

# **Convolutional Neural Networks (CNN) in Medical and General Image Pattern Recognition**

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# Development and Applications of **Convolutional Neural Networks (CNN)** in Medical Imaging

**Early 1990s** – Multi-layer perceptron (MLP) & Neocognitron [Prof. Fukushima] =>  
**Convolutional Neural Networks (CNN)**

- Wei Zhang et al – Osaka University : Recognition of alphanumeric characters
- Yann LeCun et al – AT&T : Recognition of alphanumeric handwriting
- ShihChung Ben Lo et al – Georgetown University: **Detection of lung nodule, breast lesions, ...**

**We further developed advanced CNN algorithms for various medical applications:**

**1995 - Wavelet CNN**

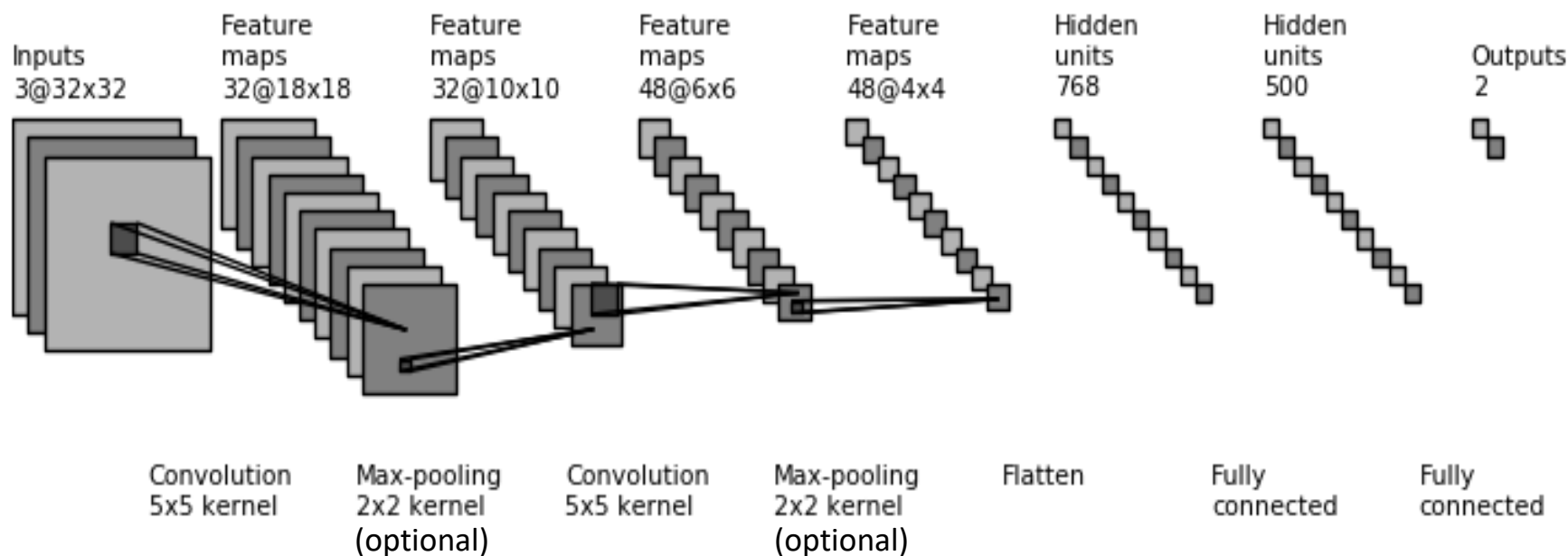
**1998 - Circular Path CNN**

**2002 - Optimization of wavelet through CNN search**

**2018 - Transformation-identical CNN (TI-CNN)**

**2018 - Geared Rotation-identical CNN (GRI-CNN)**

# A typical structure of the CNN



1. CNN - a series of convolution layers = a composed convolution with a large-sized kernel. In effect, the CNN acts as a "**spatial feature learning**" ( **no deep learning per se** )
2. An **activation function** is followed after each convolution or fully connected network process

# Convolutional Neural Network - CNN

- Imaging physics and convolution mathematics  
to understand how each component in the CNN works and how to improve it.
- Rather than take CNN as a series of black boxes.

# Image Pattern Recognition

## Medical Image Patterns

1. Orientation independent
2. Essential gray value features
3. Graphic pattern (edges) also play important roles
4. ROI patterns along boundary and in central part may be quite different
5. Size dependent
6. Structure noises (interference)

## General Image Patterns

1. Orientation dependent – most cases
2. Essential graphic pattern (edges) features
3. Size independent
4. Structure noises (interference)

# Acceptability by the users

**Medical Image – for medical experts  
(FDA cleared products)**

**1. Student/resident-in-the-box**

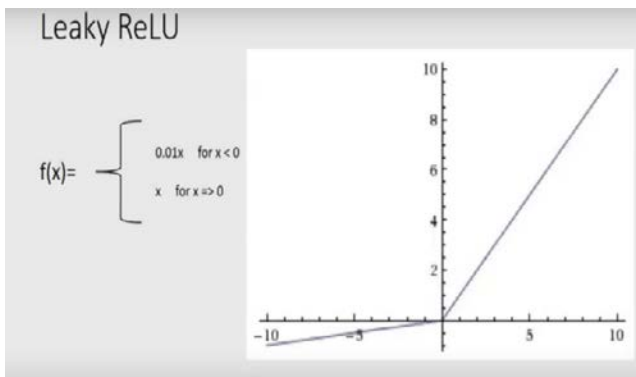
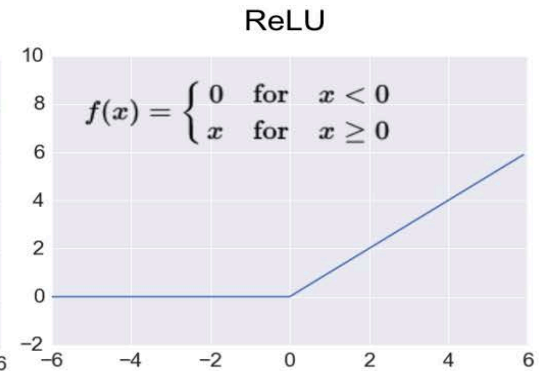
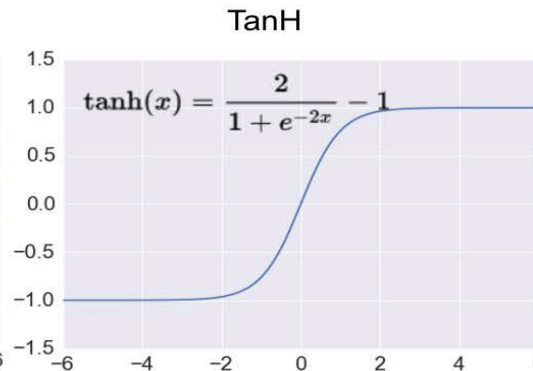
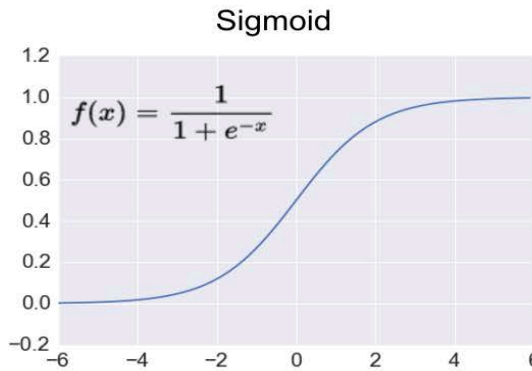
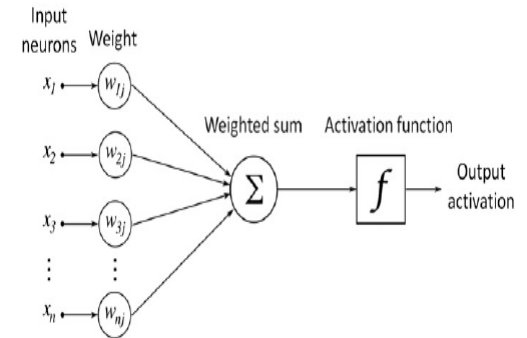
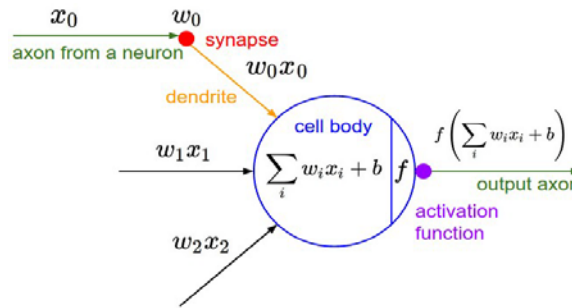
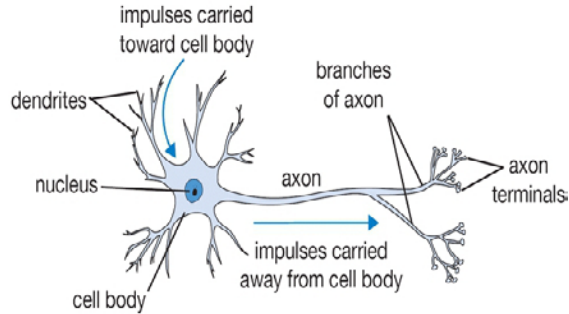
- \* no sale
- \* sale due to reimbursement but clinically ineffective

