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Announcements

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Reminder: ps3 due Thursday 10/8 at midnight (Boston)

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- ps4 out Thursday, due 10/15 (1 week)

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- Lab this week – neural network learning

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- ps3 self-grading form out Monday, due 10/19


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Neural Networks III

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Today: Outline

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- **Neural networks cont'd**

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- **Types of networks:** Feed-forward networks, convolutional networks, recurrent networks

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- **ConvNets**: multiplication vs convolution; filters (or kernels); convolutional layers; 1D and 2D convolution; pooling layers; LeNet, CIFAR10Net

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Neural Networks III

Network Architectures

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Neural networks: recap

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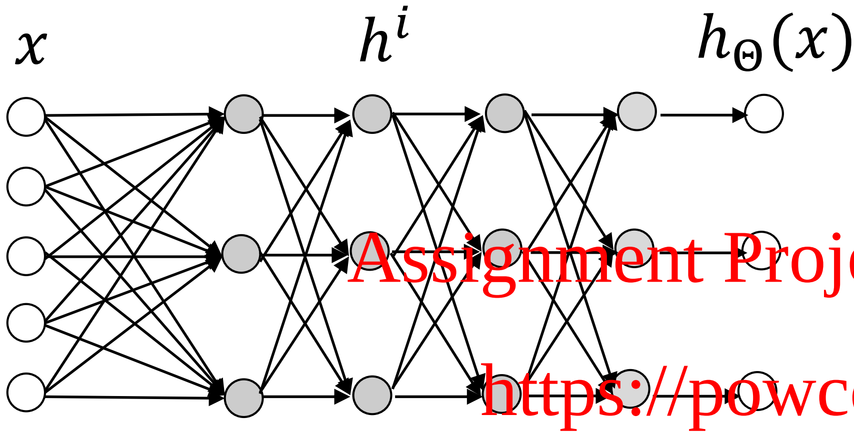

Learn parameters via gradient descent

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$$\min_{\Theta} J(\Theta)$$

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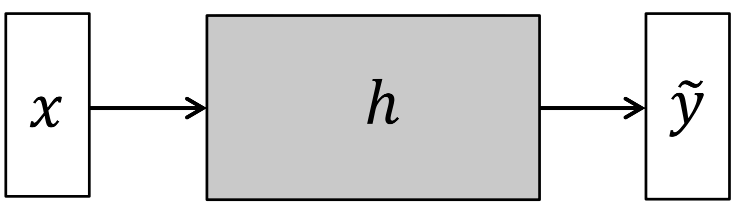

Backpropagation efficiently computes cost (forward pass) and gradient (backward pass)

$$\frac{\partial}{\partial \Theta_{ij}^{(l)}} J(\Theta)$$

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Network architectures

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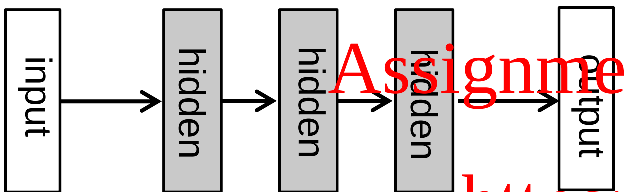
Feed-forward

