Tutorial Outline

- **Part 1:** Background and challenges (20 min)
- **Part 2:** Preliminaries of invariance (20 min)
- *Q&A / Break (10 min)*
- **Part 3:** Invariance in the era before deep learning (30 min)
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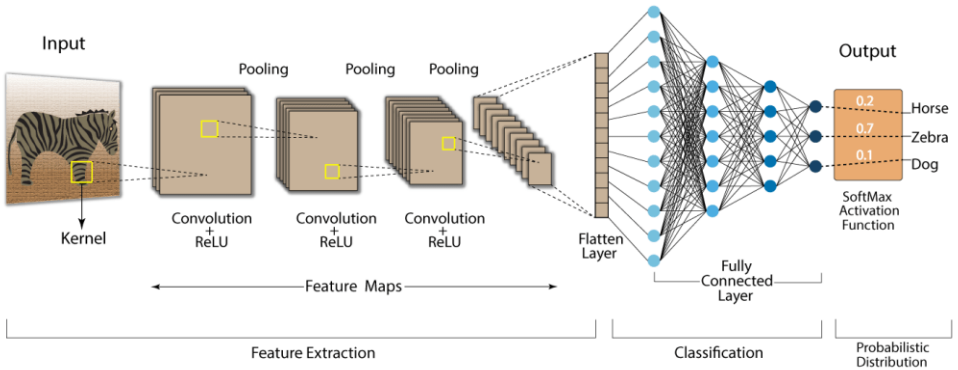
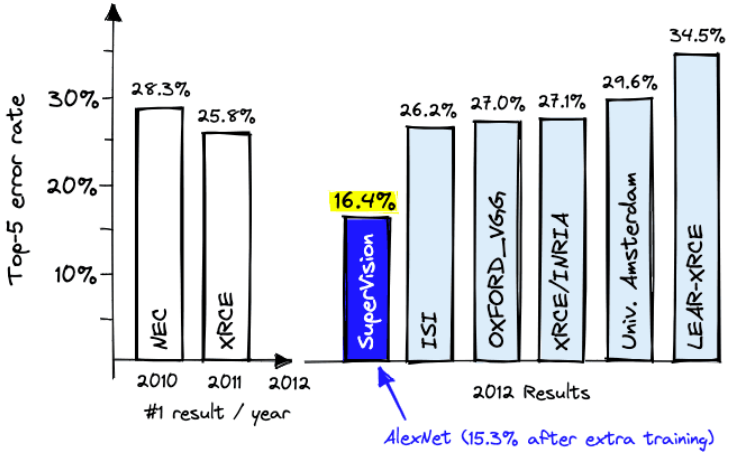
A Historical Perspective of Data Representation
Rethinking Deep Learning with Invariance: The Good, The Bad, and The Ugly

From Knowledge Driven To Data Driven

Invariance in The Early Era of Deep Learning

- Knowledge Driven: Despite decades of research, these hand-crafted representations still fail to provide sufficient discriminability for large-scale tasks, especially in the discrimination of real-world semantic content.
- Data Driven: As we enter the early era of deep learning, convolutional neural networks achieve strong discriminative power for large-scale tasks, known as *ImageNet moment*.





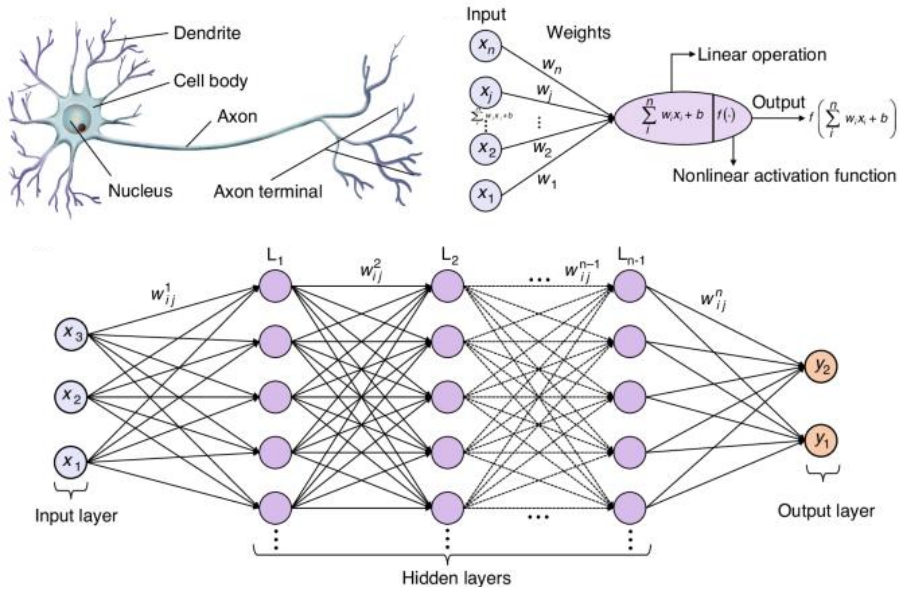
The Success of Deep Learning
AlexNet Wins ILSVRC 2012 Competition