**2. Fellow/expert-in-the-box**

**General Image – for public**

1. Alexa, google home...

# A selected activation function is used after each network processing

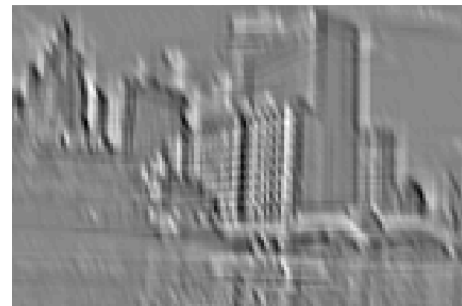
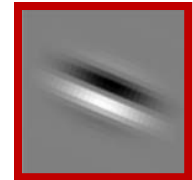
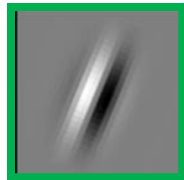
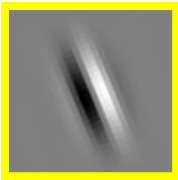
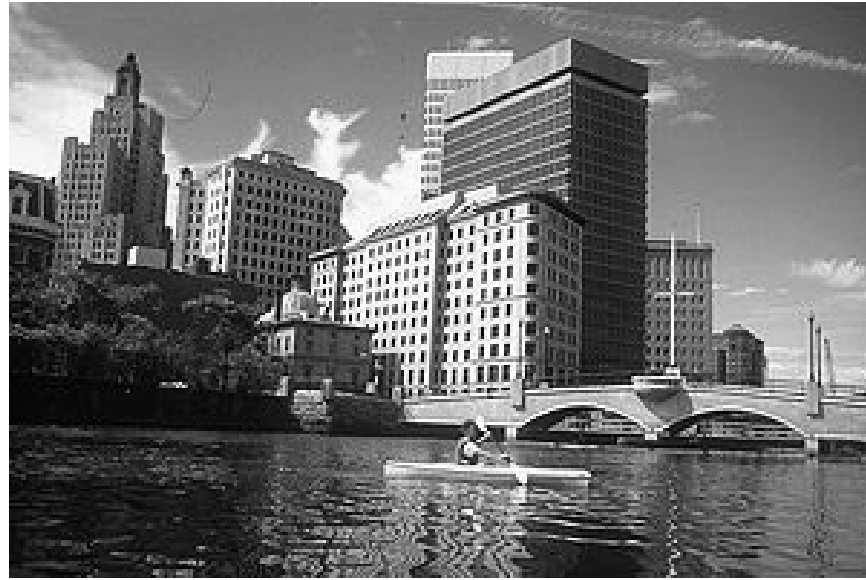


## Softmax (output layer)

$$\sigma(\mathbf{z})_j = \frac{e^{z_j}}{\sum_{k=1}^K e^{z_k}} \quad \text{for } j = 1, \dots, K.$$

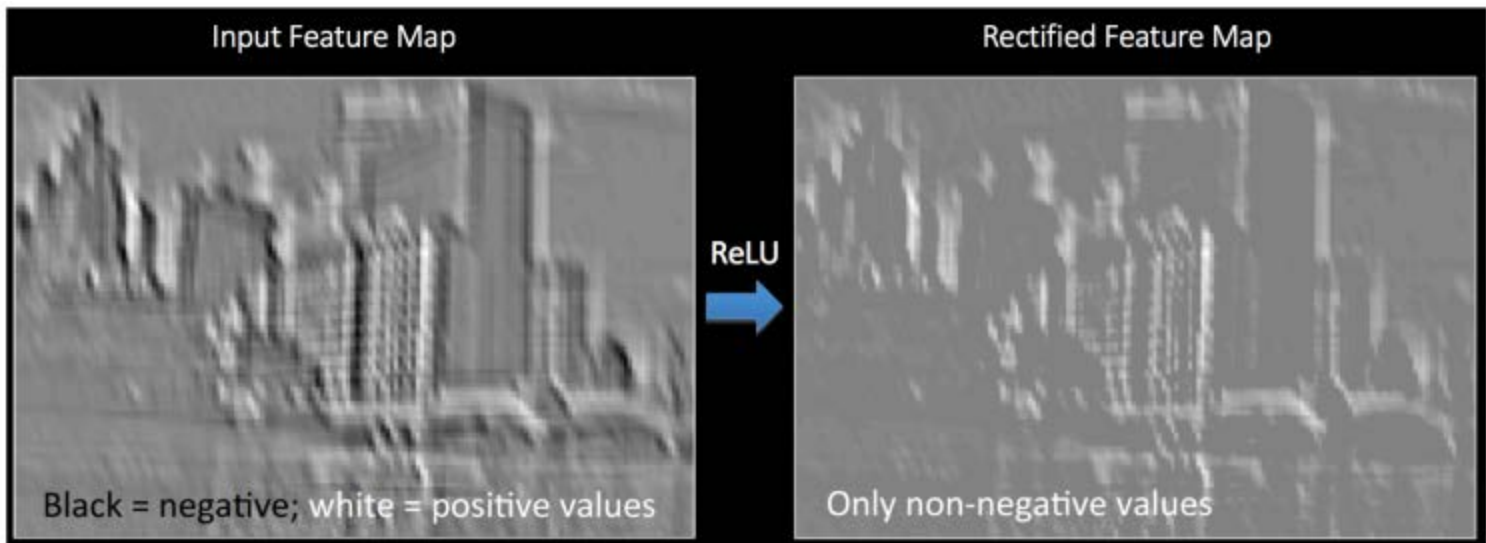
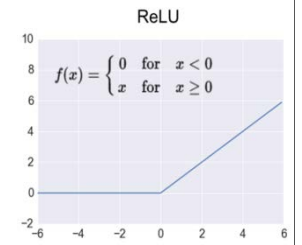
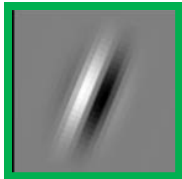
Softmax function is used to impart probabilities when you have more than one outputs you get probability distribution of outputs.