Fully connected



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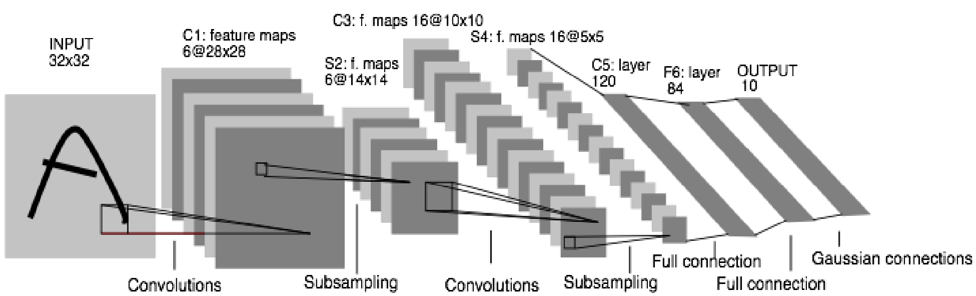
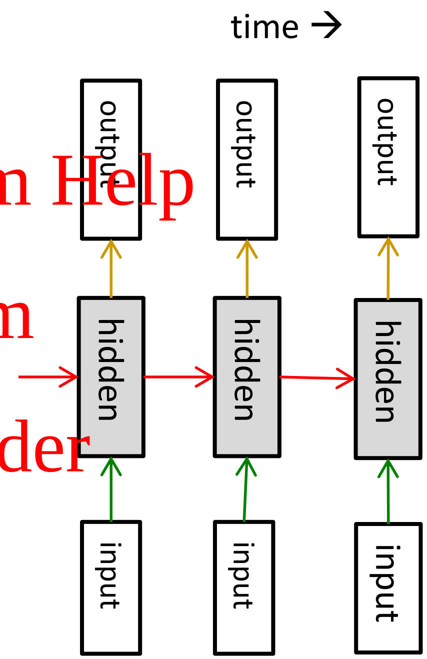
Convolutional



Recurrent



Neural Networks III

Convolutional Architectures

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Multiplication vs convolution

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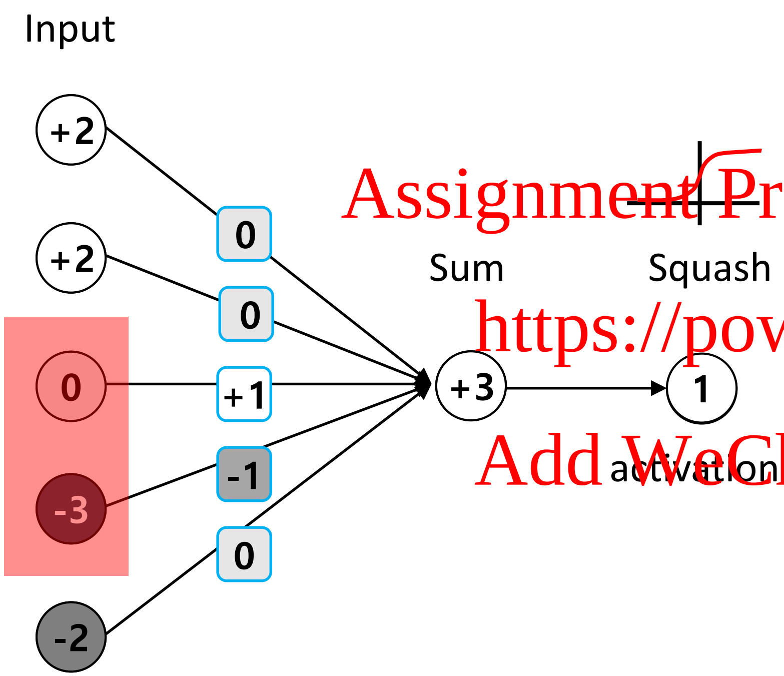

- Recall, a neuron can be thought of as learning to spot certain features in the input
- E.g., this neuron detects change from high to low (light to dark) between 3rd and 4th inputs

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Multiplication vs convolution

