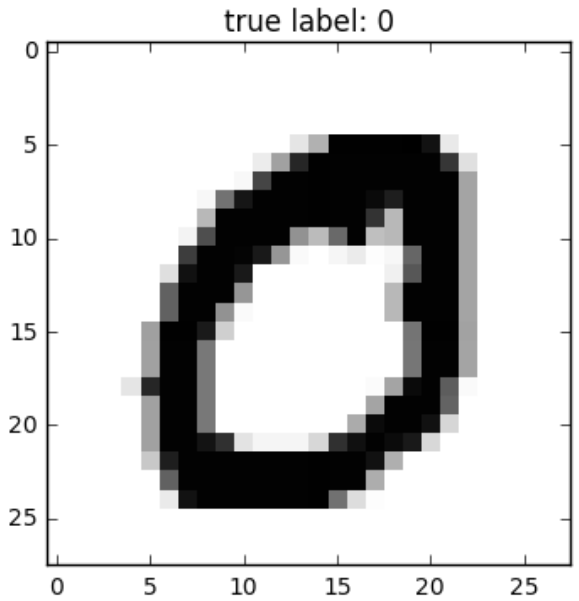
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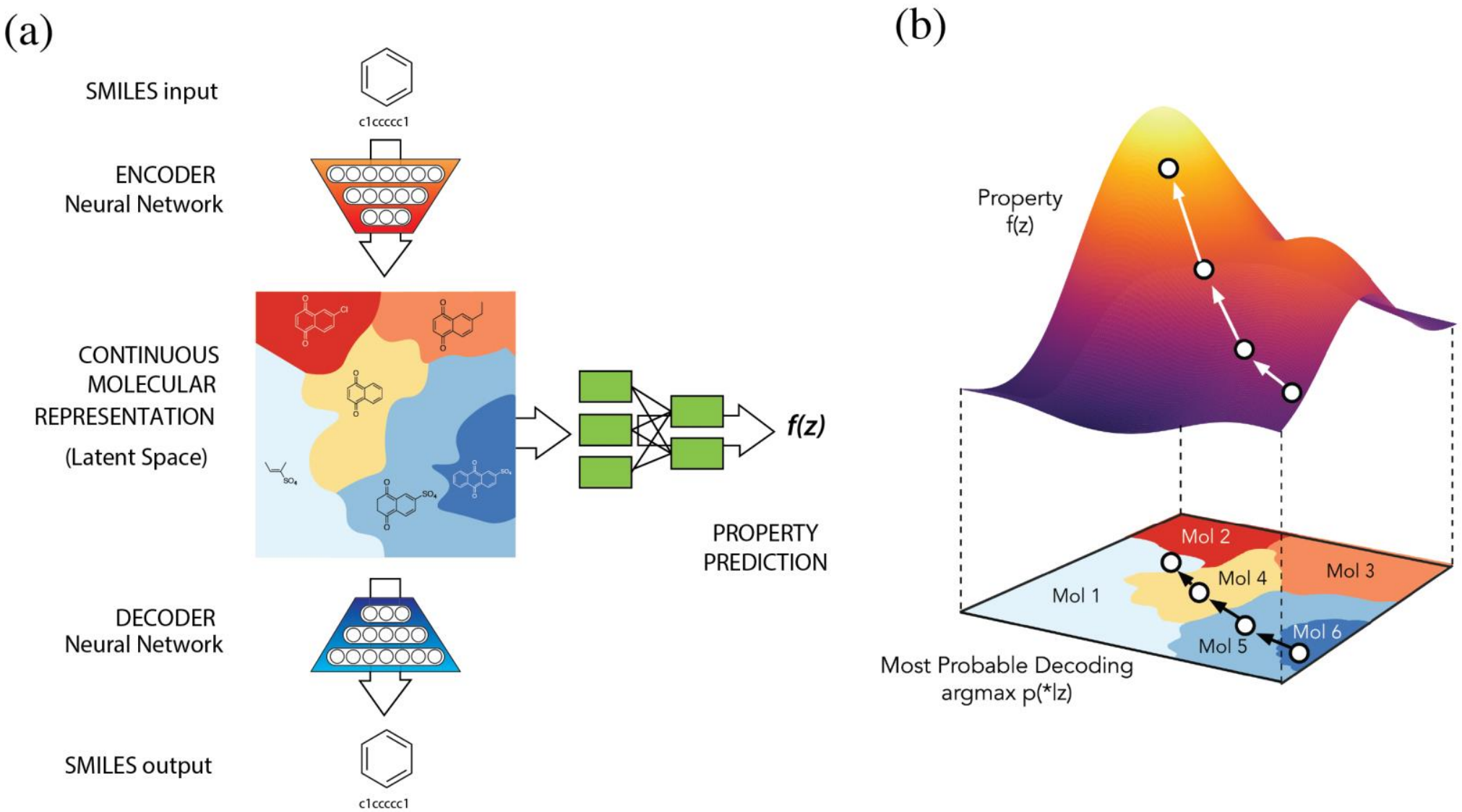
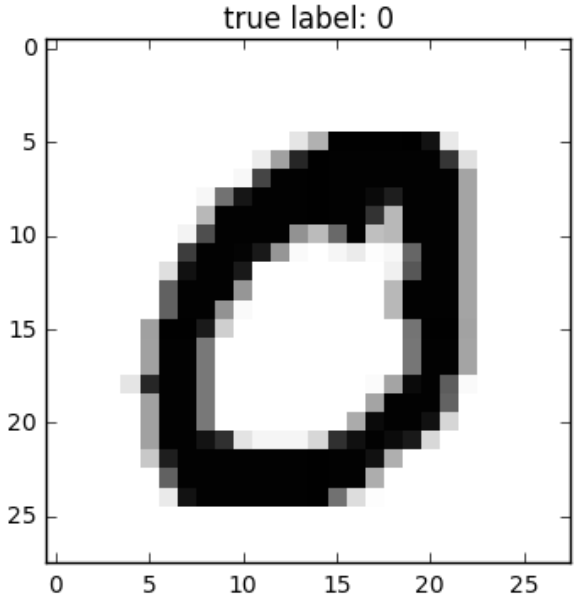


Auto-encoders: Gómez-Bombarelli *et al.* ACS Central Science (2019)

Convolutional neural network (CNN)



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144	178	167	231	210	232	170	67	115	88	76	62	83	85	88	139	192	190	135	80	53	99	141	165	201	97	79	192	245	235	248	249
127	145	149	196	204	213	197	95	133	122	117	133	126	108	110	139	191	197	167	129	127	148	147	171	188	110	121	228	233	180	215	212
87	112	100	79	85	82	65	75	142	148	151	153	138	125	120	149	191	190	193	175	174	193	198	190	208	127	163	239	219	149	198	196
63	83	109	134	129	106	39	78	132	142	155	159	139	111	124	164	196	200	186	192	191	196	200	202	200	143	217	253	249	242	238	234
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65	49	77	89	50	68	43	61	109	127	141	147	113	100	121	145	148	189	181	176	181	201	201	205	202	174	166	169	178	183	188	184
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115	123	126	134	145	102	27	54	52	38	46	69	105	135	175	189	193	216	206	166	139	111	164	203	74	5	121	151	142	142	143	146
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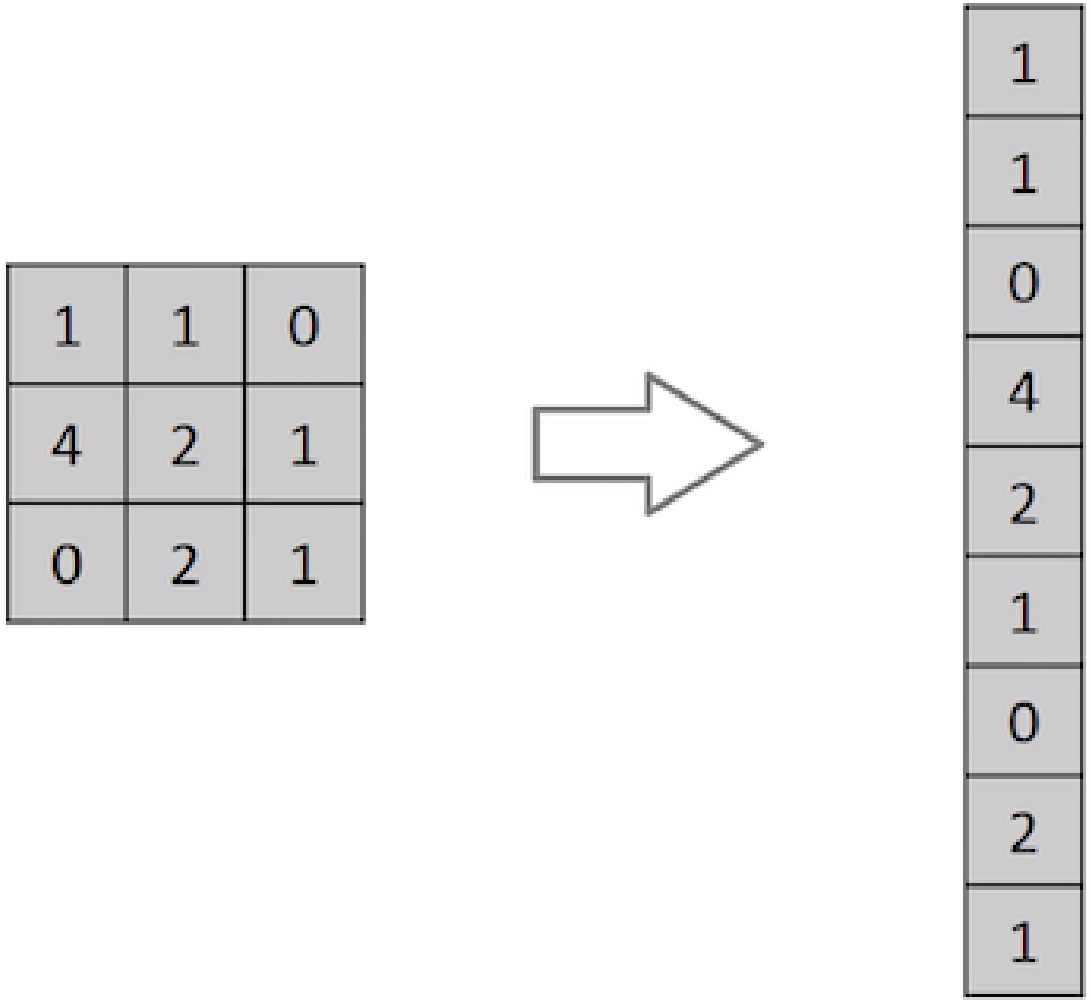
98	97	97	98	104	76	34	33	30	48	41	49	51	58	74	53	55	66	63	89	150	188	209	156	62	108	140	149	125	133	131	131
102	102	97	88	73	35	30	23	42	50	65	41	90	60	59	51	57	82	123	157	187	206	169	62	98	151	106	101	154	135	130	129

Convolutional filters: https://setosa.io/ev/image-kernels/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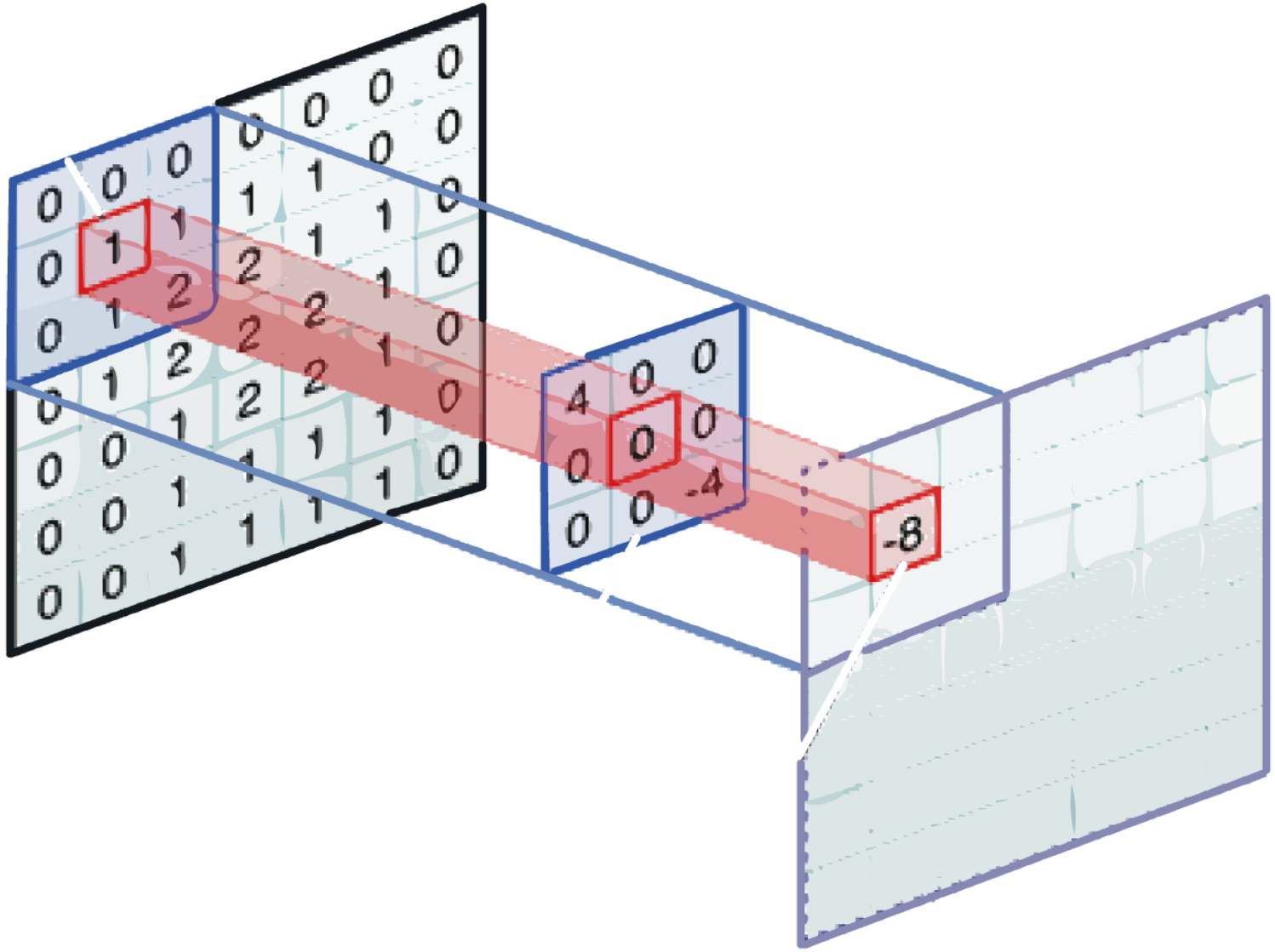
4 2 1
0 2 1
1
1
0
4
2
1
0
2
1