# Convolution is a Matter of Filtering



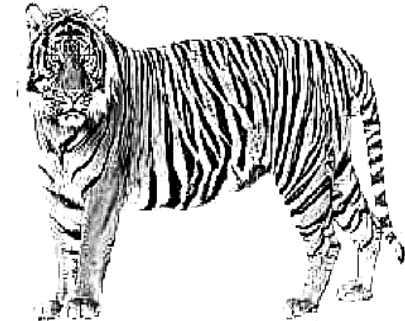
Feature maps



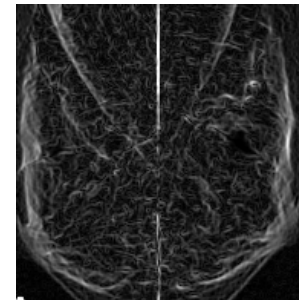
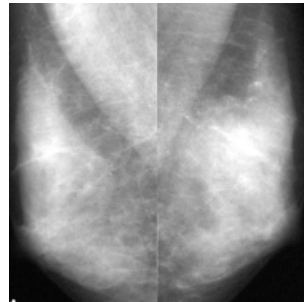


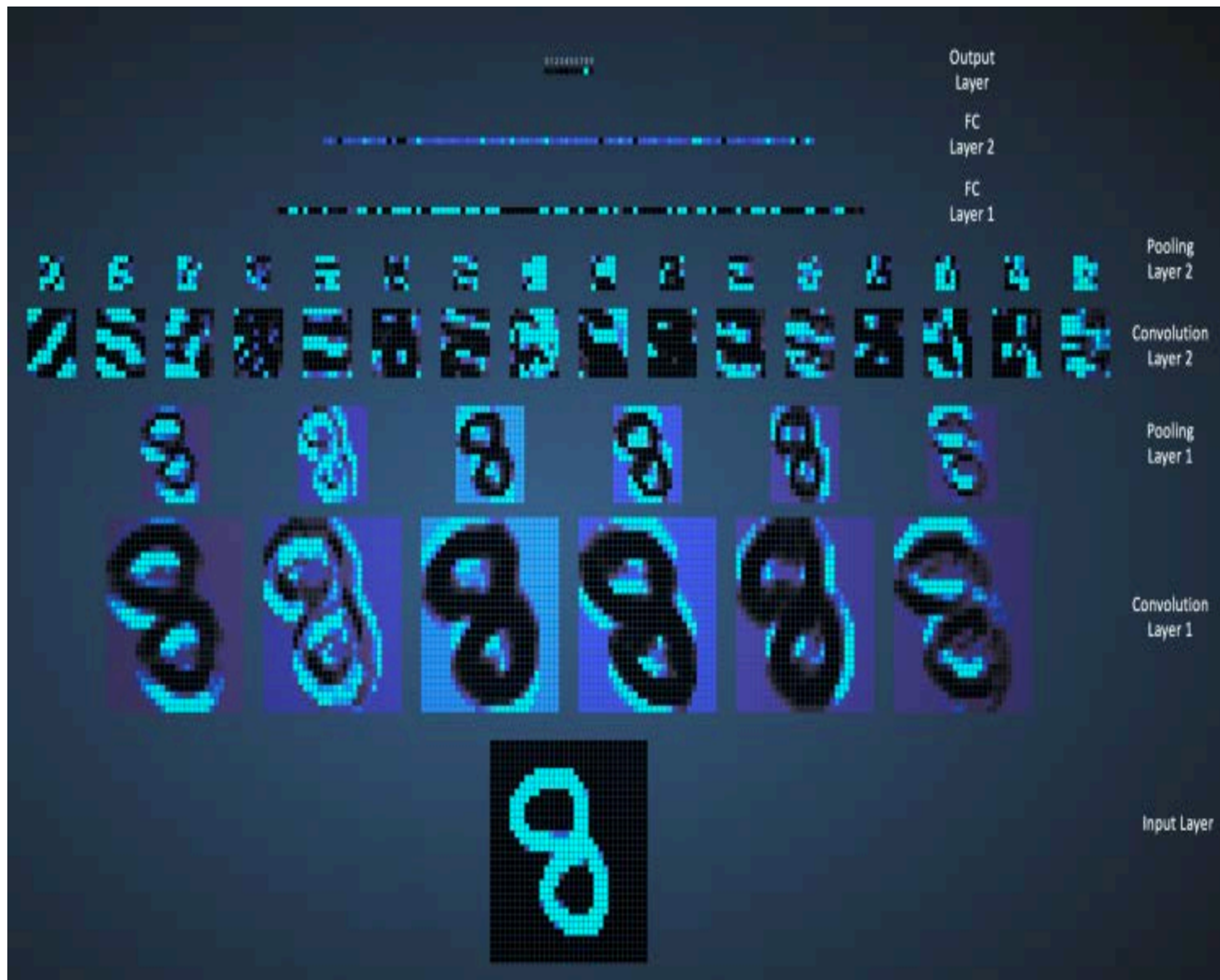
# Image Features lead to Recognition

- **Graphic feature**



- **Gray-value feature**

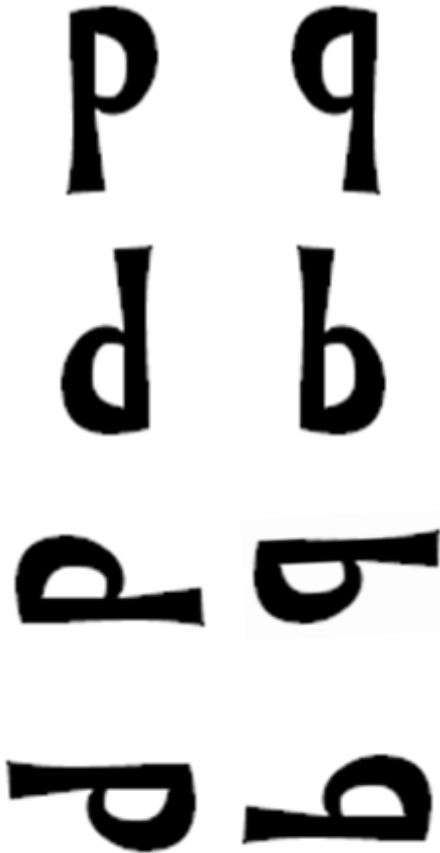




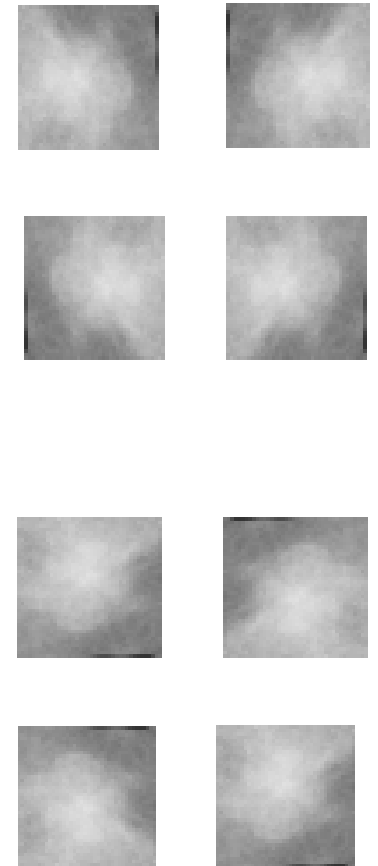
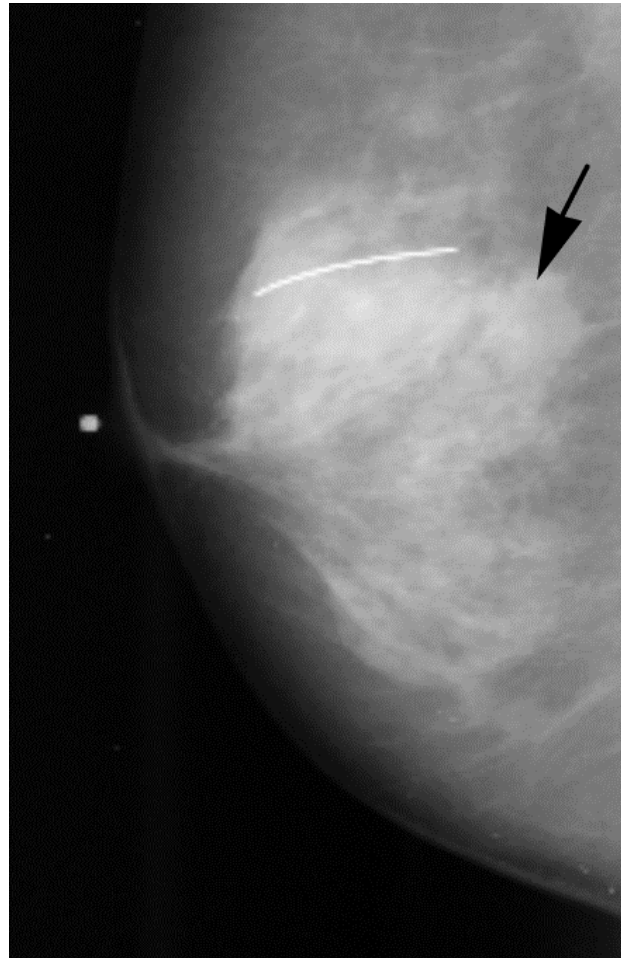
# Intent Categorization

Do you classify them the same or different category when the input is transformed?

Most CS scientists work on orientation dependent dataset initially



We have worked on orientation independent dataset since early 1990s.

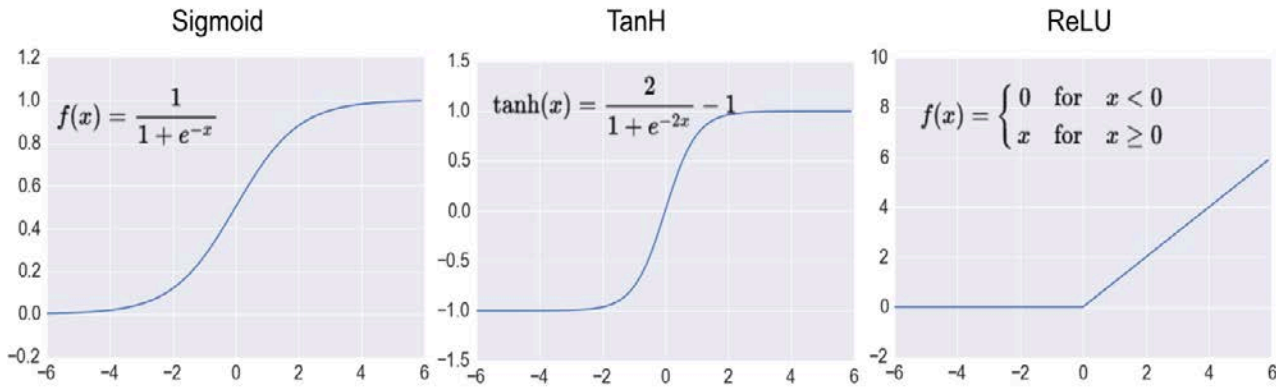