A. Krizhevsky, 2012
AlexNet

- A Krizhevsky, I Sutskever, GE Hinton. ImageNet classification with deep convolutional neural networks. *NIPS* , 2012.

A Huge Span of Time

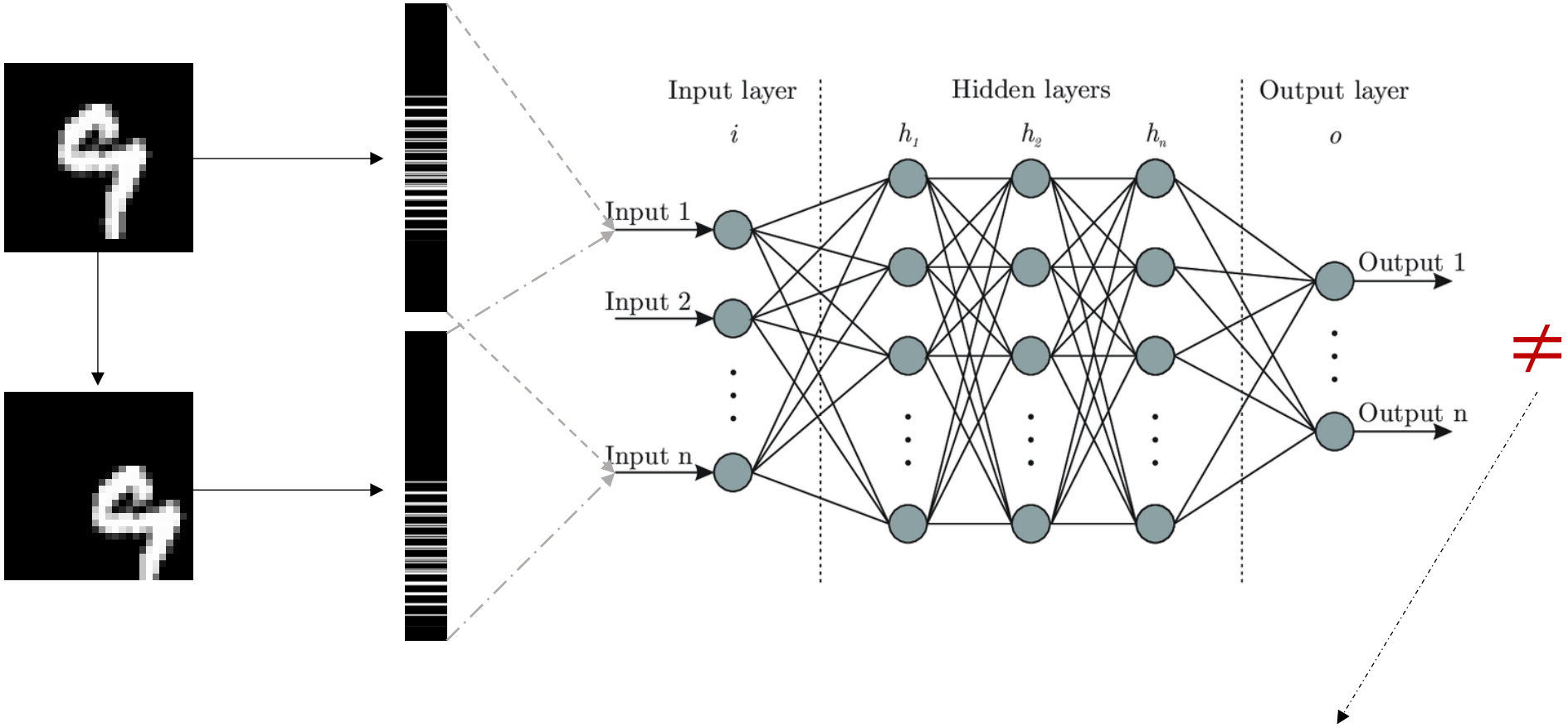
- Neural networks were proposed quite early, dating back to 1950s for the perceptron; but it was not until AlexNet in 2012 that the remarkable achievement was realized.
- What is the missing key?