Convolutional filters: https://setosa.io/ev/image-kernels/

208	205	247	245	244	253	247	245	138	151	255	255	255	255	255	255	234	207	231	255	254	254	255	255	254	255	252	255	255	254	255	247
244	181	137	244	254	255	254	255	118	103	209	228	156	153	238	193	74	52	88	173	255	254	254	255	255	255	254	255	254	253	244	184
192	154	75	200	249	255	255	255	110	98	84	61	35	44	89	53	44	45	43	54	140	213	253	255	255	255	255	245	187	188	178	223
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67	69	107	198	238	255	255	255	104	25	34	35	29	20	25	34	32	30	32	34	53	85	100	142	231	242	247	249	255	255	255	255
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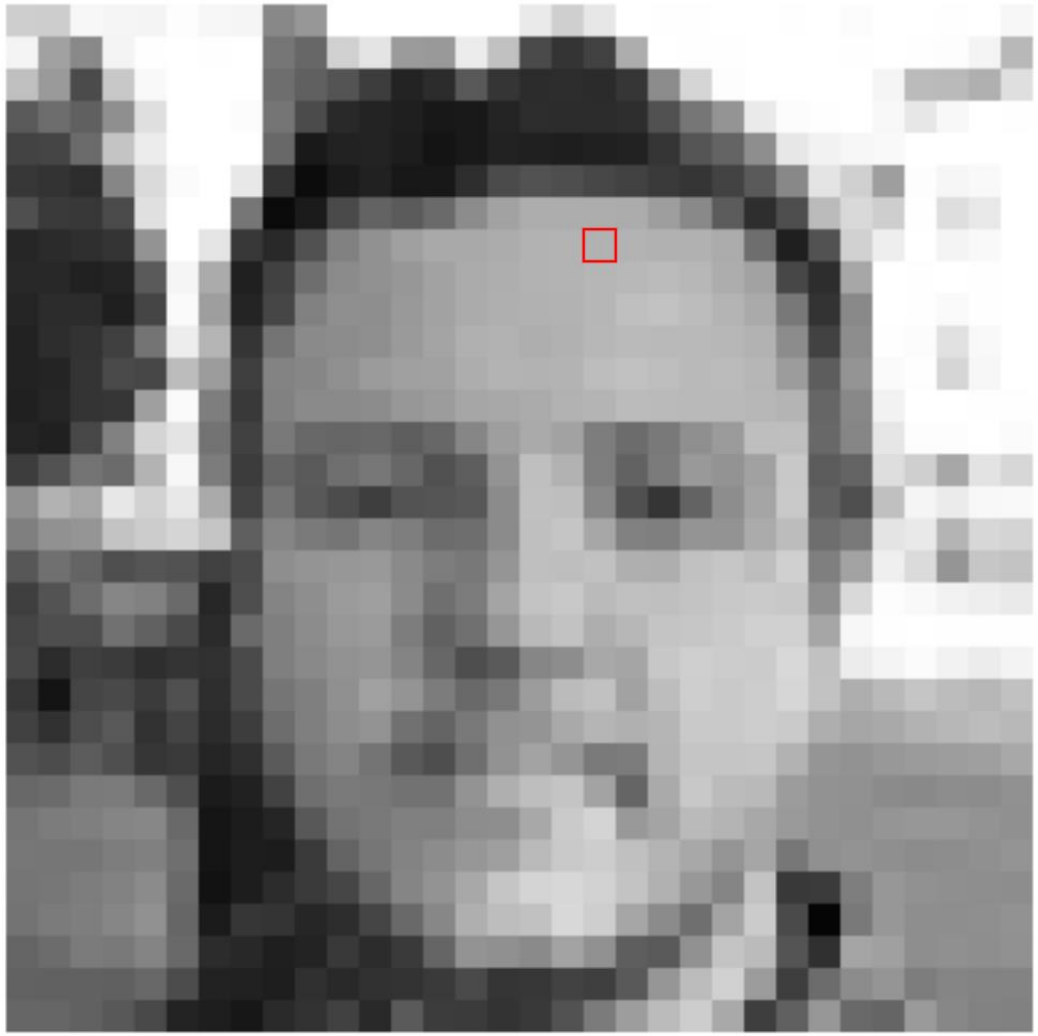
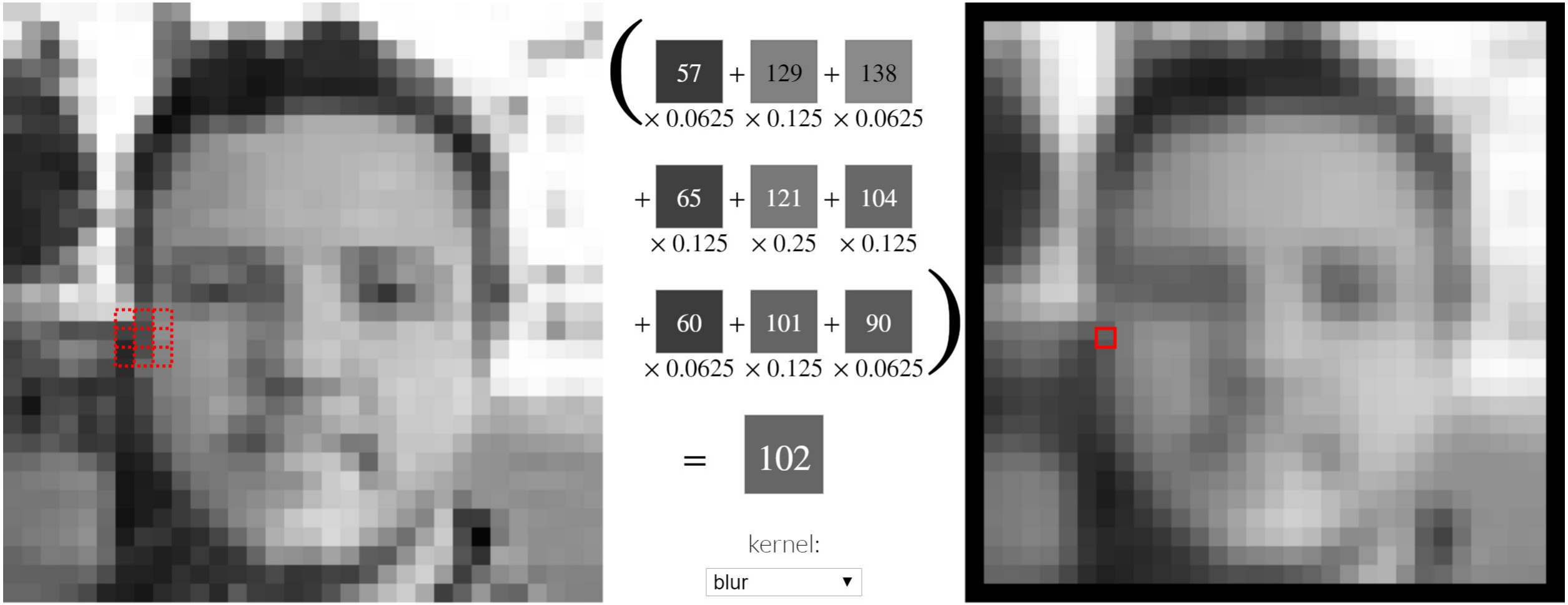


Convolutional filters: https://setosa.io/ev/image-kernels/

blur ▼

$$\begin{pmatrix} 0.0625 & 0.125 & 0.0625 \\ 0.125 & 0.25 & 0.125 \\ 0.0625 & 0.125 & 0.0625 \end{pmatrix}$$

Convolutional filters: https://setosa.io/ev/image-kernels/



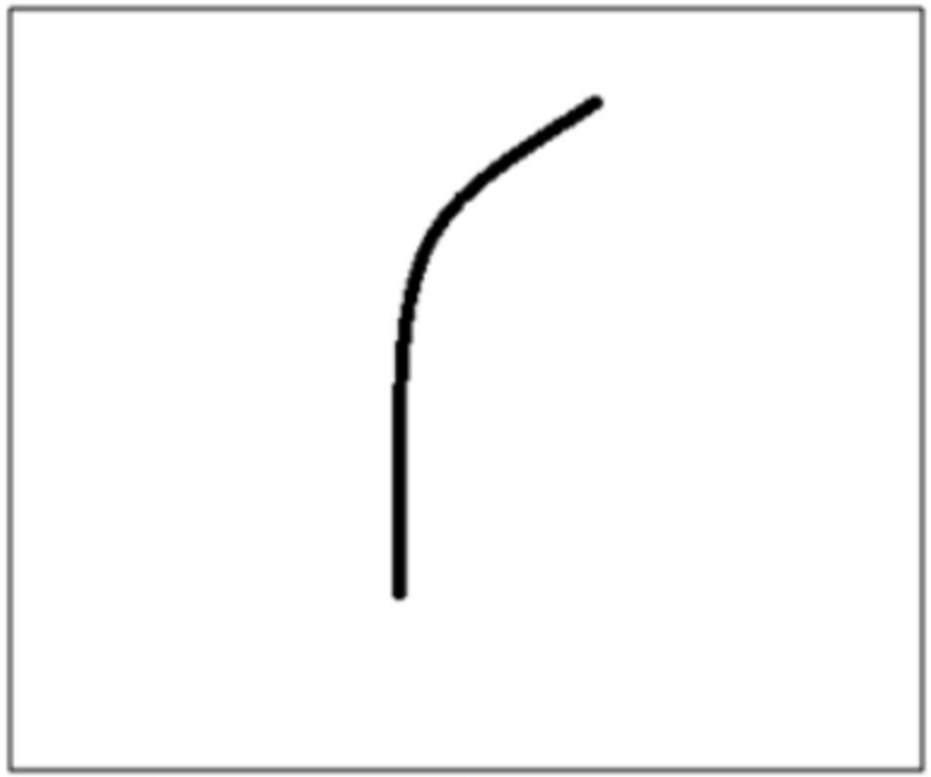
input image

output image

Convolutional filters: https://setosa.io/ev/image-kernels/

0	0	0	0	0	30	0
0	0	0	0	30	0	0
0	0	0	30	0	0	0
0	0	0	30	0	0	0
0	0	0	30	0	0	0
0	0	0	30	0	0	0
0	0	0	0	0	0	0

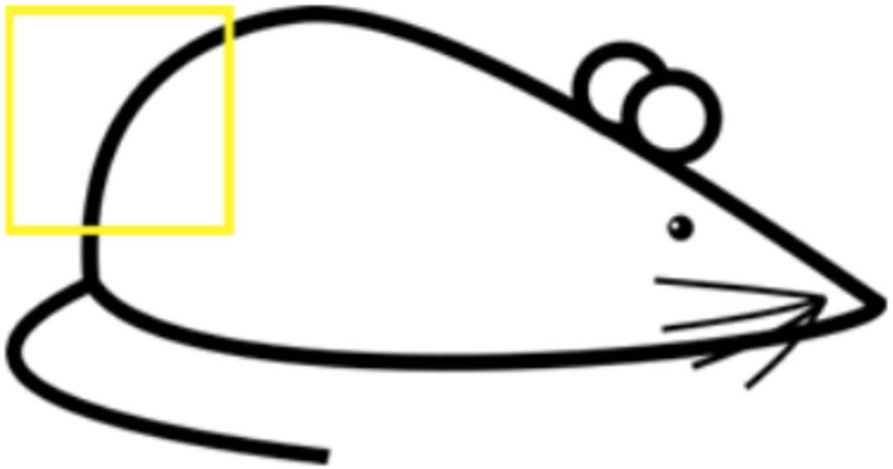
Pixel representation of filter



Visualization of a curve detector filter

Convolutional filters: https://setosa.io/ev/image-kernels/

Original image



Visualization of the filter on the image

Visualization of the receptive field

0	0	0	0	0	0	30
0	0	0	0	50	50	50
0	0	0	20	50	0	0
0	0	0	50	50	0	0
0	0	0	50	50	0	0
0	0	0	50	50	0	0
0	0	0	50	50	0	0

Pixel representation of the receptive field

*

0	0	0	0	0	30	0
0	0	0	0	30	0	0
0	0	0	30	0	0	0
0	0	0	30	0	0	0
0	0	0	30	0	0	0
0	0	0	30	0	0	0
0	0	0	0	0	0	0

Pixel representation of filter

Convolutional filters: https://setosa.io/ev/image-kernels/

Visualization of the filter on the image

0	0	0	0	0	0	0
0	40	0	0	0	0	0
40	0	40	0	0	0	0
40	20	0	0	0	0	0
0	50	0	0	0	0	0
0	0	50	0	0	0	0
25	25	0	50	0	0	0

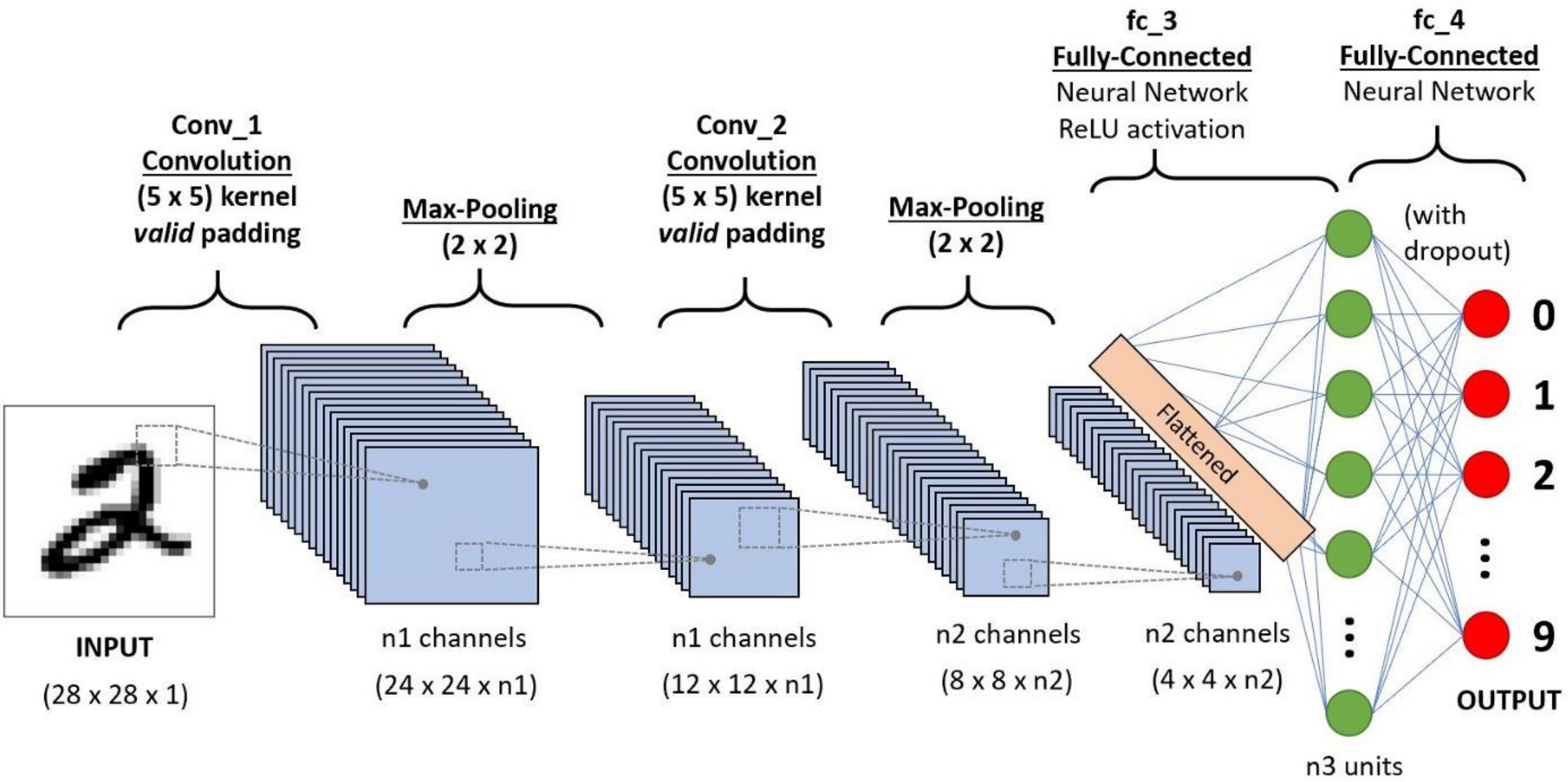
Pixel representation of receptive field

$*$

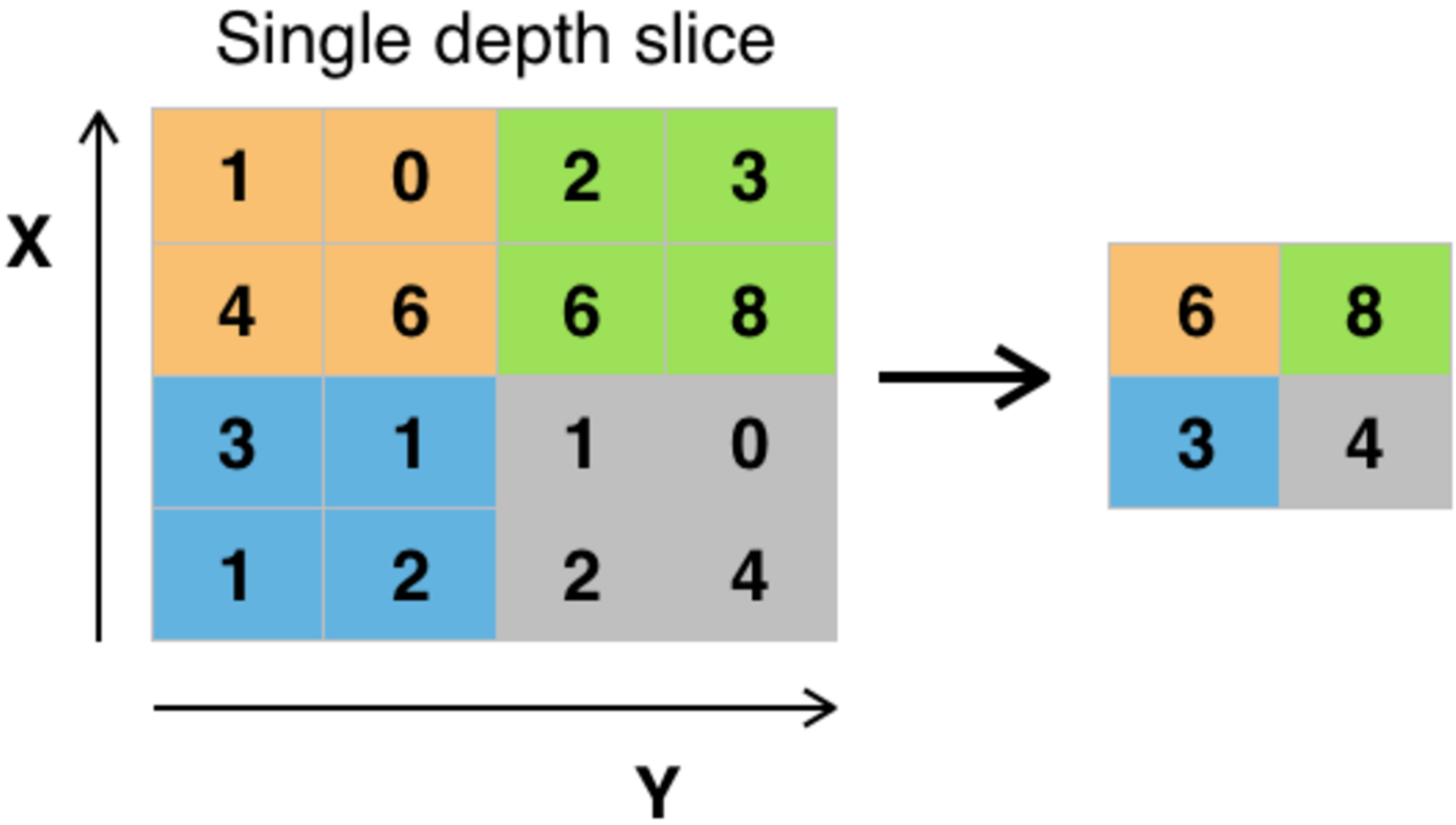
0	0	0	0	0	30	0
0	0	0	0	30	0	0
0	0	0	30	0	0	0
0	0	0	30	0	0	0
0	0	0	30	0	0	0
0	0	0	30	0	0	0
0	0	0	0	0	0	0