# Redesign of CNN for medical image pattern recognition

**1. Use of “lightning” activation - to improve recognition of gray value essential features.**

2. Use of symmetric filters and altering CNN structure design - to construct a transformation-identical CNN system quantitatively.

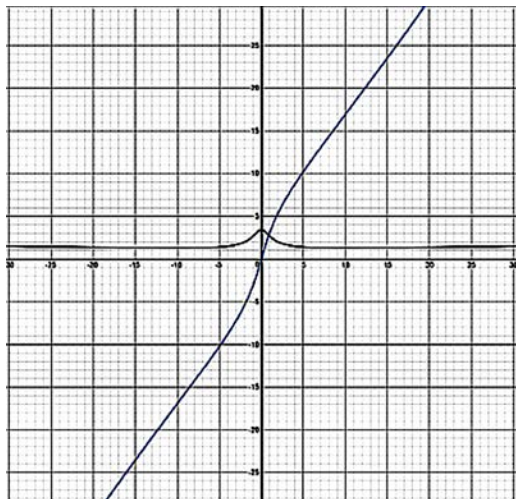
# Conventional activation functions designed for graphic feature essential image



Their derivative are  $df/dx < 1$

Signal range is suppressed

## A proposed gray-value enhanced activation function designed for gray-value features essential image



The "lightning" function (blue line) and its derivative ( $df/dx > 1$ ) curves for mapping a low value to a moderate high value.

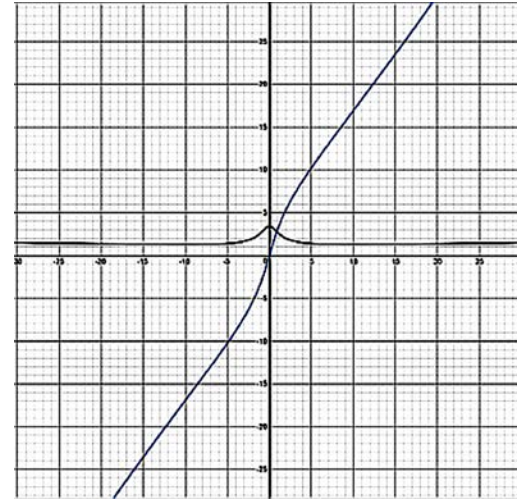
Signal range is expanded after the activation function.