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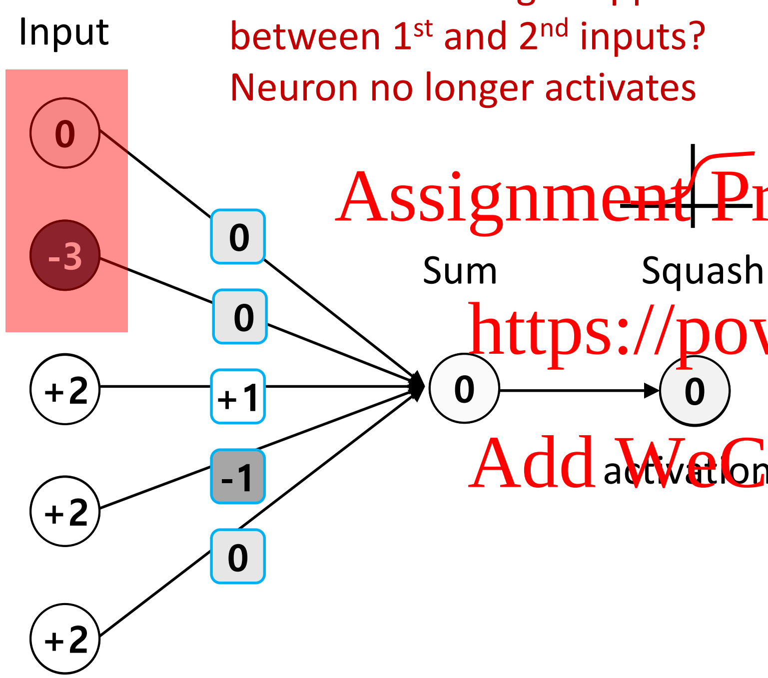
What if the change happens between 1st and 2nd inputs? Neuron no longer activates



- Must have a new neuron for each new location of pattern???
- This is not efficient
- Solution: use convolution instead of multiplication

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Multiplication vs convolution

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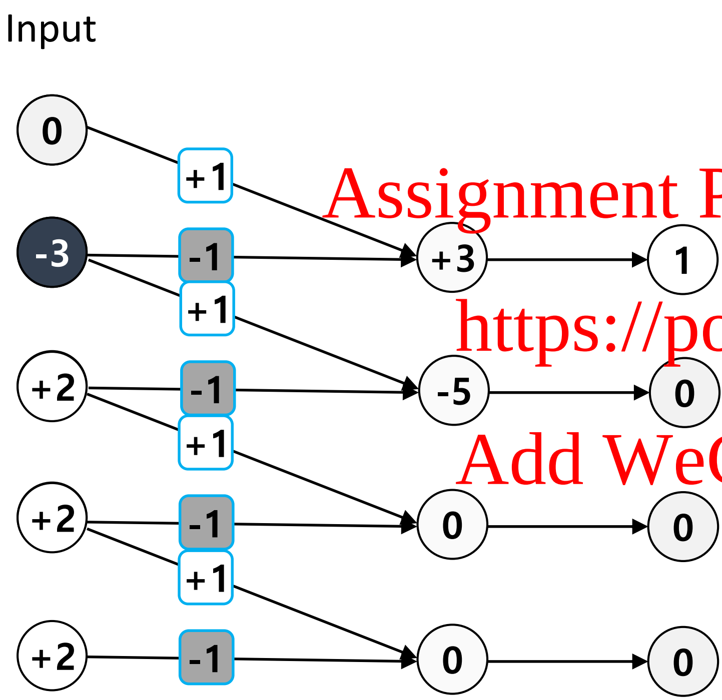

- New weights are of size 2 x 1; called filter, or kernel
- New output is the size of input minus 1 because of boundary
- New convolutional neurons all share the same weights! This is much more efficient; we learn the weights once instead of many times for each position

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Multiplication vs convolution