Pixel representation of filter

Convolutional filters: https://setosa.io/ev/image-kernels/

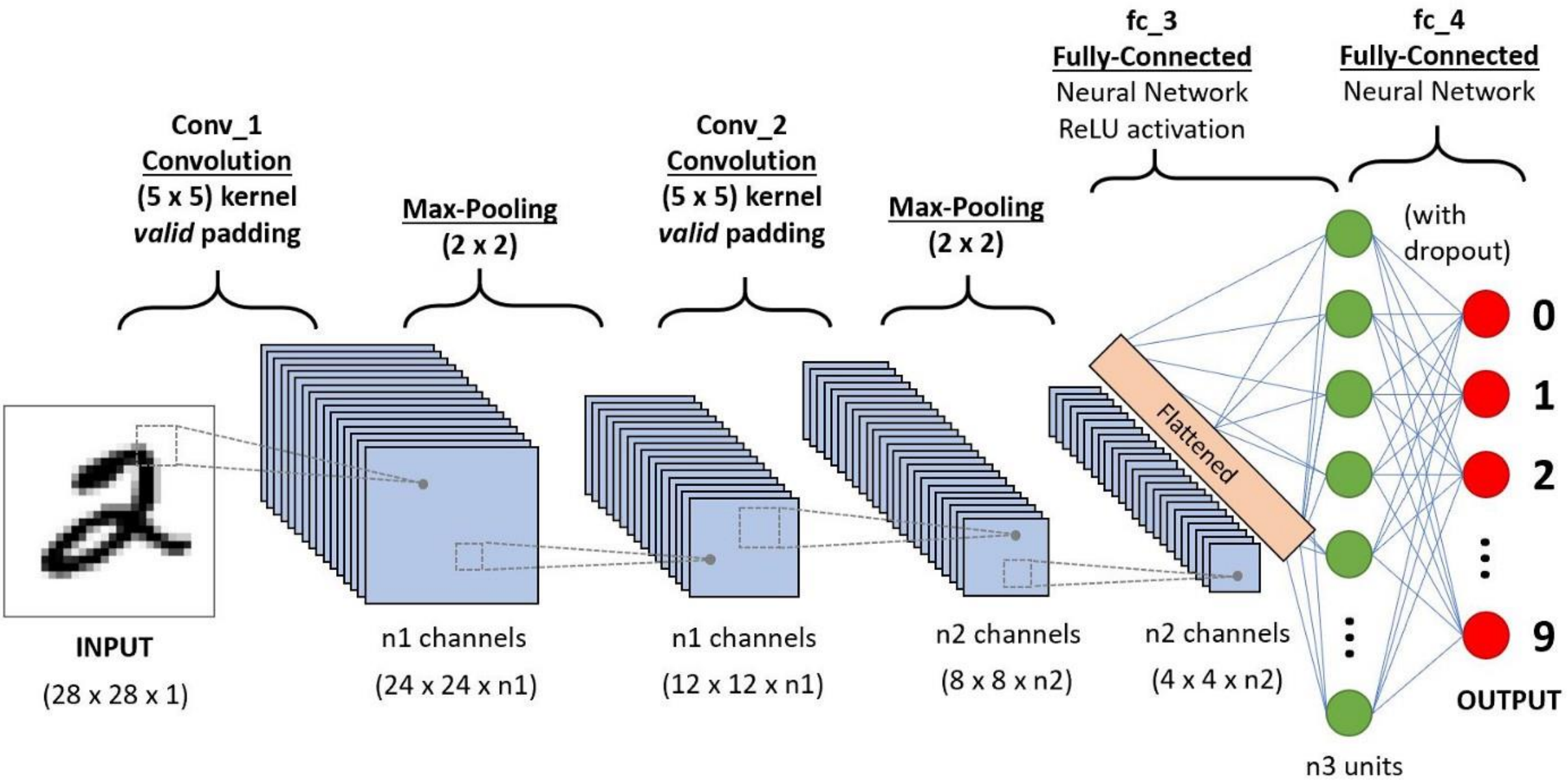


Convolutional neural network (CNN)

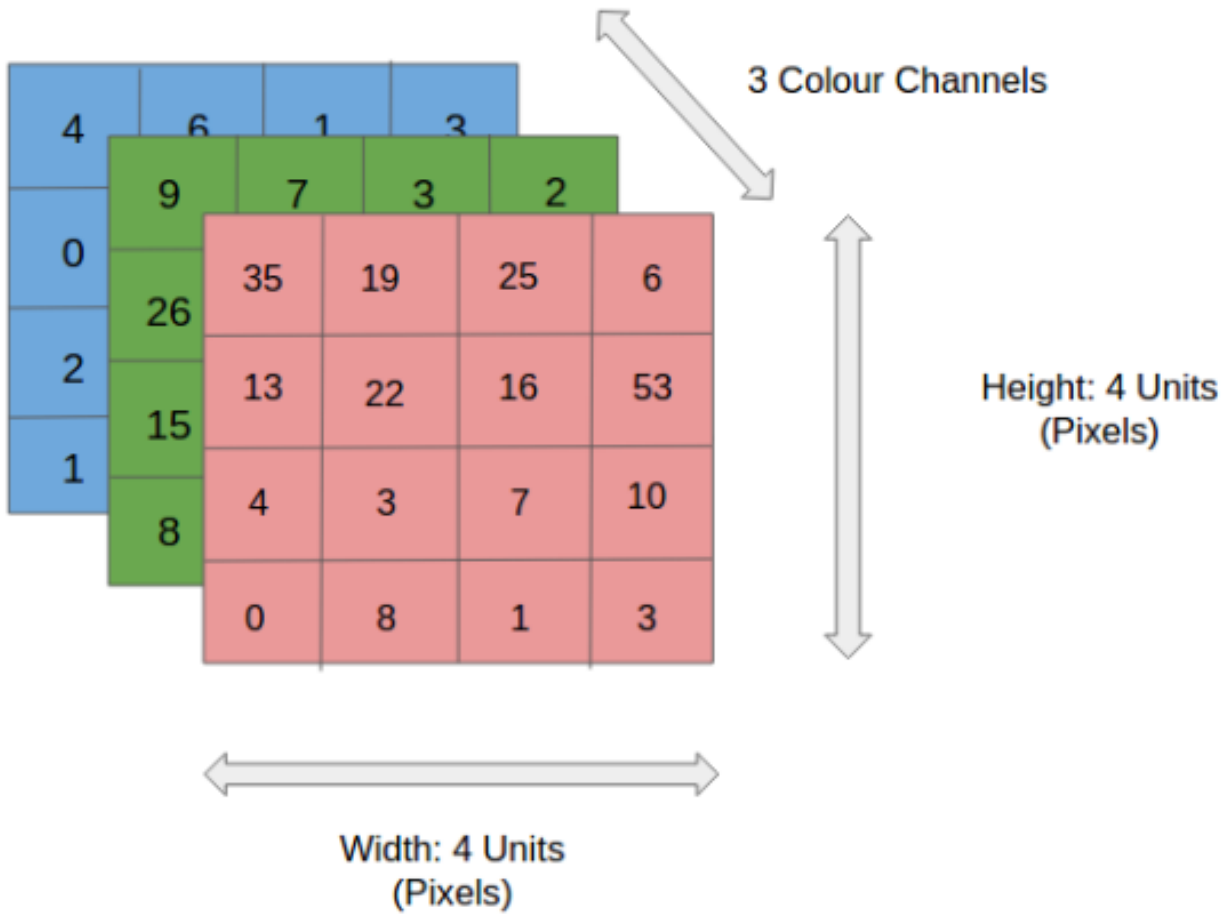


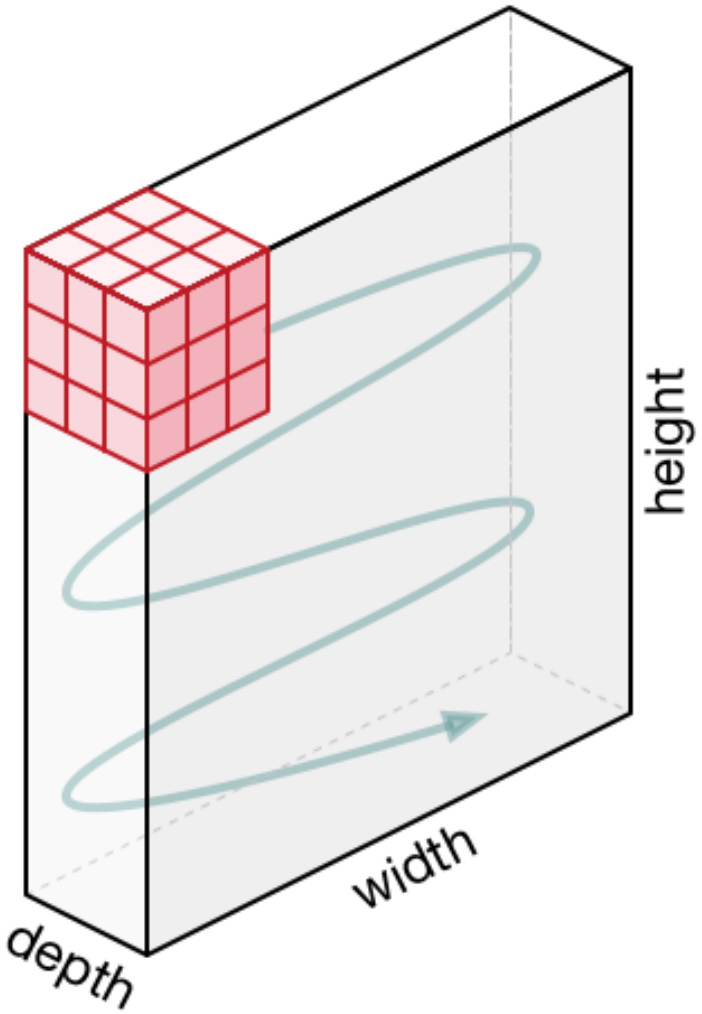
Example of Maxpool with a 2x2 filter and a stride of 2

Convolutional filters: https://setosa.io/ev/image-kernels/

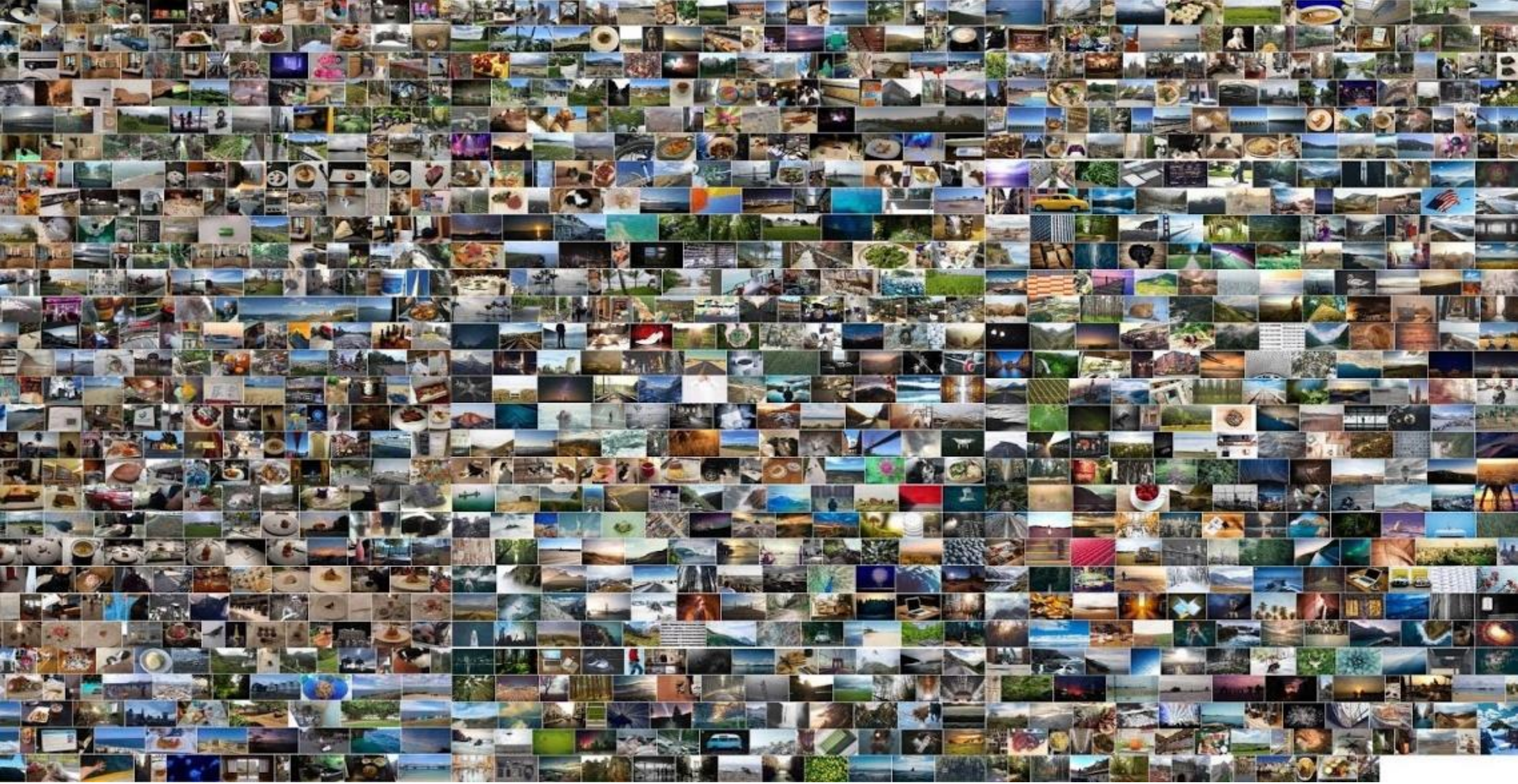


Convolutional neural network (CNN)