# The "lightning" activation function

A range of activation functions can be designed to amplify signal range for convolution layers.

$$f(x) = \frac{1}{3} \sqrt{1 + x^{2/3}} + A \cdot \ln(|x + \sqrt{1 + x^2}|)$$

where "A" can be varied and bend activation map at low values.



- The curve shown on the figure is plotted when A=3.
- If one chooses "A" with a higher value, the curve would be bended toward vertical direction as per design.

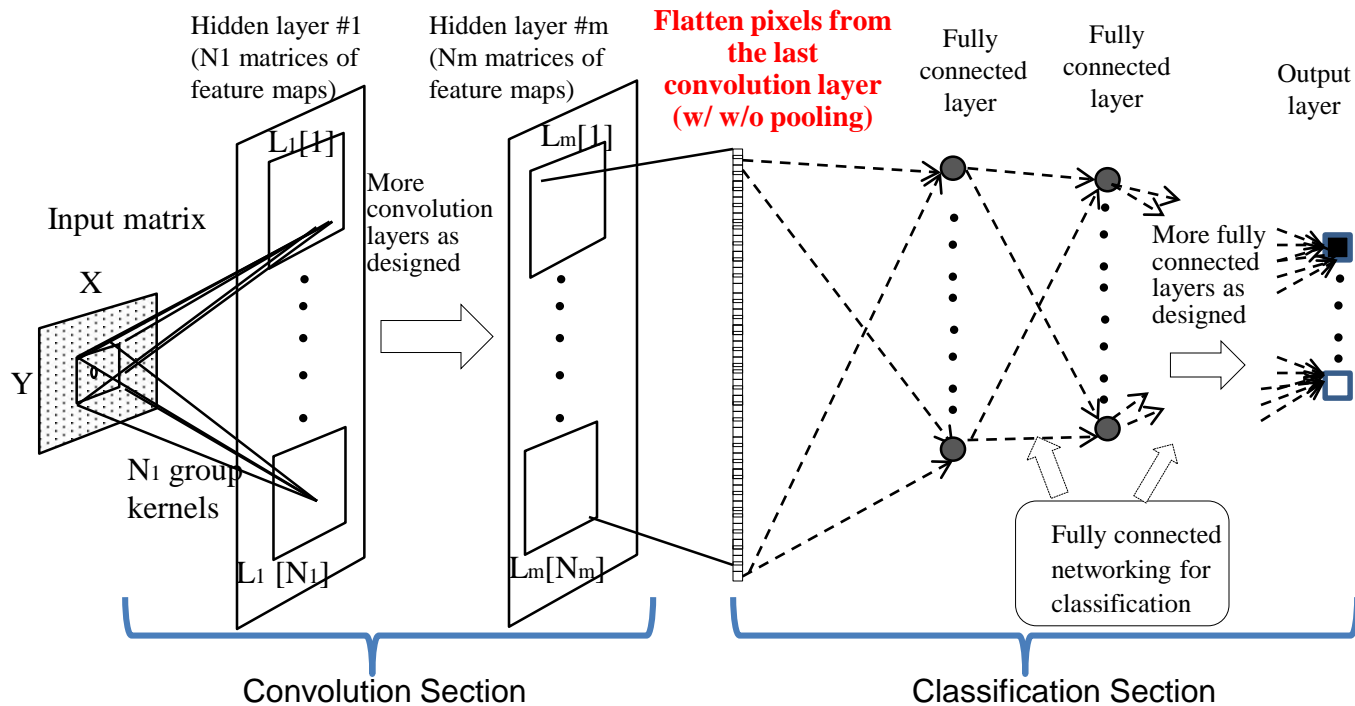
# Redesign of CNN for medical image pattern recognition

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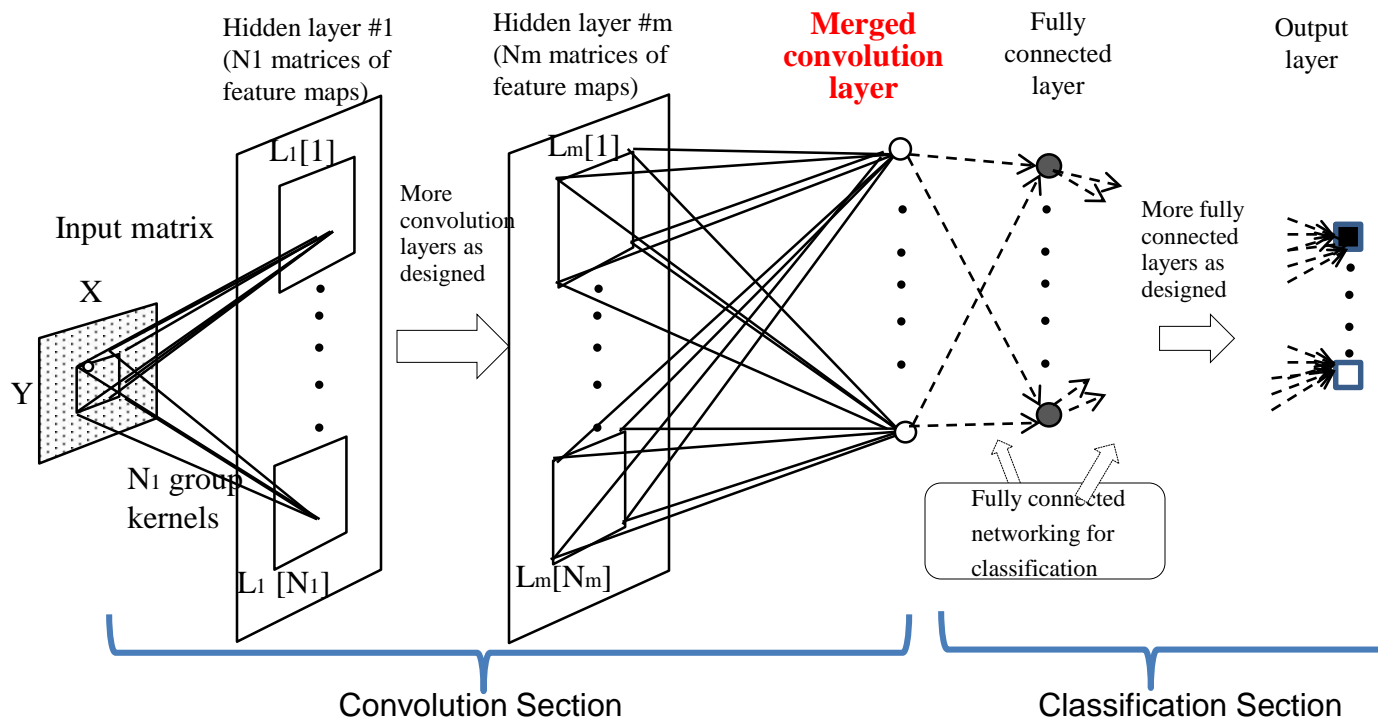
# Review of a Typical CNN Structure



We urge to correct the name of one layer in the CNN.