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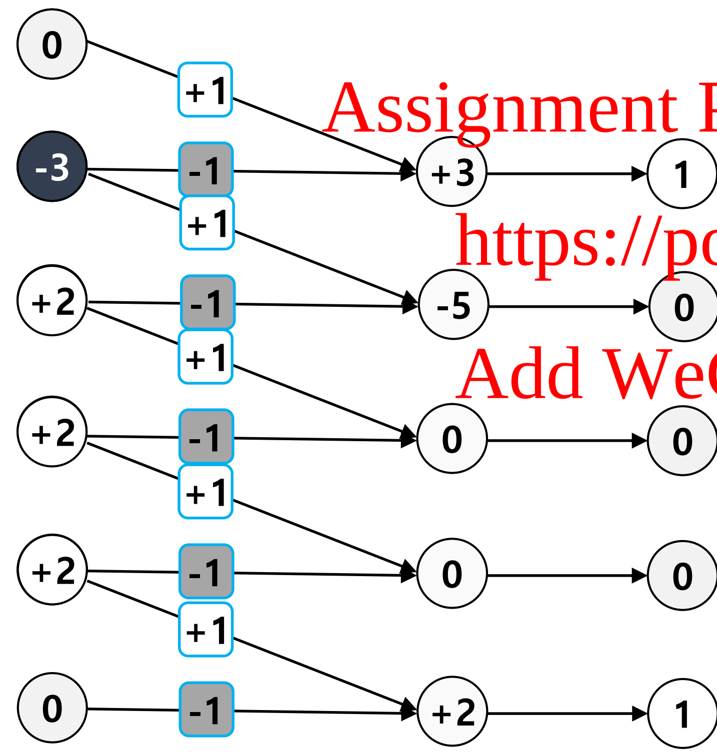
Padded Input



- New output is the size of input minus 1 because of boundary
- We can fix the boundary effect by padding the input with 0 and adding one more neuron

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Multiplication vs convolution

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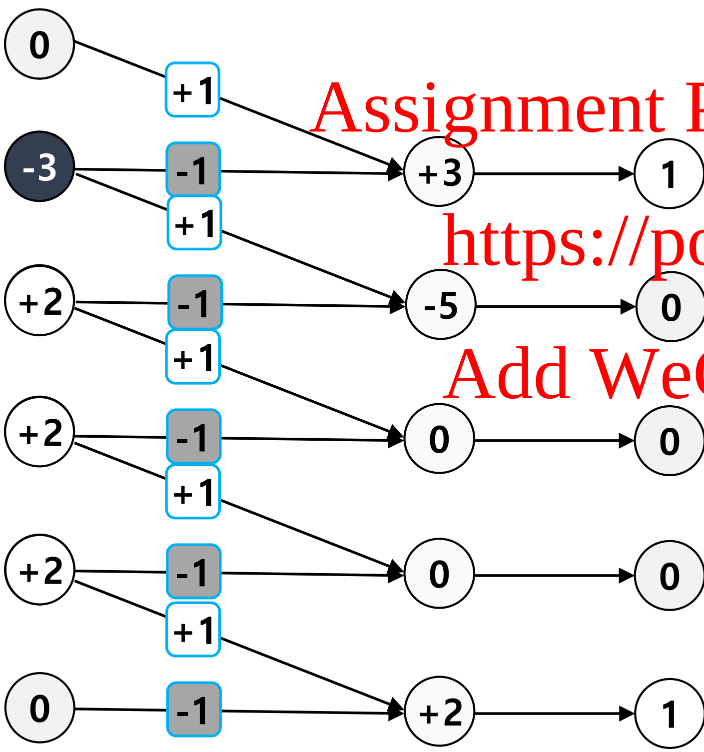
Padded Input



- Note, we move the filter by 1 each time, this is called stride

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Multiplication vs convolution