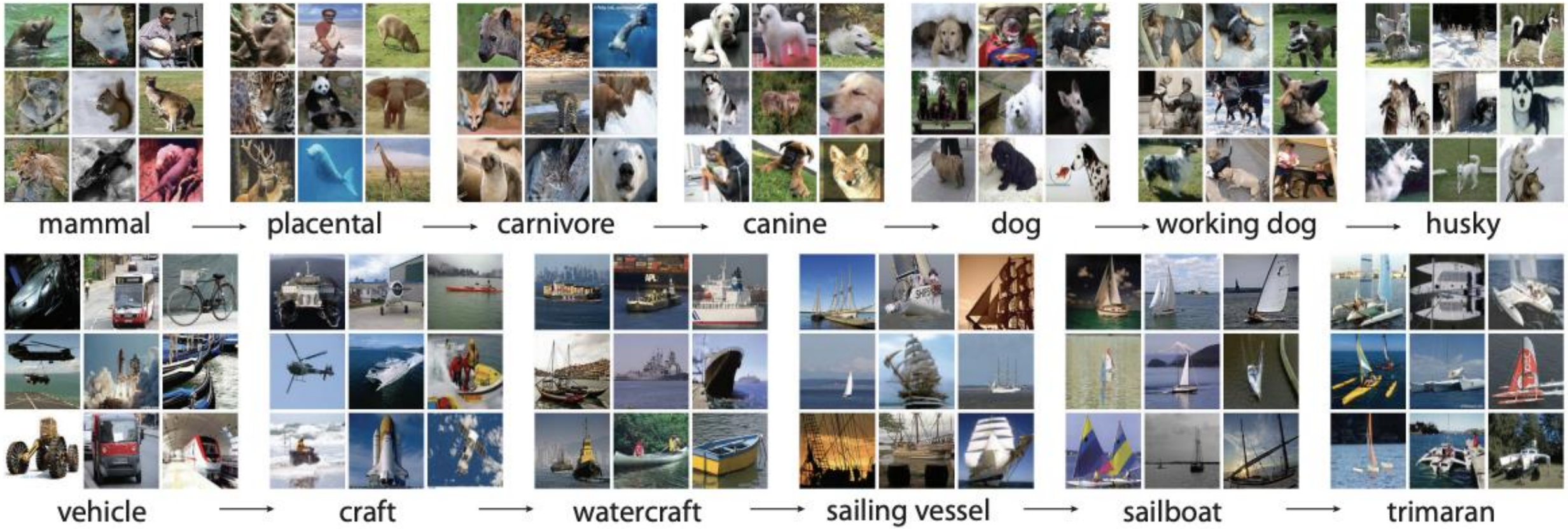




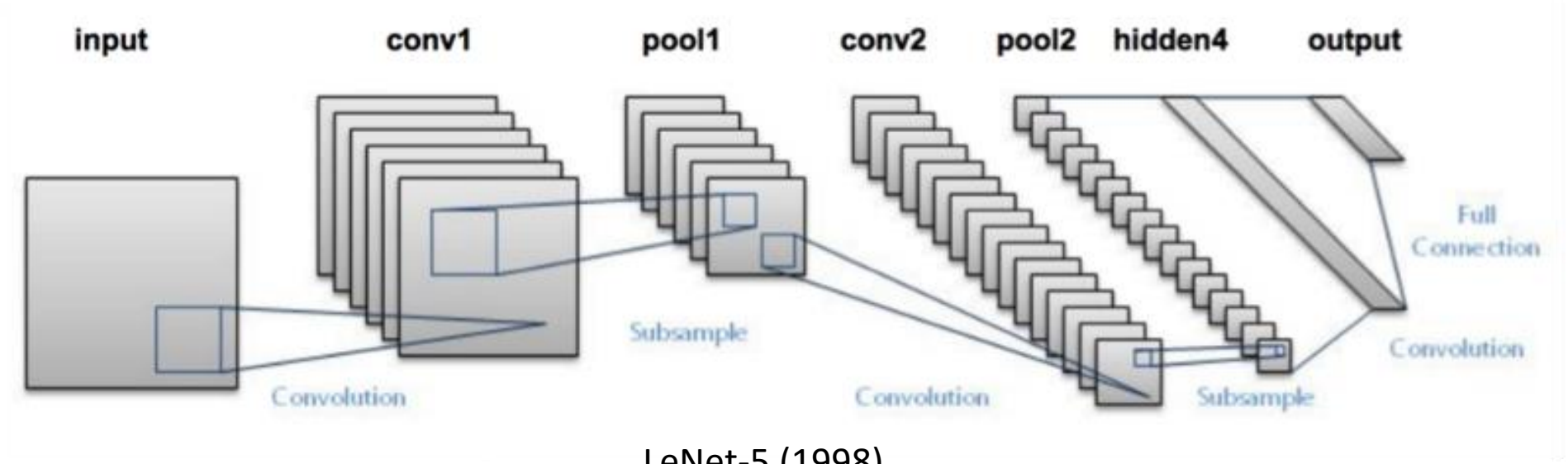
Convolutional filters: https://setosa.io/ev/image-kernels/



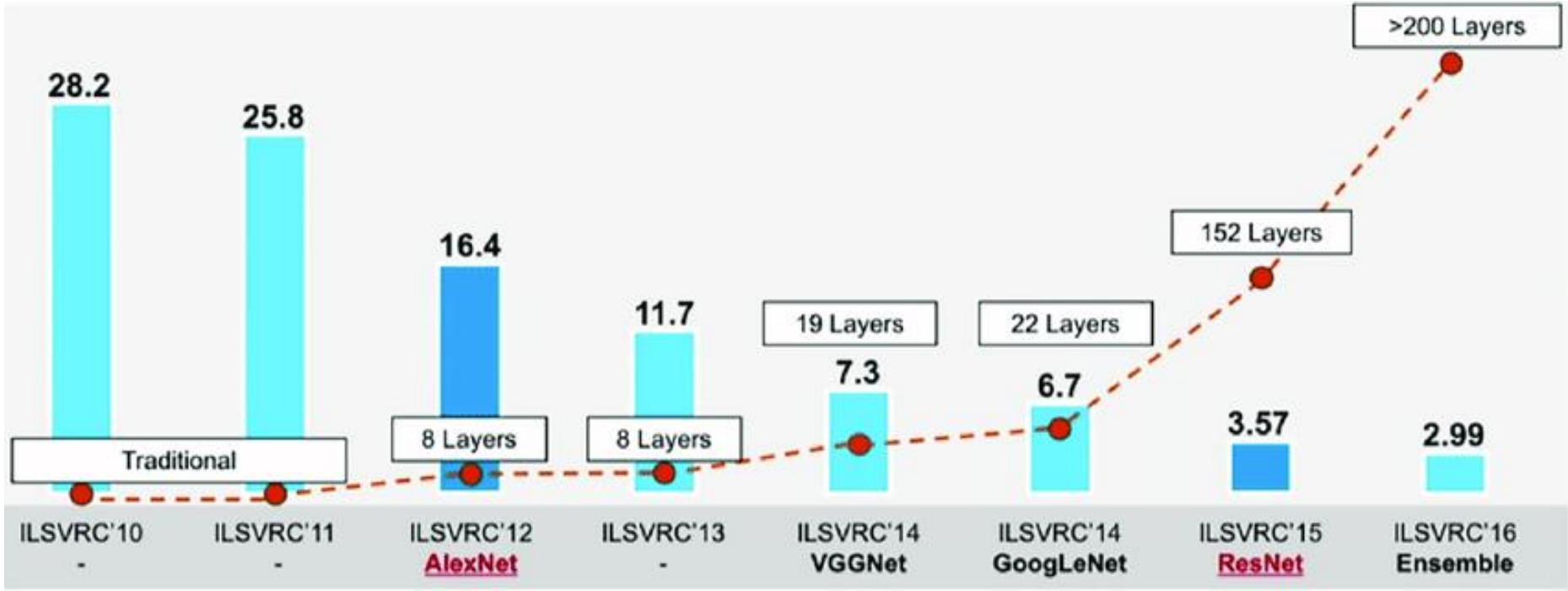
J. Deng *et al.*, "ImageNet: A large-scale hierarchical image database," *2009 IEEE Conference on Computer Vision and Pattern Recognition*



J. Deng *et al.*, "ImageNet: A large-scale hierarchical image database," *2009 IEEE Conference on Computer Vision and Pattern Recognition*



LeNet-5 (1998)

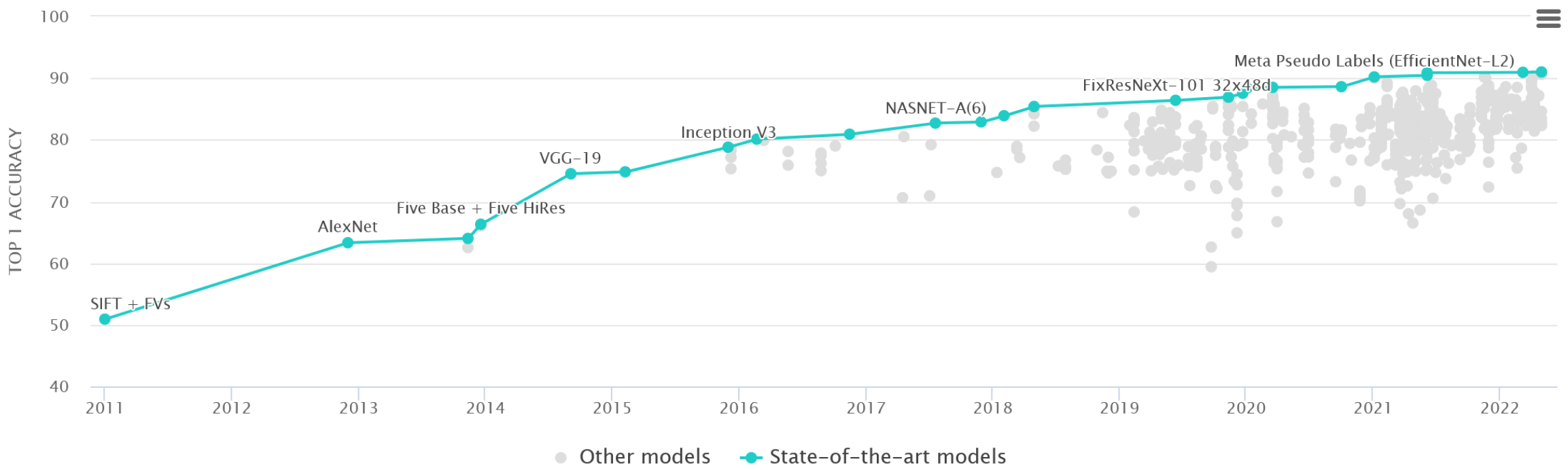


ImageNet Large Scale Visual Recognition Challenge: https://www.image-net.org/challenges/LSVRC/

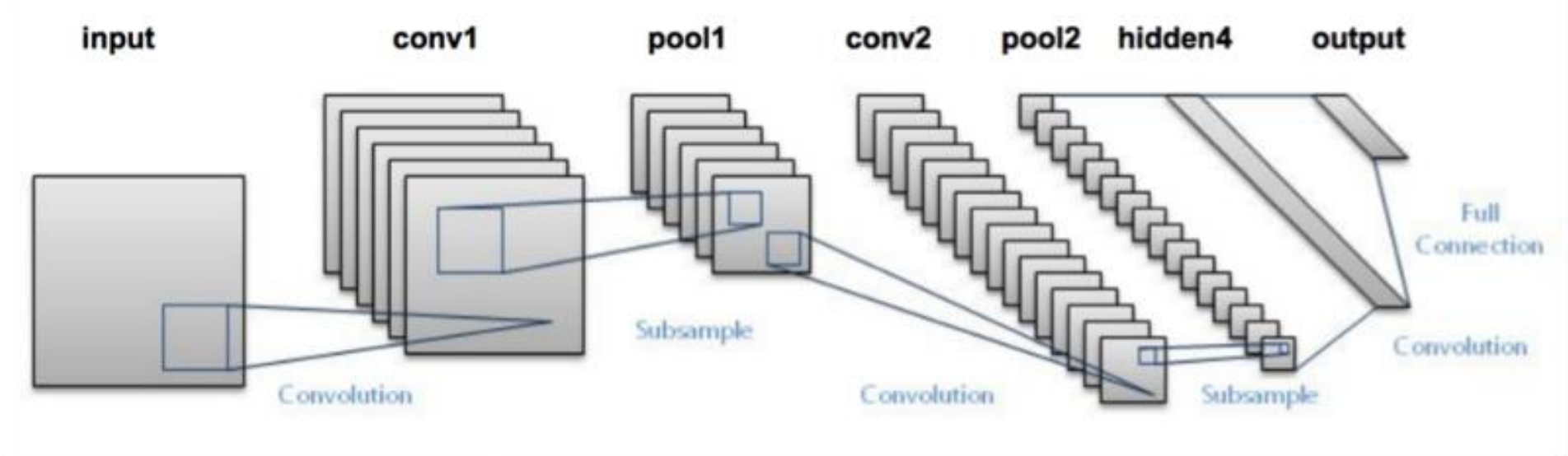
Image Classification on ImageNet

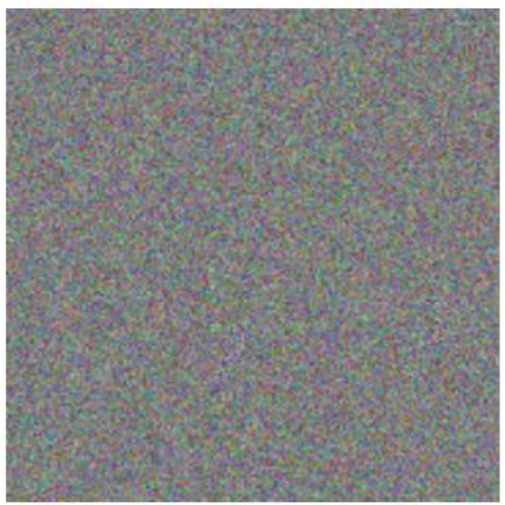
Leaderboard Dataset

View Top 1 Accuracy by Date for All models



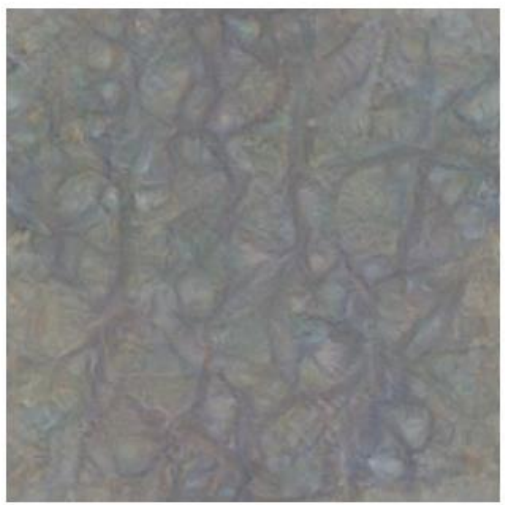
https://paperswithcode.com/sota/image-classification-on-imagenet