One should not call the layer between convolution and classification sections flatten~~X~~ layer or dense~~X~~ layer that would mislead AI investigators. It should be called the **“merged convolution layer.”** ✓

# A CNN Structure using merged convolution layer



We urge to correct the name of one layer in the CNN.

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# Symmetric Kernels

Regular kernel

a	b	c	d	e
f	g	h	i	j
k	l	m	n	o
p	q	r	s	t
u	v	w	x	y

Dih4 symmetric kernel

f	e	c	e	f
e	d	b	d	e
c	b	a	b	c
e	d	b	d	e
f	b	c	e	f

90° rotation symmetric kernel

f	e	c	g	f
g	d	b	d	e
c	b	a	b	c
e	d	b	d	g
f	g	c	e	f

No. of free parameters:

25

6

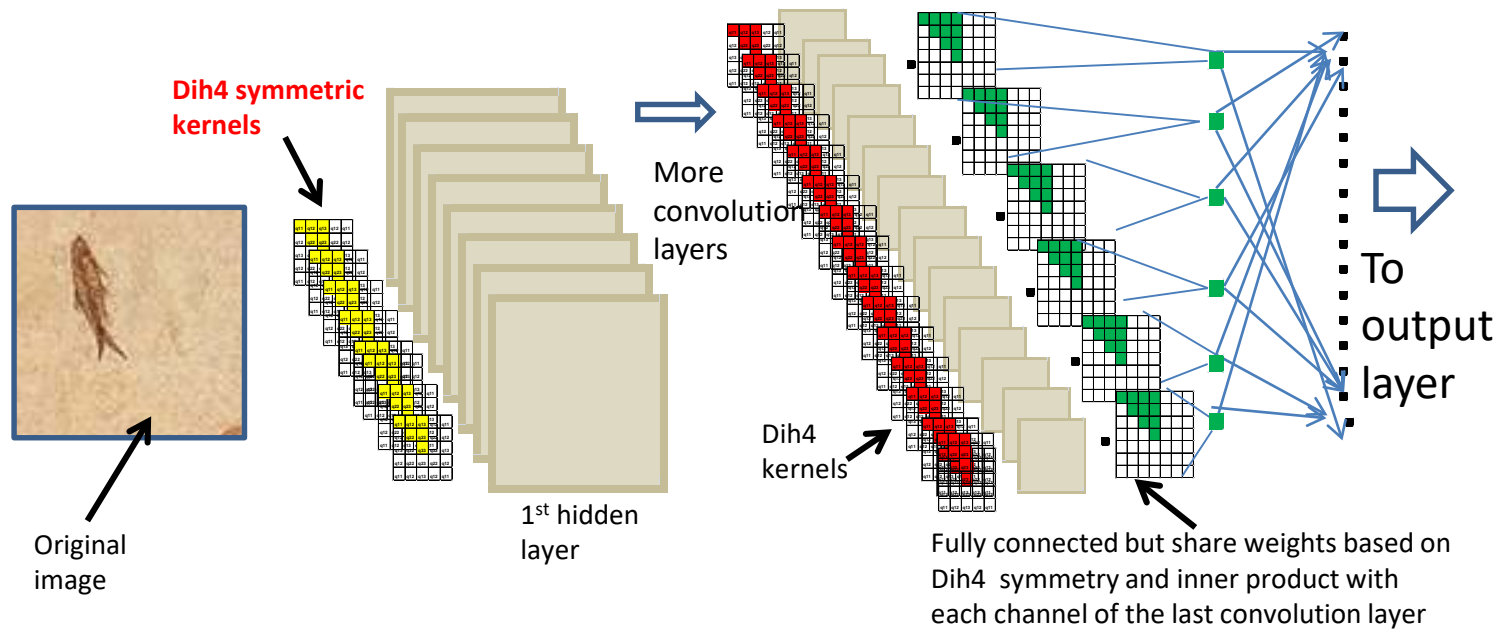
9

Current CNN

TI-CNN w/  
Dih4 symmetry

TI-CNN w/  
90° rotation  
symmetry

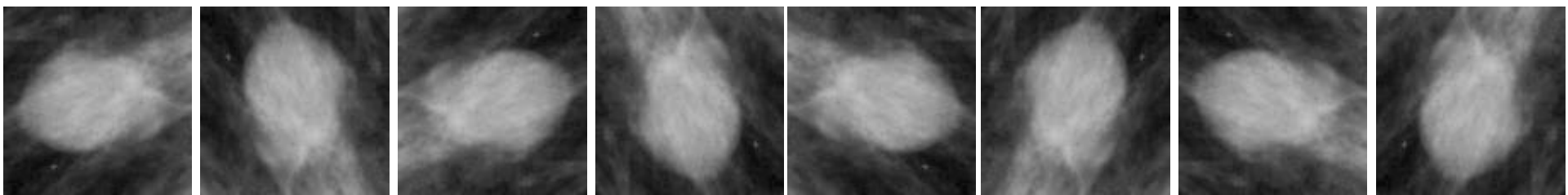
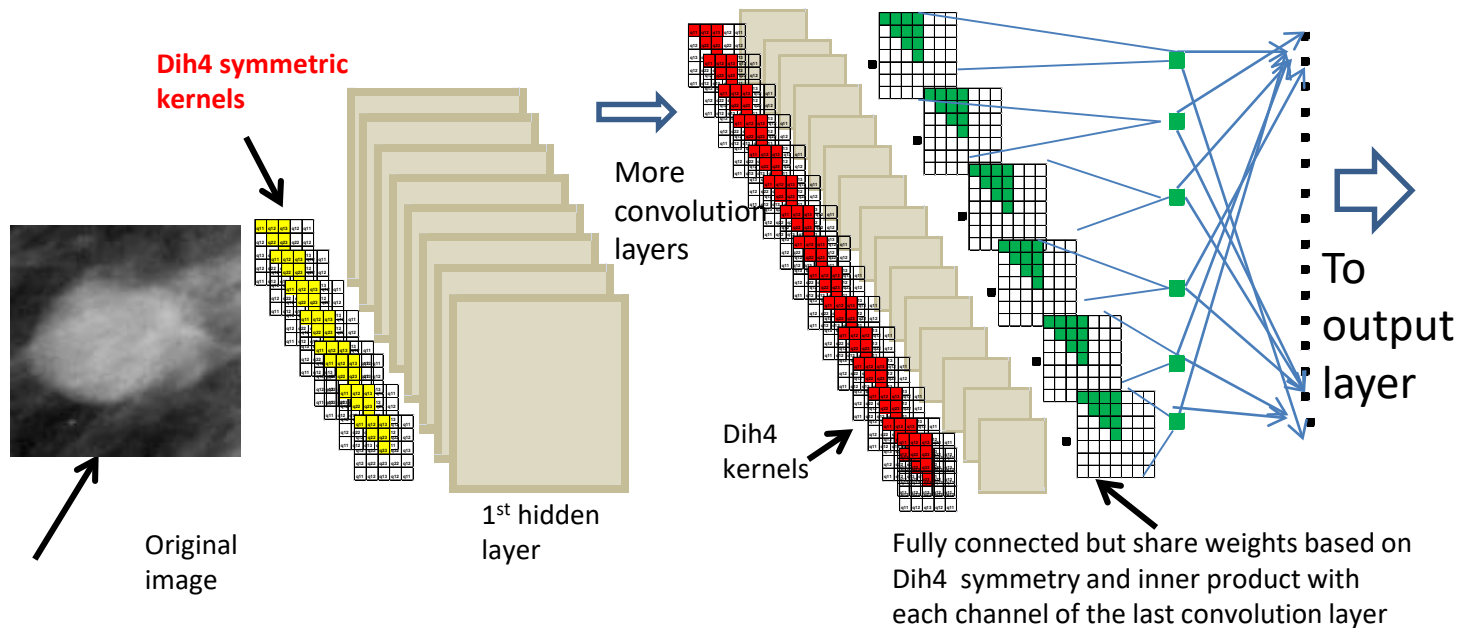
# Transformation-identical convolutional neural network structure (TI-CNN-1)