F. Rosenblatt, 1958
Perceptron

- F Rosenblatt. The perceptron: a probabilistic model for information storage and organization in the brain. *Psychological Review*, 1958.

Translations on Neural Networks



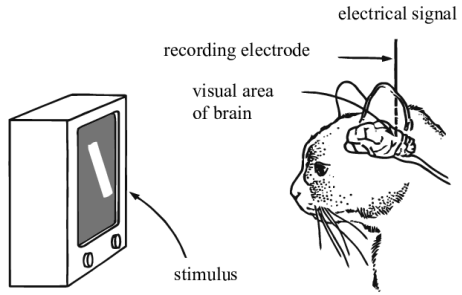
"The response of [Perceptrons] was severely affected by the shift in position [...] of the input patterns. Hence, their ability for pattern recognition was not so high." — Fukushima

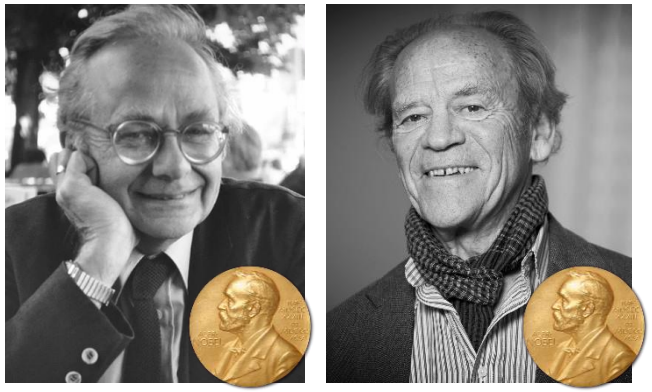
- K Fukushima, S Miyake. Neocognitron: A new algorithm for pattern recognition tolerant of deformations and shifts in position. *Pattern Recognition*, 1982.

Convolution And Translation Equivariance

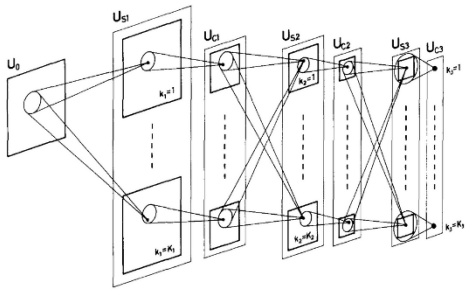
Convolutional Neural Networks

- Convolution with its Translation Equivariance (see also Wavelet Transform) are the key to enabling neural networks successful in visual tasks.
  - First, local structures was discovered in the biological vision by Hubel and Wiesel.
  - Then, convolution was introduced into neural networks by Fukushima.
  - Finally, such networks were equipped with learnability and backpropagation by LeCun.
- Invariance still plays an important role, even in the rise of the learning paradigm.