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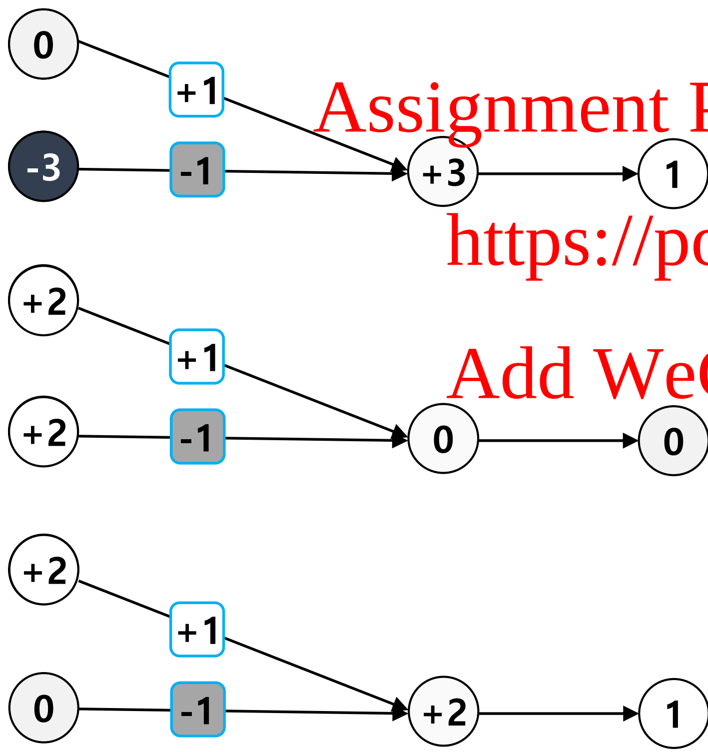
Padded
Input



- Note, we move the filter by 1 each time, this is called stride
- Stride can be larger, e.g. here is stride 2

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Multiplication vs convolution

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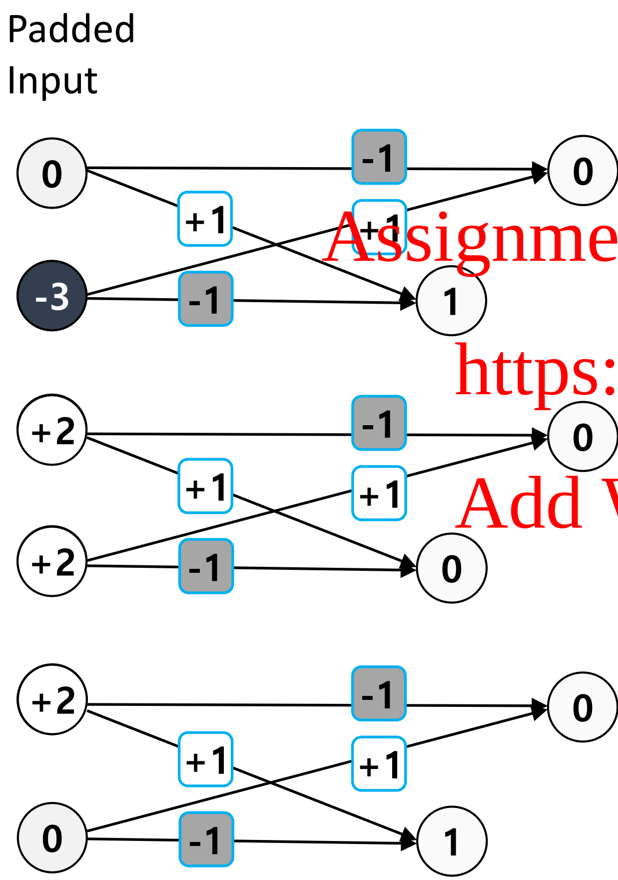

- We can add another filter, this time to detect opposite change with weights [-1 +1]

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- Unique filters are called channels

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Multiplication vs convolution