By entering each of these 7 versions of rotated and/or reflected images, the TI-CNN would produce the same output values



# Transformation-identical convolutional neural network structure (TI-CNN-1)



# Software modules to be changed for making a TI-CNN

(A) Initialization for all sets of convolutional kernels

q11	q12	q13	q12	q11
q12	q22	q23	q22	q12
q13	q22	q23	q22	q12
q12	q22	q23	q22	q12
q11	q12	q13	q12	q11

Randomize or transfer coefficients for free parameters and duplicate coefficients at corresponding symmetric elements

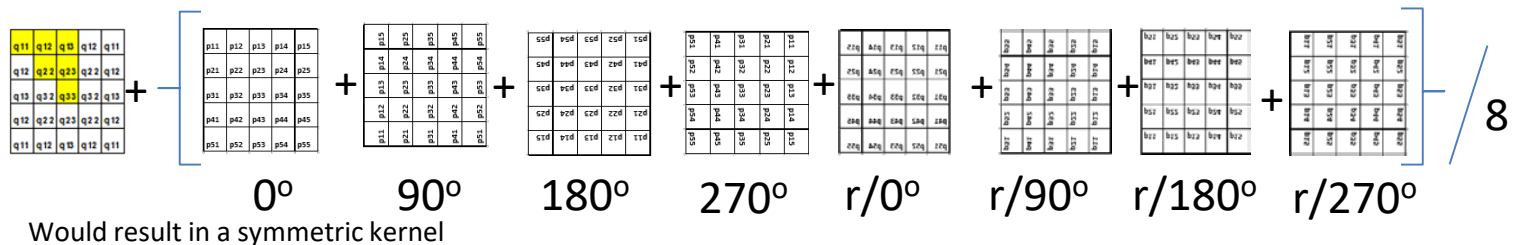
(B) Update each kernel

q11	q12	q13	q12	q11
q12	q22	q23	q22	q12
q13	q22	q23	q22	q12
q12	q22	q23	q22	q12
q11	q12	q13	q12	q11

p11	p12	p13	p14	p15
p21	p22	p23	p24	p25
p31	p32	p33	p34	p35
p41	p42	p43	p44	p45
p51	p52	p53	p54	p55

Kernel coefficients learned from error backpropagation & to be added on to the kernel

Would not result in a symmetric kernel

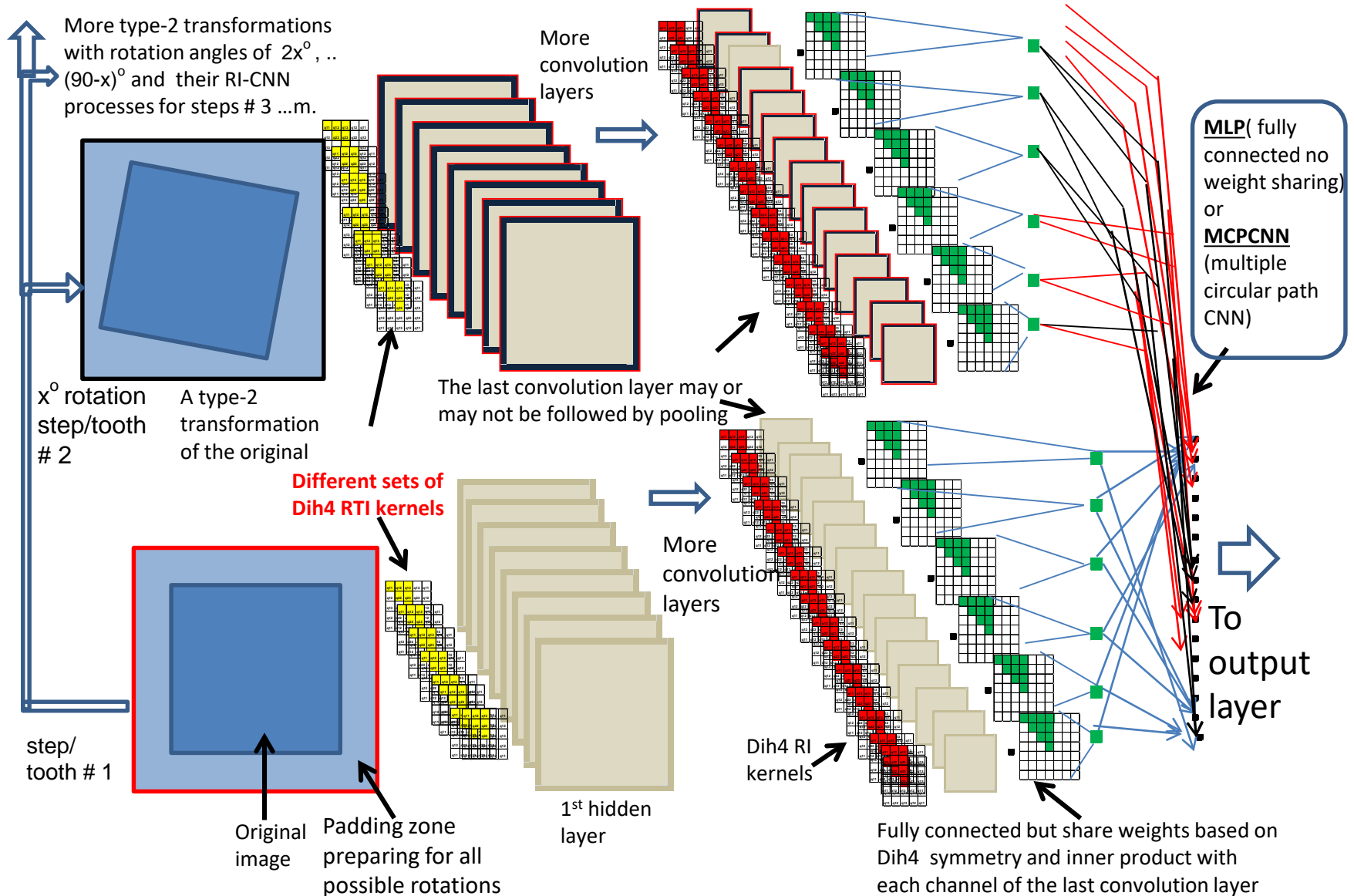


(C) Speed up computation by adding symmetric positions of the 1st operand followed by multiplying the corresponding kernel coefficient (Optional)