D. Hubel & T. Wiesel, 1959
Structure of Visual Cortex

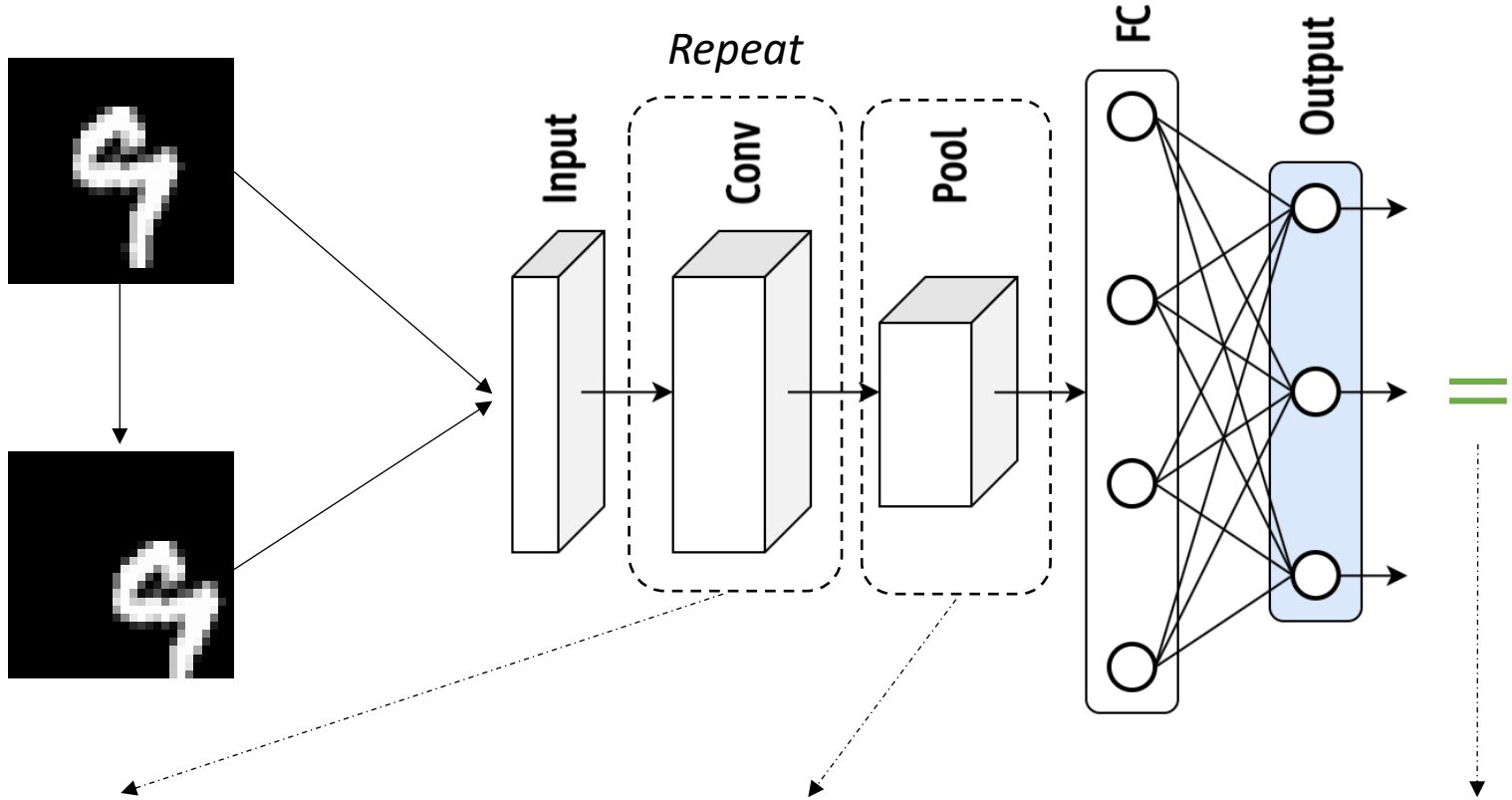


K. Fukushima, 1982
Neocognitron

Y. LeCun, 1989
LeNet

- Y LeCun, B Boser, J Denker, et al. Handwritten digit recognition with a back-propagation network. *NIPS*, 1989.

Translation Equi/In-variance of Convolutional Neural Networks



Translation Equivariance of Convolution

$$(\tau_x f) * g = \tau_x (f * g)$$

Translation Invariance of Global Pooling

$$\mathrm{pool}(\tau_x f) = \mathrm{pool}(f)$$

Hierarchical Invariance of Classification to Translation

$$\mathrm{C}(\tau_x f) = \mathrm{C}(f)$$

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Time for
a Break!!