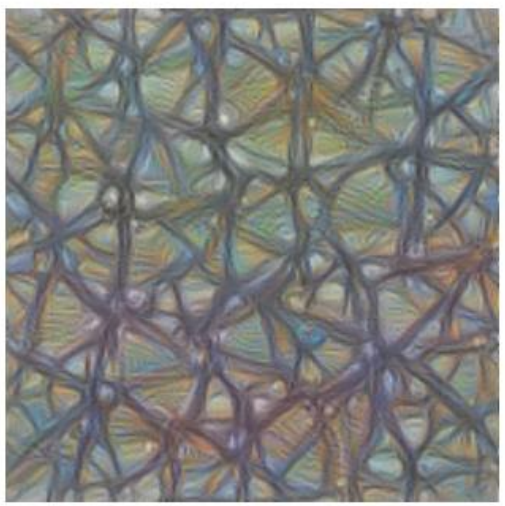
Step 0

→



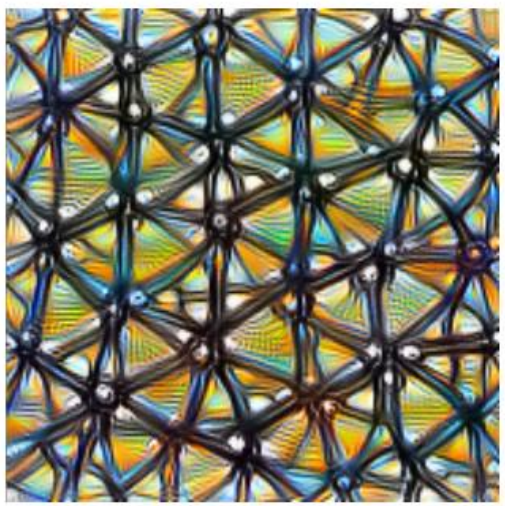
Step 4

→



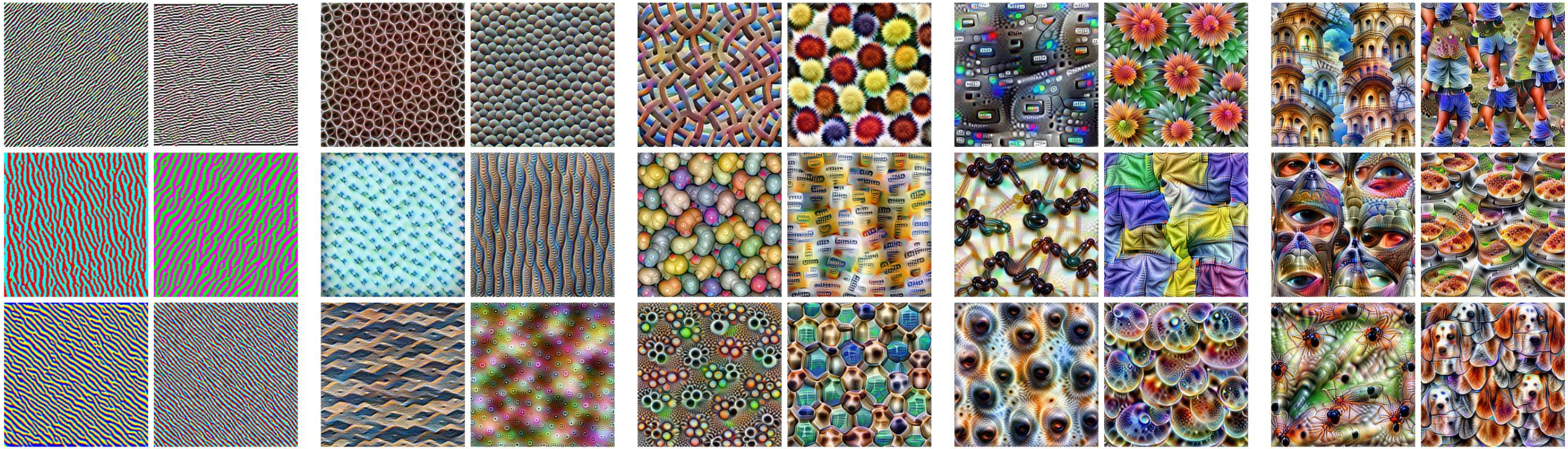
Step 48

→



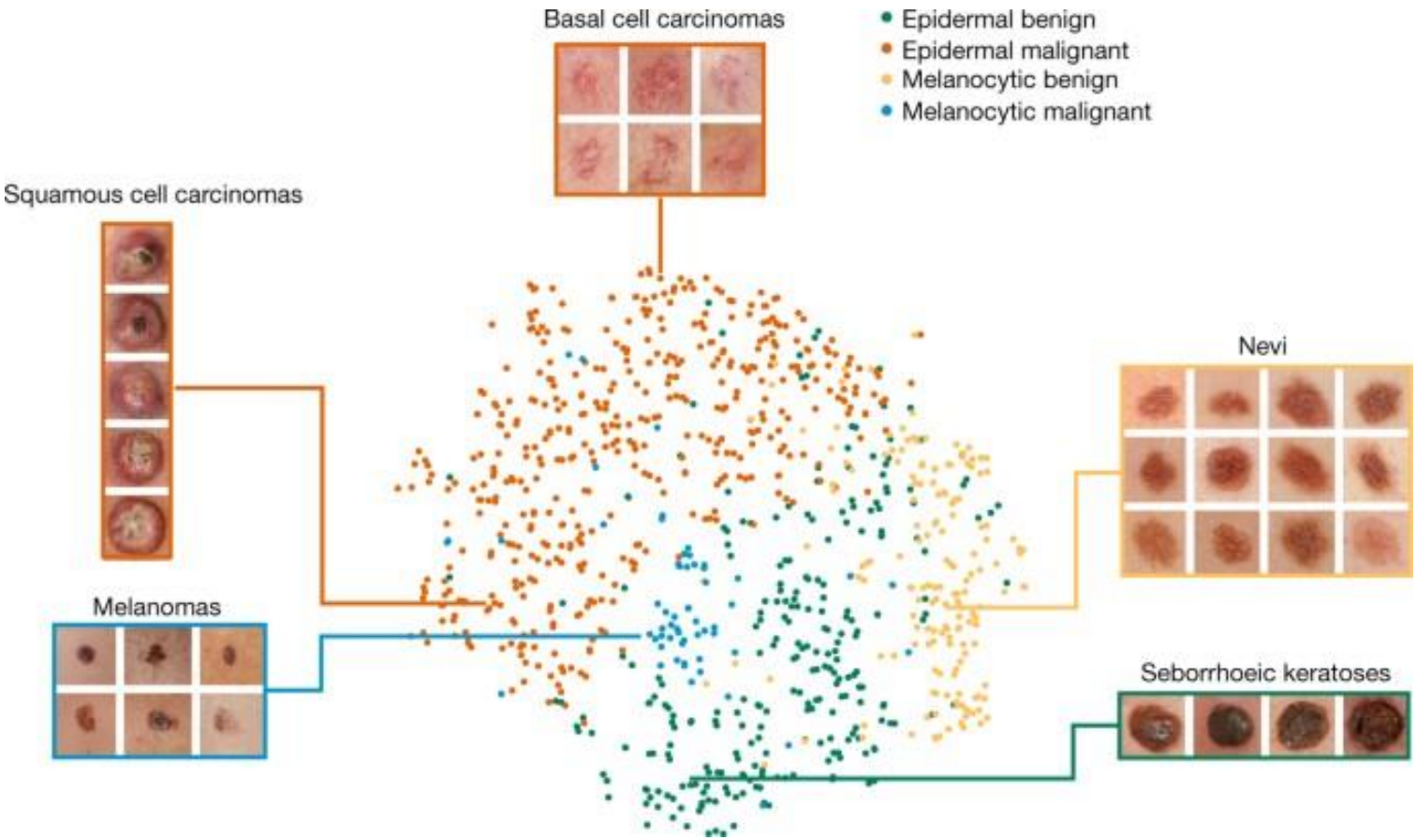
Step 2048

Neural network input optimization: https://distill.pub/2017/feature-visualization/

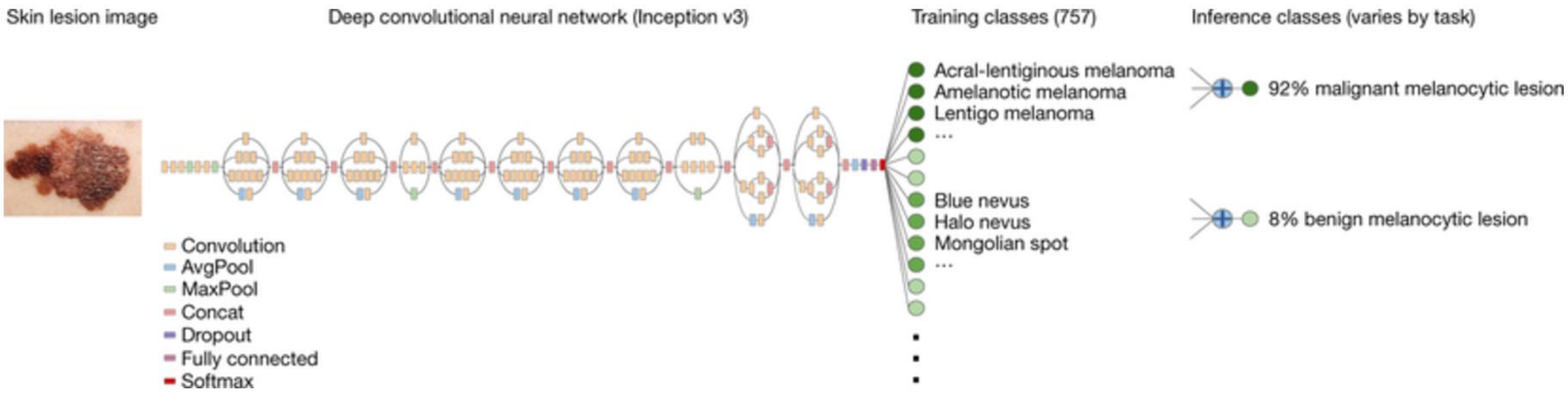


Edges (layer conv2d0) **Textures** (layer mixed3a) **Patterns** (layer mixed4a) **Parts** (layers mixed4b & mixed4c) **Objects** (layers mixed4d & mixed4e)

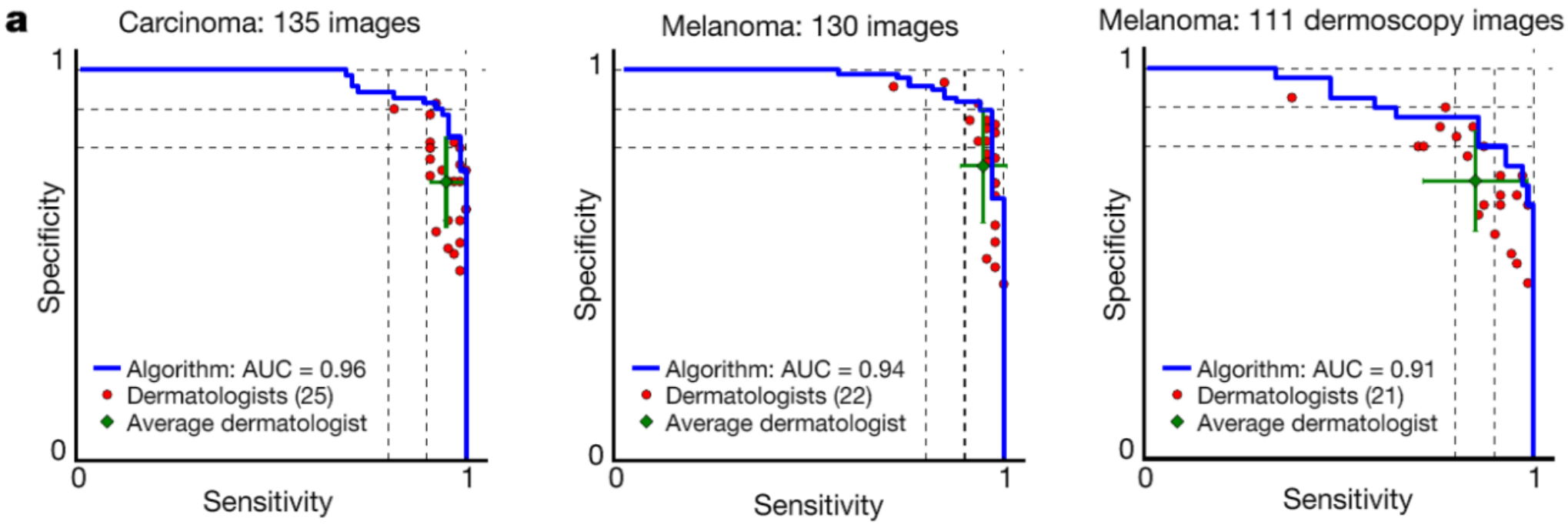
Neural network input optimization: https://distill.pub/2017/feature-visualization/



Thrun *et al*., Dermatologist-level classification of skin cancer with deep neural networks, Nature (2017)



Thrun *et al*., Dermatologist-level classification of skin cancer with deep neural networks, Nature (2017)

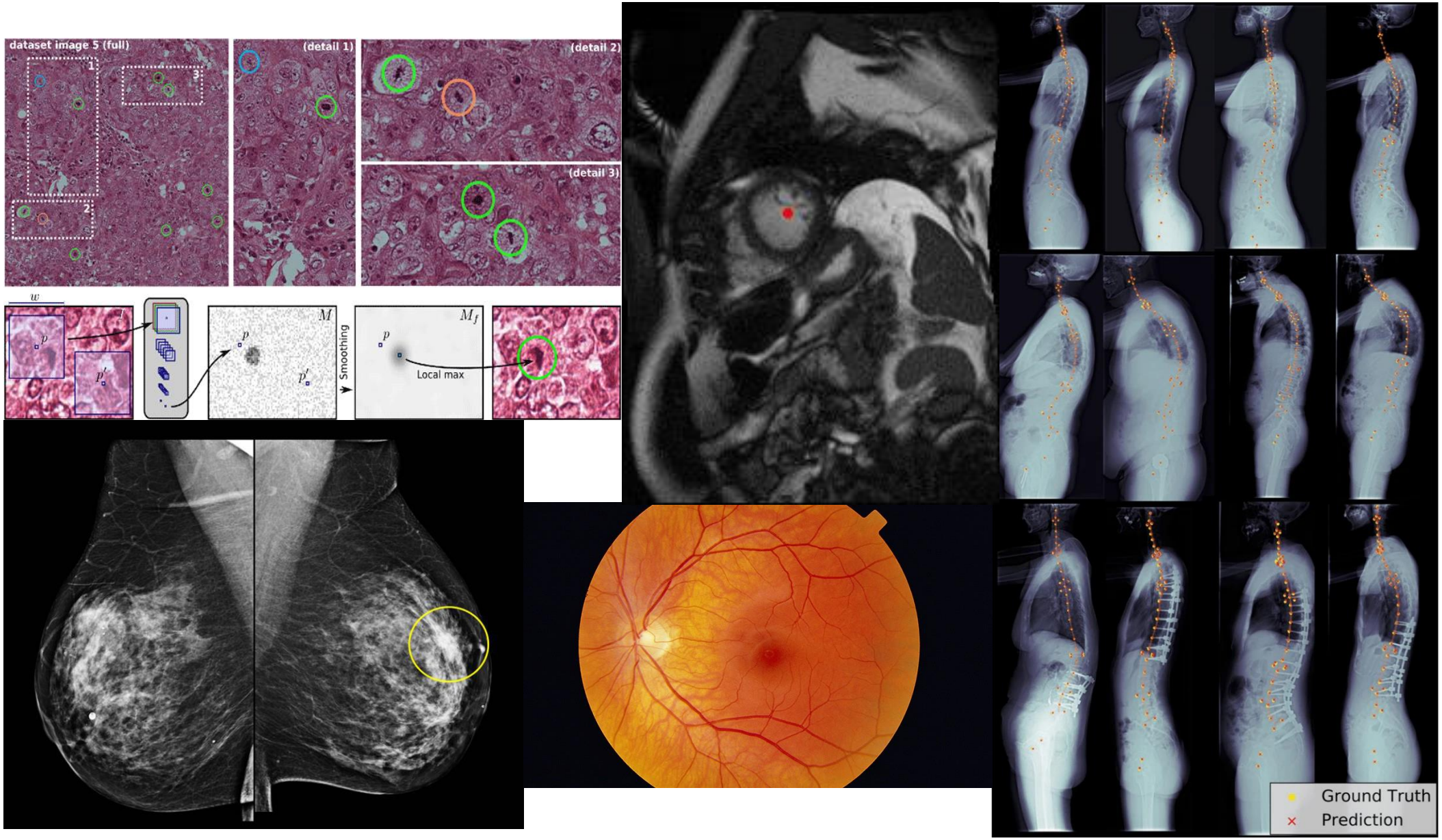


keratinocyte carcinomas: 65
benign seborrheic keratoses: 75

malignant melanomas: 33
benign nevi: 97

malignant melanomas: 71
benign nevi: 40

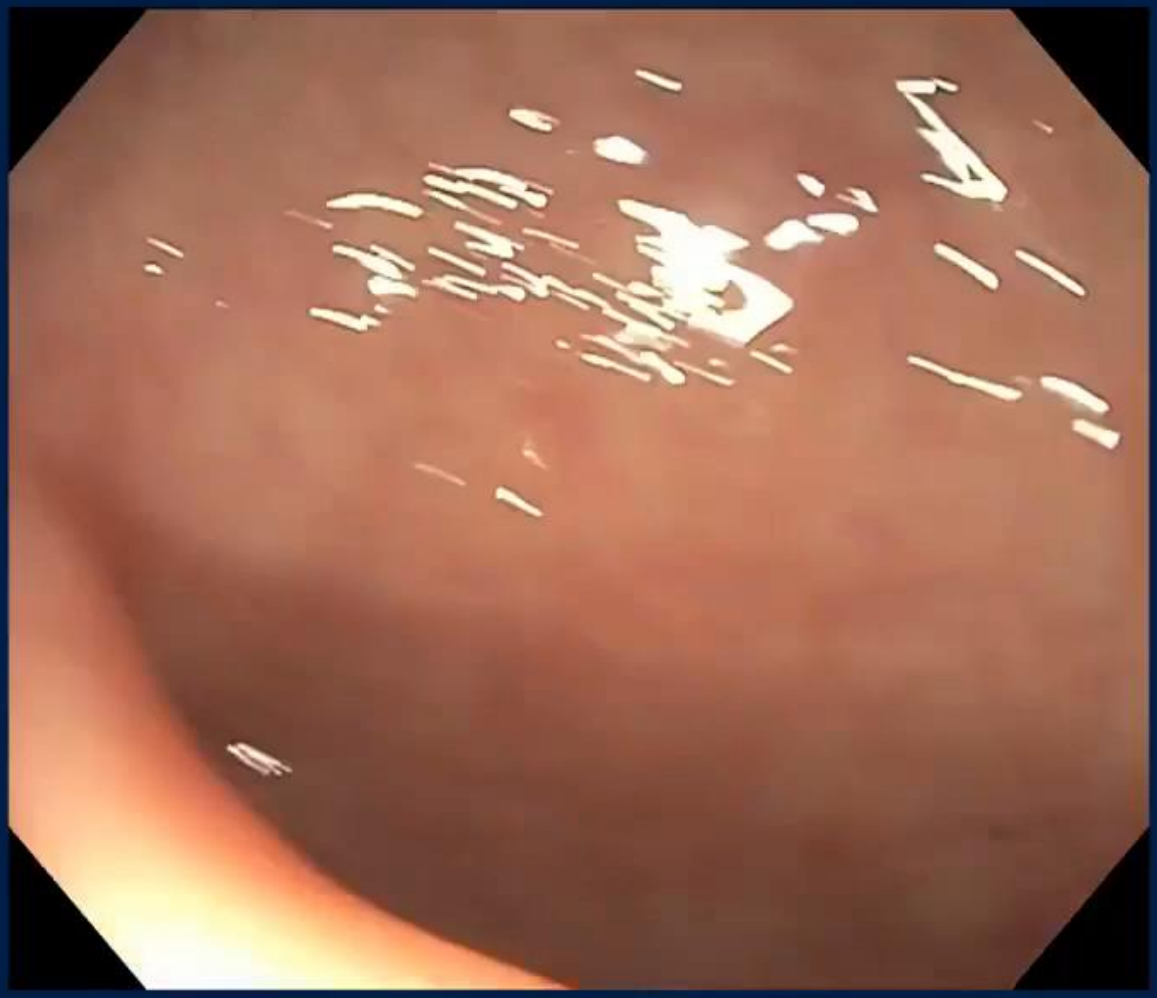
Thrun *et al.*, Dermatologist-level classification of skin cancer with deep neural networks, Nature (2017)



http://people.idsia.ch/~juergen/deeplearningwinsMICCAIgrandchallenge.html
kaggle.com/second-annual-data-science-bowl (2015)