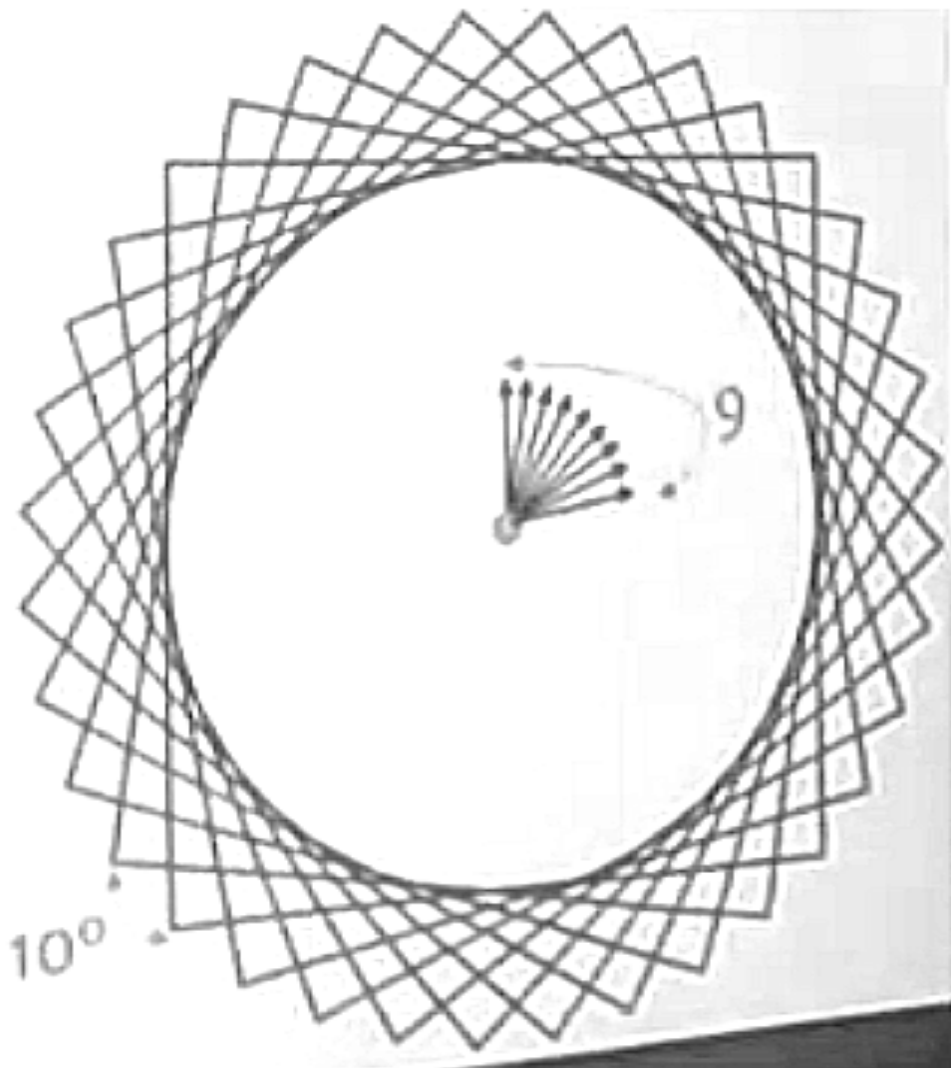
(D) Treat the 1<sup>st</sup> flatten layer as the same as a convolution layer (i.e., merged convolution layer) with the same property of symmetric kernel

# One of GRI-CNN structures – A virtually isotropic CNN system that can produce identical output with a small step angle rotation

No beginning and no ending angle!



**$X=10^\circ \Rightarrow 9$  frames (8 additional images would be intrinsically created) in the GRI-CNN algorithm**

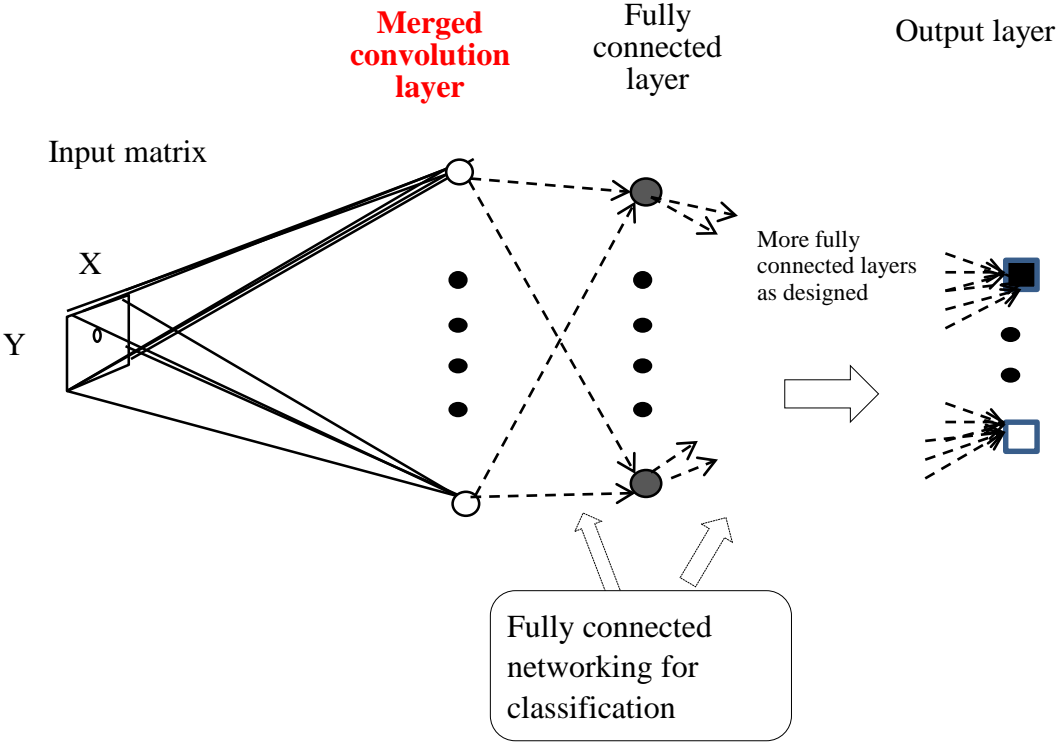


**If  $X=1^\circ \Rightarrow m=90$**



# Can we use neural network without convolution layer to construct TI-NN and GRI-NN?

Answer: yes



# Conclusions and Discussion

- 1. The foundation of CNN is based on convolution/filter processes, feature extraction, and image physics – not black boxes**
2. Medical image pattern featured in gray value/graphic, ROI boundary, orientation independent, size dependent
- 3. The TI-CNNs can be constructed using (i) symmetric operators, (ii) symmetric operations, (iii) symmetric input data made artificially.**
- 4. The GRI-CNNs can be constructed using the TI-CNNs with a fine step angle design.**
5. Several new groups of CNNs have been developed and can systematically produce identical results. When the structure getting complex, further research is need to investigate its performance.