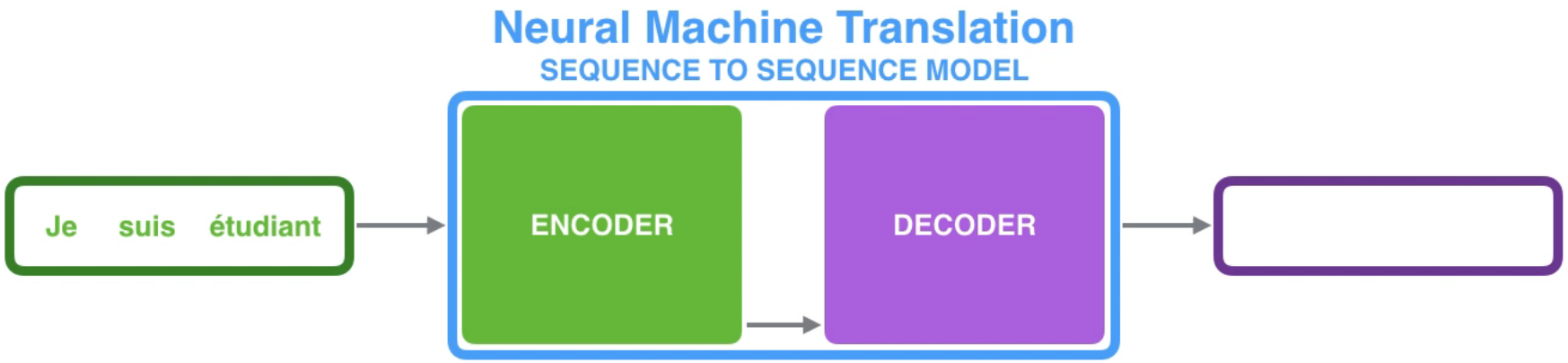
Yeh, YC. *et al.* Deep learning approach for automatic landmark detection and alignment analysis in whole-spine lateral radiographs. *Sci Rep* **11,** 7618 (2021)

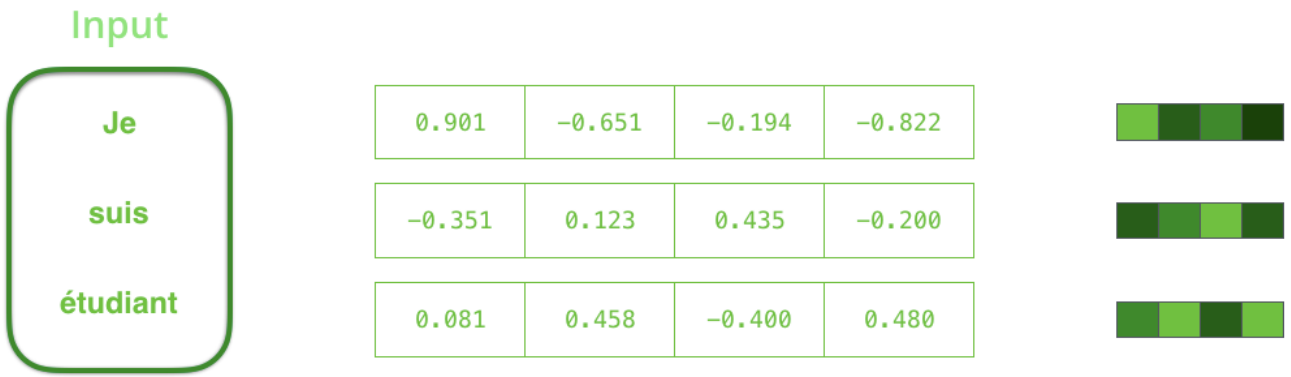
GI Genius™ Intelligent Endoscopy Module



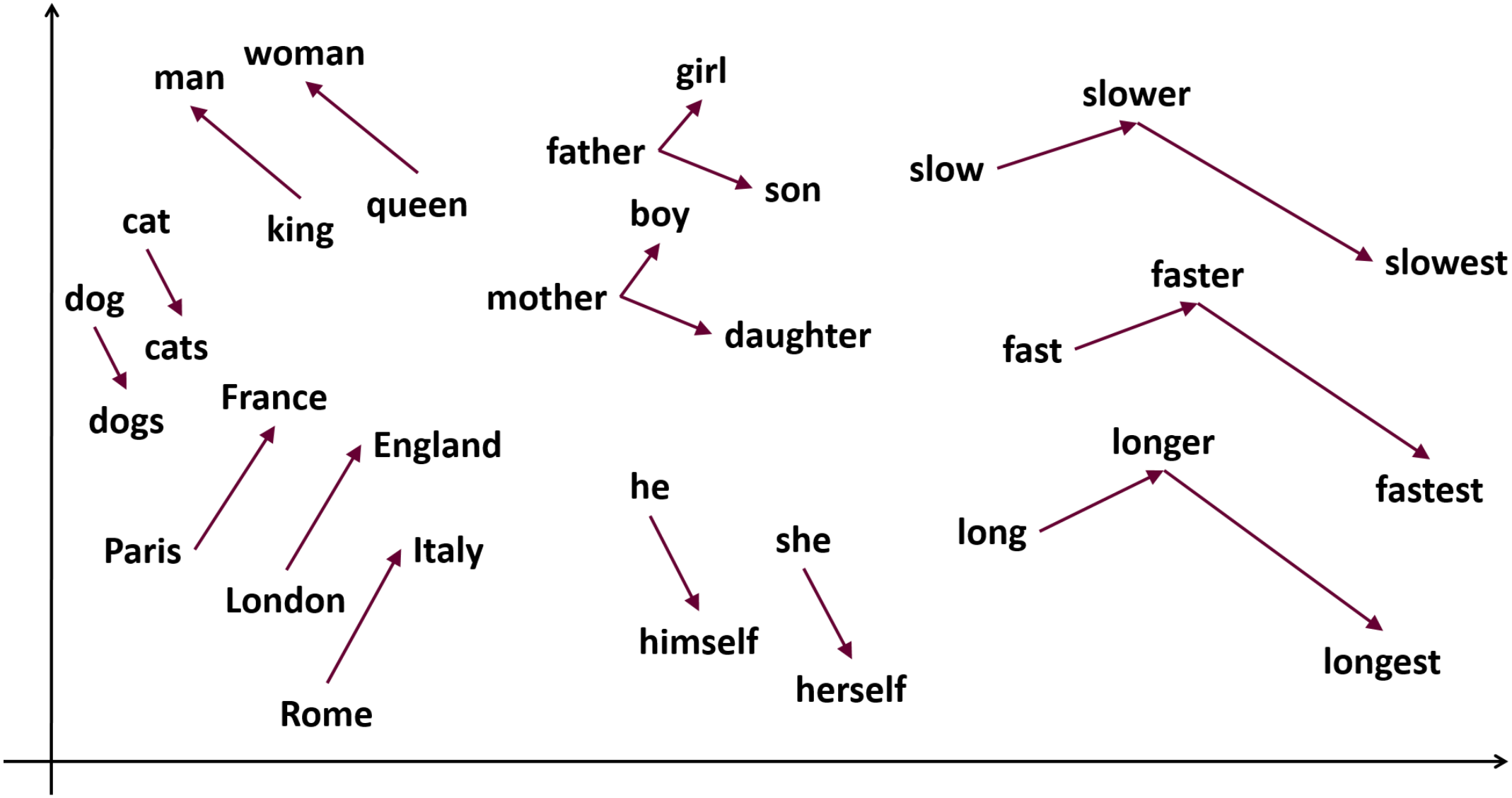
Artificial Intelligence + Colonoscopy

Medtronic's GI Genius





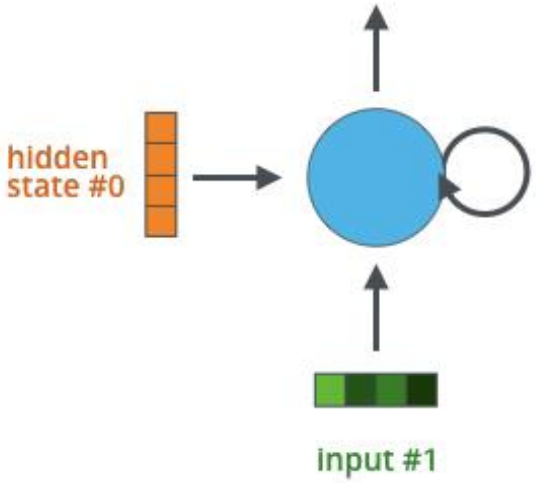
Recurrent neural network (RNN): https://jalammar.github.io/visualizing-neural-machine-translation-mechanics-of-seq2seq-models-with-attention/



Mikolov *et al*. Proceedings of the International Conference on Learning Representations (2013)

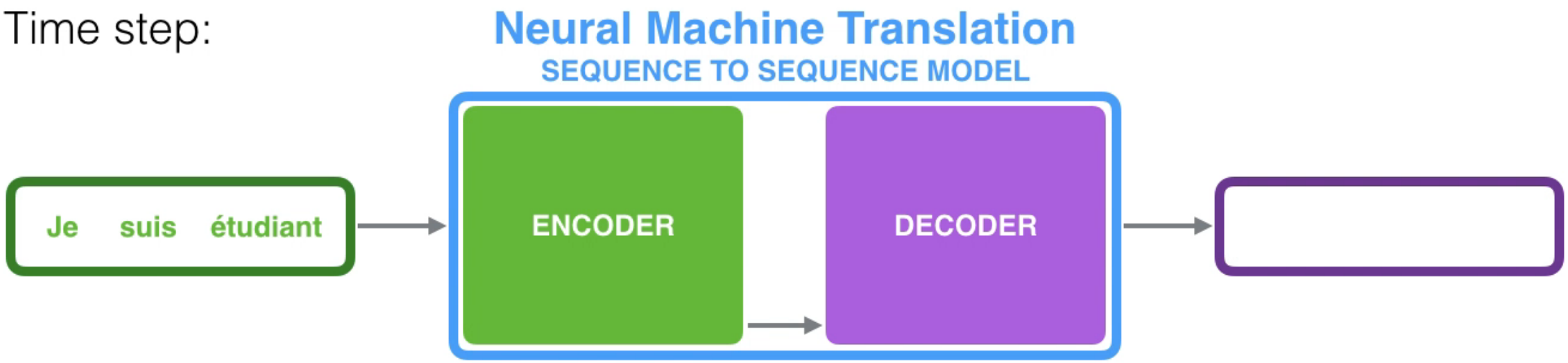
Recurrent Neural Network

Time step #1:
An RNN takes two input vectors:



Recurrent neural network (RNN): https://jalammar.github.io/visualizing-neural-machine-translation-mechanics-of-seq2seq-models-with-attention/

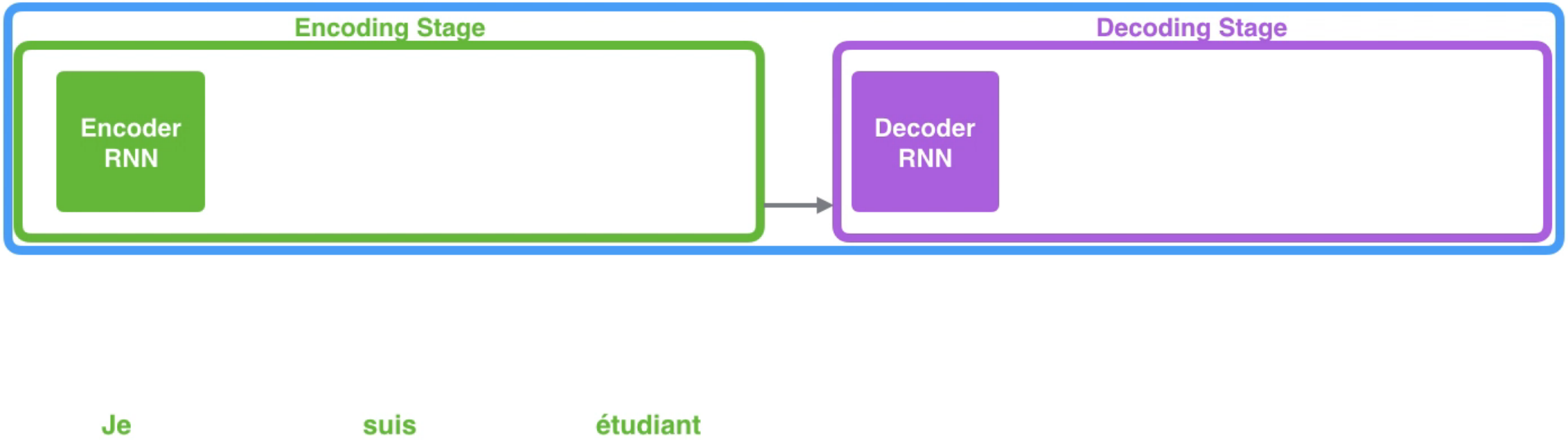
Time step:



Encoder-decoder architecture: https://jalammar.github.io/visualizing-neural-machine-translation-mechanics-of-seq2seq-models-with-attention/

Neural Machine Translation

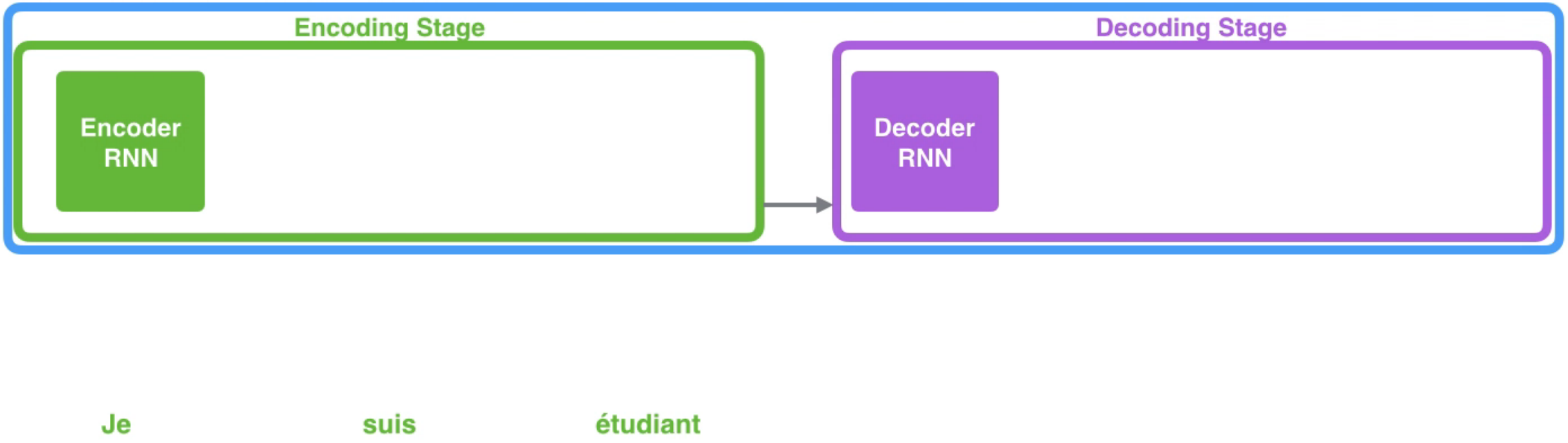
SEQUENCE TO SEQUENCE MODEL



Encoder-decoder architecture: https://jalammar.github.io/visualizing-neural-machine-translation-mechanics-of-seq2seq-models-with-attention/

Neural Machine Translation

SEQUENCE TO SEQUENCE MODEL



Encoder-decoder architecture: https://jalammar.github.io/visualizing-neural-machine-translation-mechanics-of-seq2seq-models-with-attention/

Neural Machine Translation

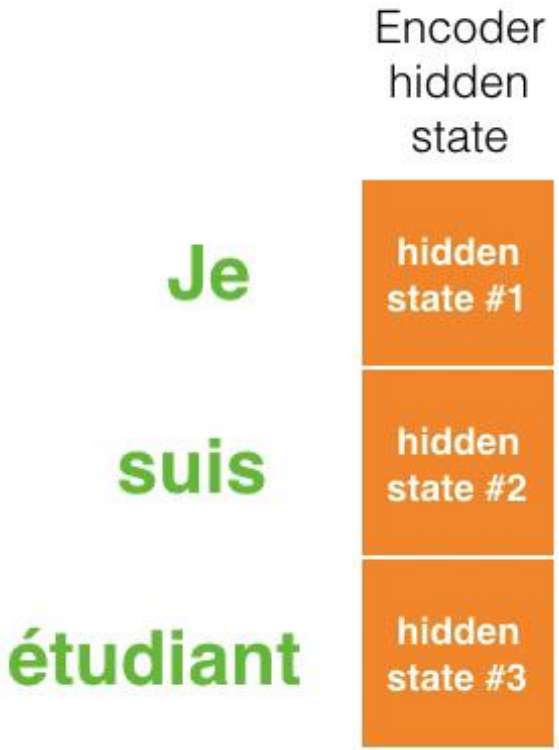
SEQUENCE TO SEQUENCE MODEL WITH ATTENTION

Je suis étudiant

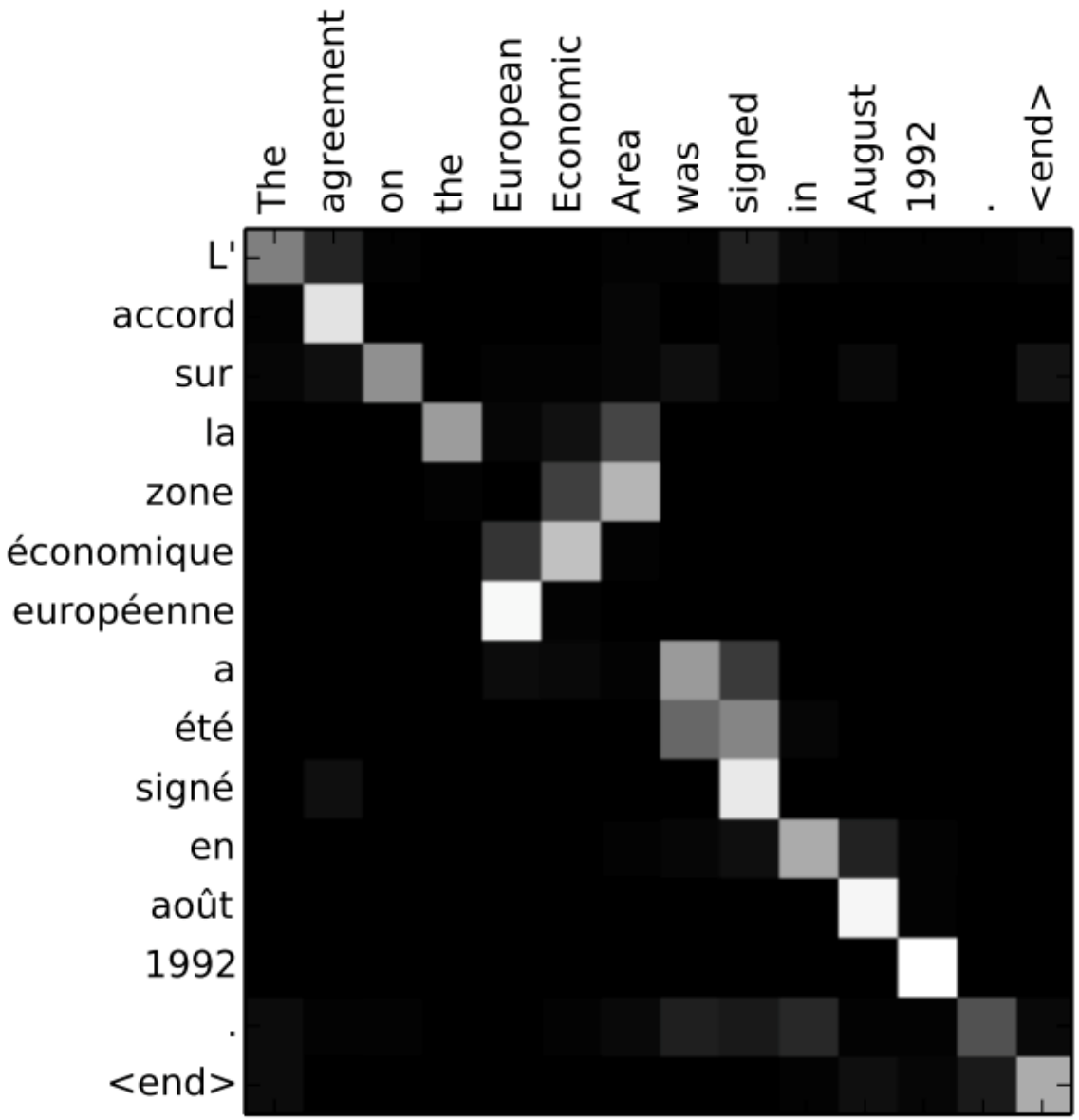
Encoder-decoder architecture: https://jalammar.github.io/visualizing-neural-machine-translation-mechanics-of-seq2seq-models-with-attention/

Attention at time step 4

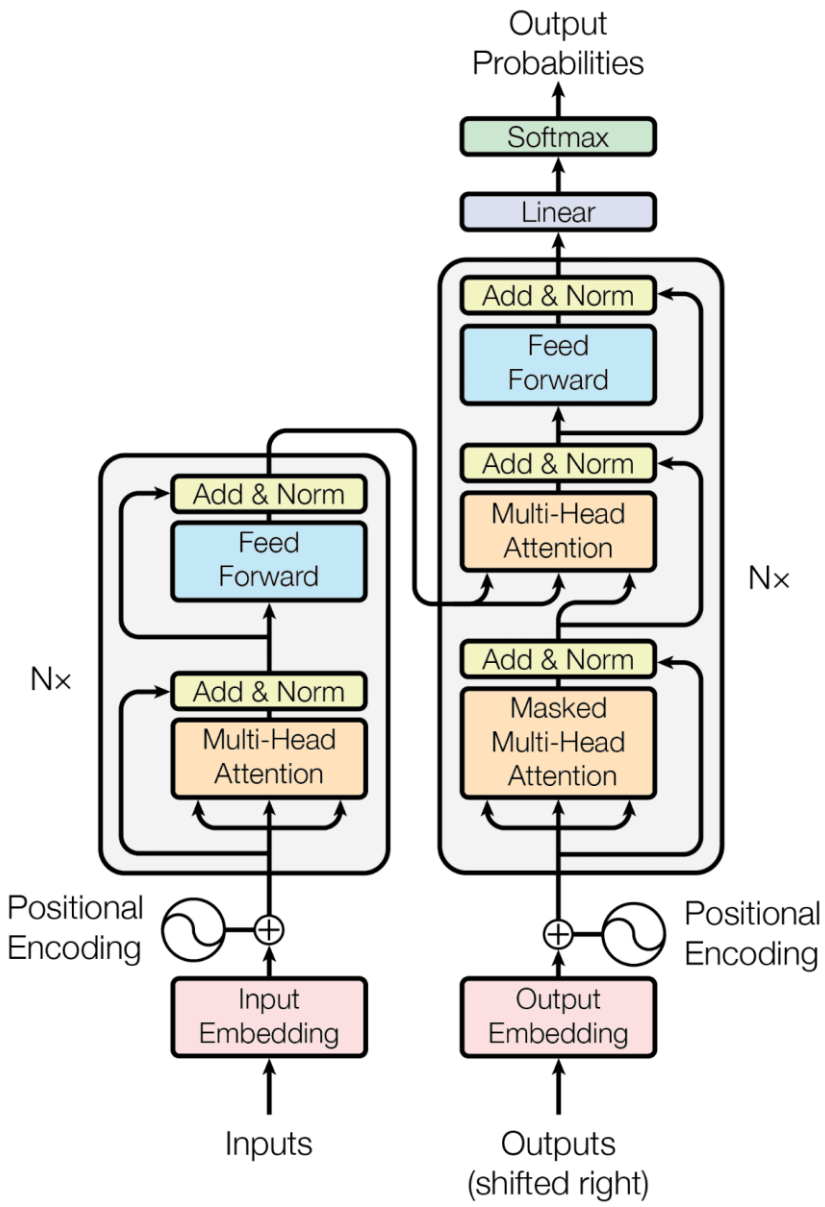
Encoder-decoder architecture: https://jalammar.github.io/visualizing-neural-machine-translation-mechanics-of-seq2seq-models-with-attention/



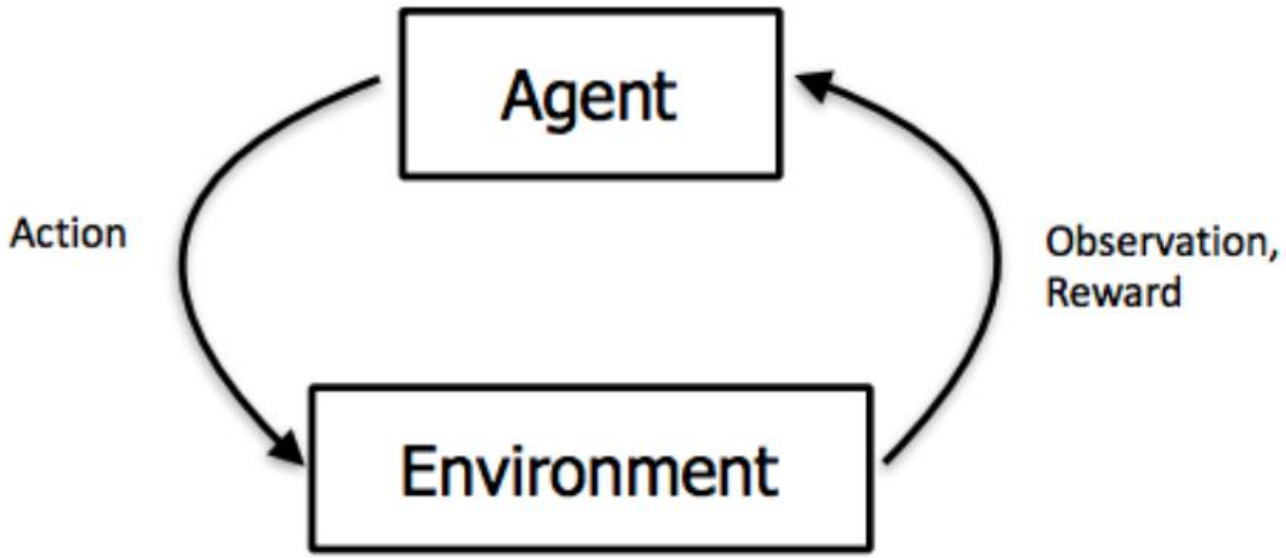
Encoder-decoder architecture: https://jalammar.github.io/visualizing-neural-machine-translation-mechanics-of-seq2seq-models-with-attention/



Encoder-decoder architecture: https://jalammar.github.io/visualizing-neural-machine-translation-mechanics-of-seq2seq-models-with-attention/



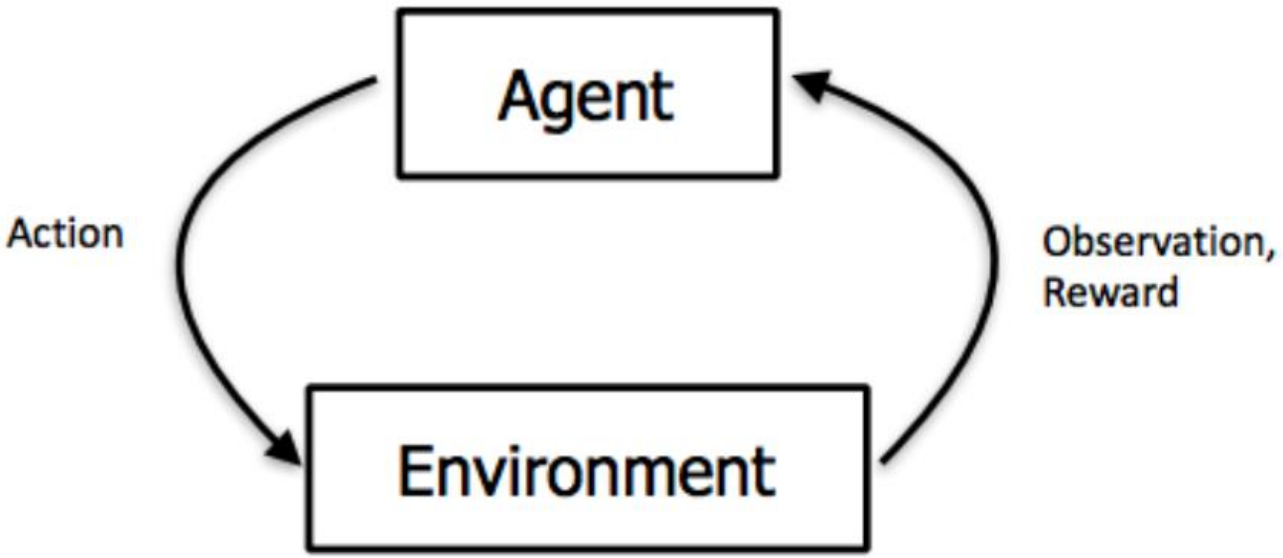
Ashish Vaswani et al., Attention is all you need. (NIPS'17)
Transformer architecture: https://jalammar.github.io/illustrated-transformer/



The agent **observes** the environment, takes an **action** to interact with the environment, and receives positive or negative **reward.** Diagram from Berkeley's CS 294: Deep Reinforcement Learning by John Schulman & Pieter Abbeel

$$a = \pi(s)$$

A **policy** is a map from **state** to **action.**



The agent **observes** the environment, takes an **action** to interact with the environment, and receives positive or negative **reward.** Diagram from Berkeley's CS 294: Deep Reinforcement Learning by John Schulman & Pieter Abbeel

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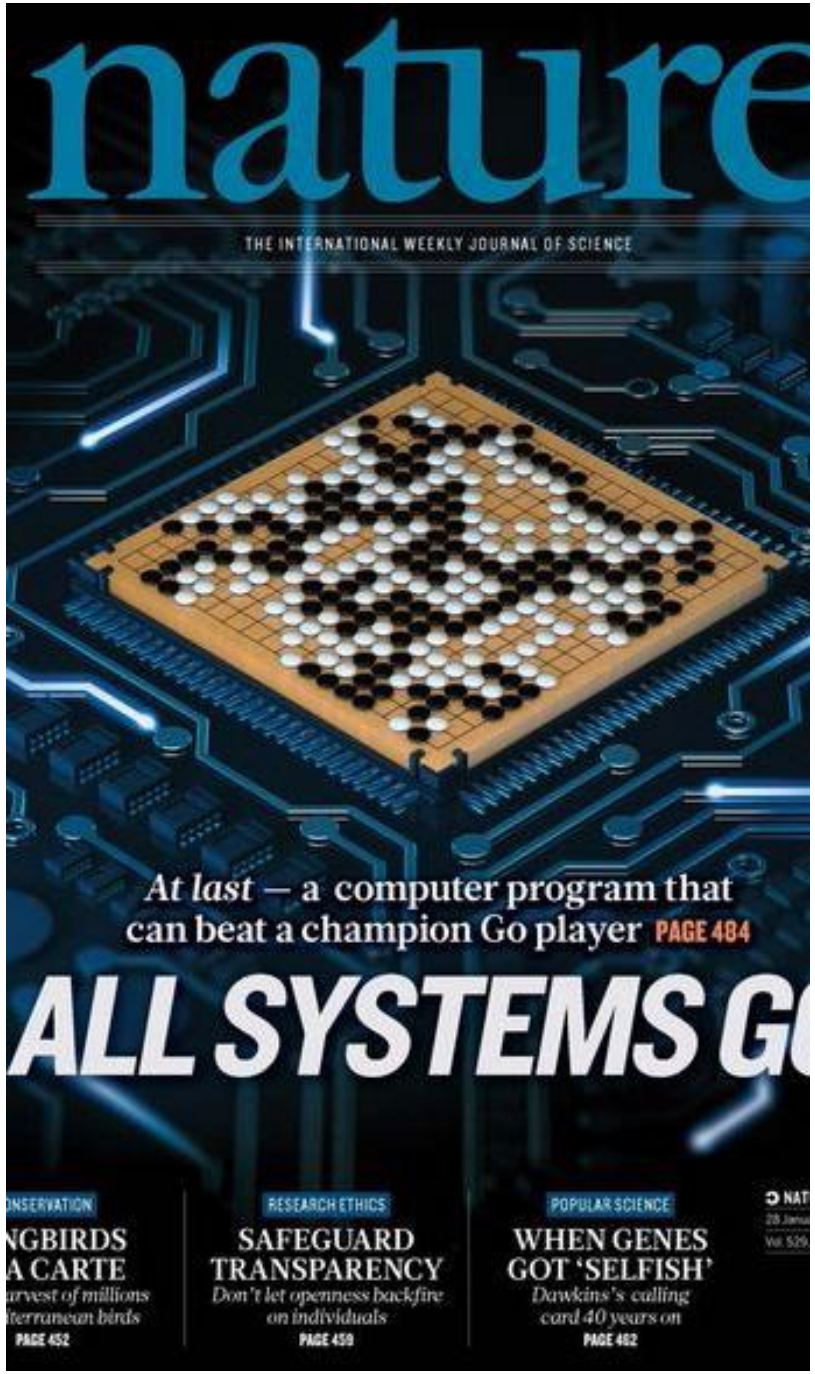
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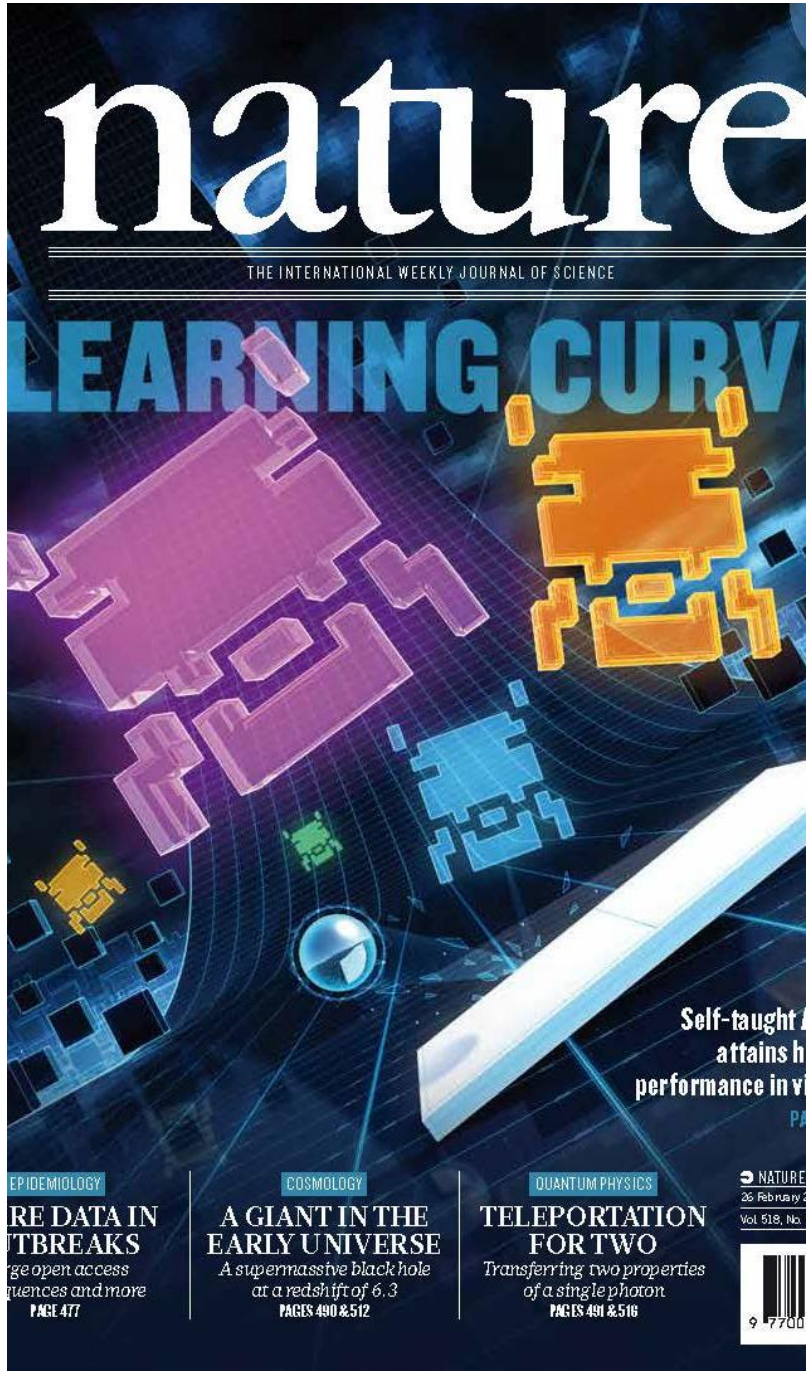
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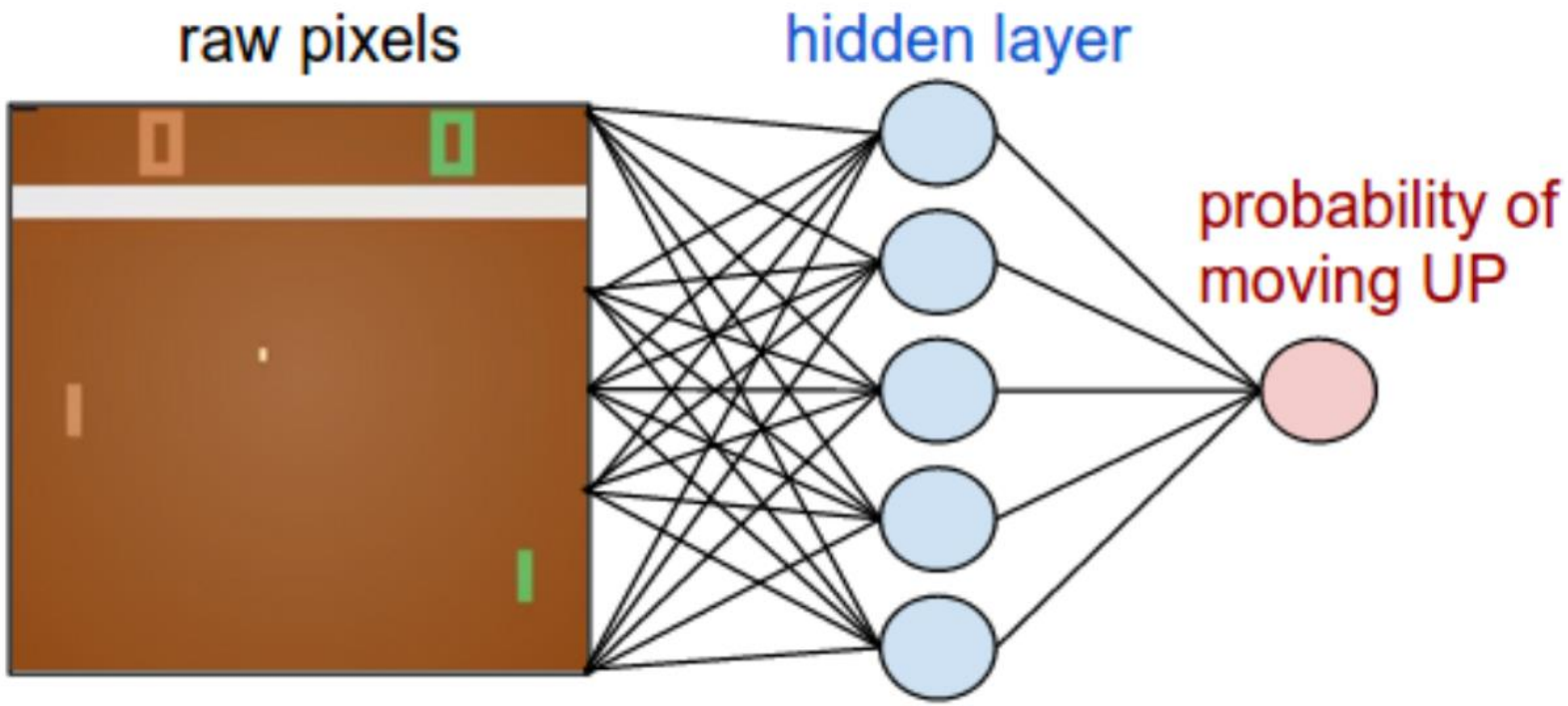
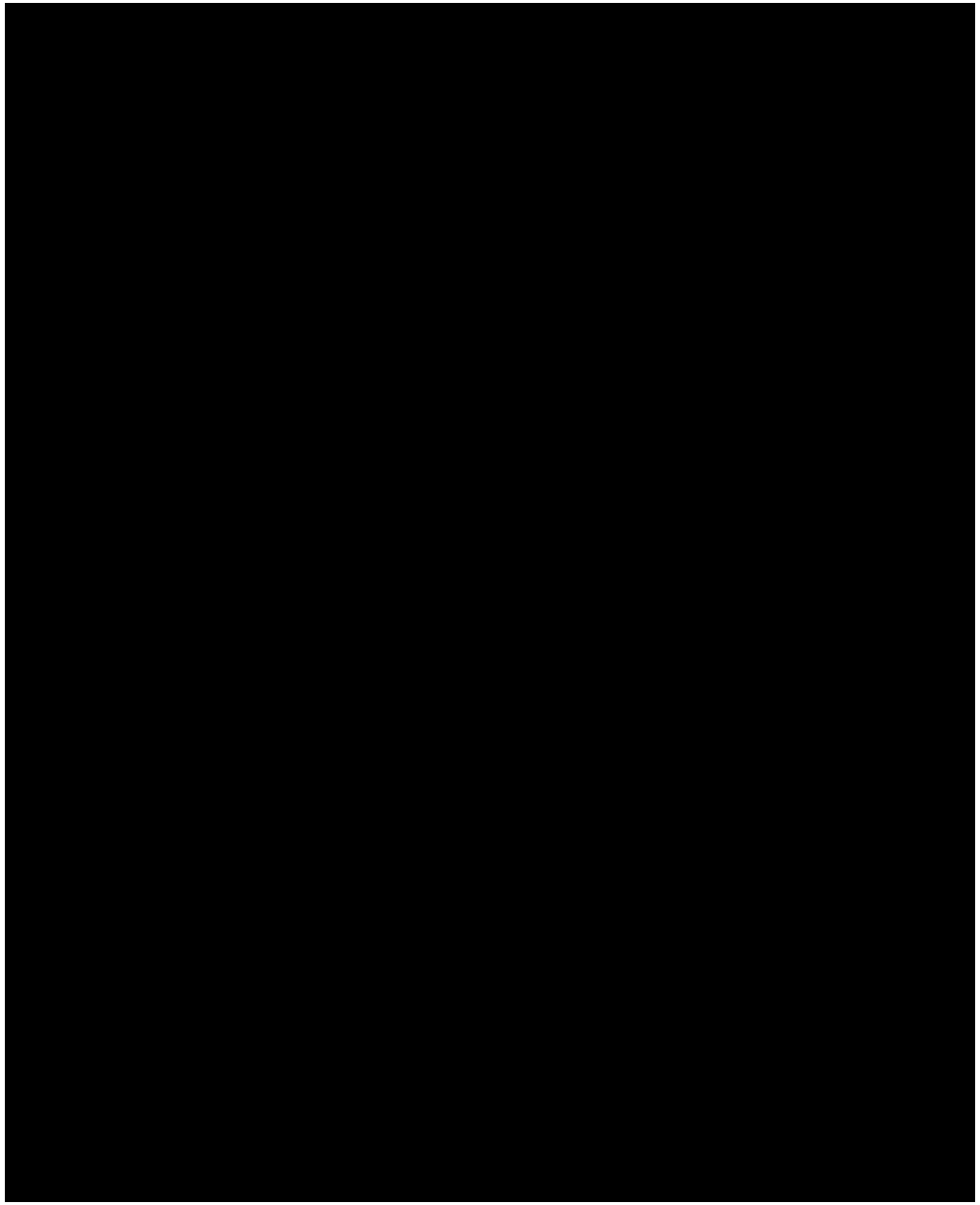
FOR TWO
Transferring two properties
of a single photon
PAGES 491 & 516
NATURE
26 February
Vol. 518, No.



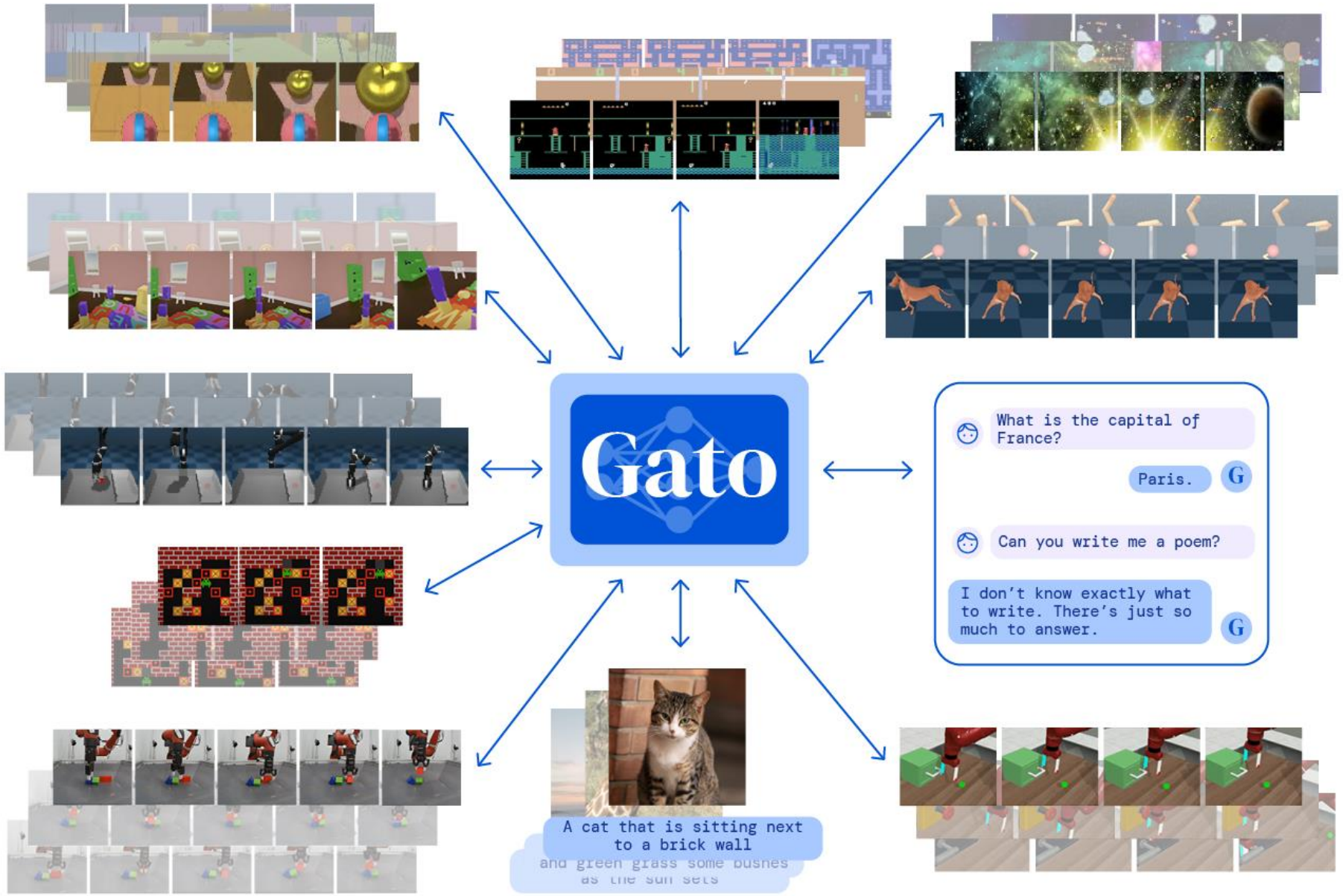
In a policy gradient network, the agent learns the optimal policy by adjusting its weights through gradient descent based on reward signals from the environment. Image via http://karpathy.github.io/2016/05/31/rl/

Mnih, Volodymyr *et al*., Playing Atari with Deep Reinforcement Learning (2013)



Mnih, Volodymyr *et al*., Playing Atari with Deep Reinforcement Learning (2013)

https://openai.com/blog/emergent-tool-use/



https://www.deepmind.com/publications/a-generalist-agent