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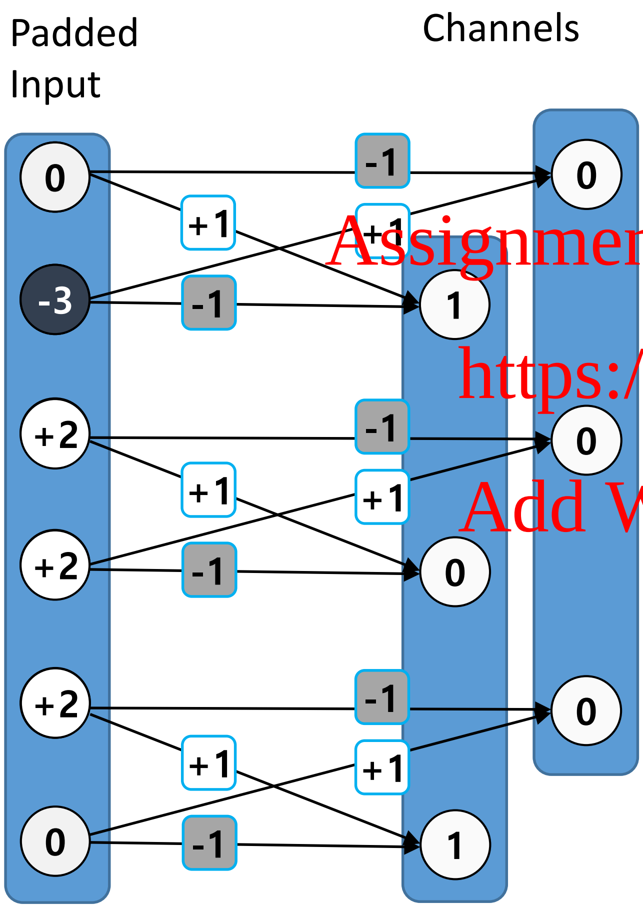

- We can add another filter, this time to detect opposite change with weights [-1 +1]
- Unique filters are called channels

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Multiplication vs convolution

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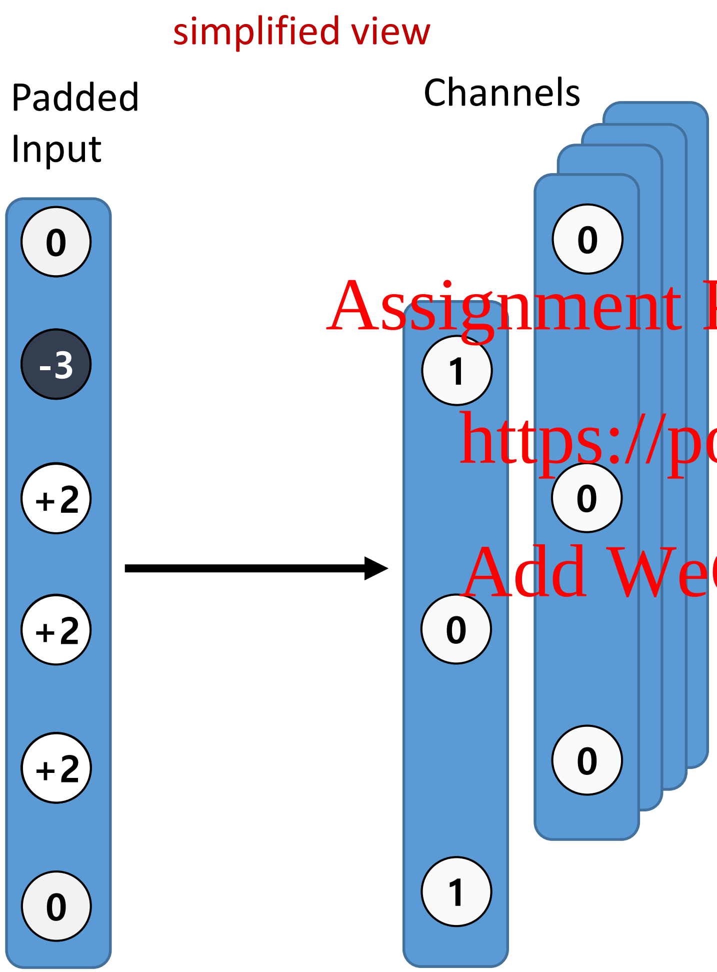

To summarize, this layer has

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- Input 5 x 1, padded to 6 x 1
- Kernel 2 x 1 with weights [+1,-1]
- Stride 2
- Output 3 x 1
- No. channels K

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Convolutional Neural Networks

For images and other 2-D signals

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Representing images

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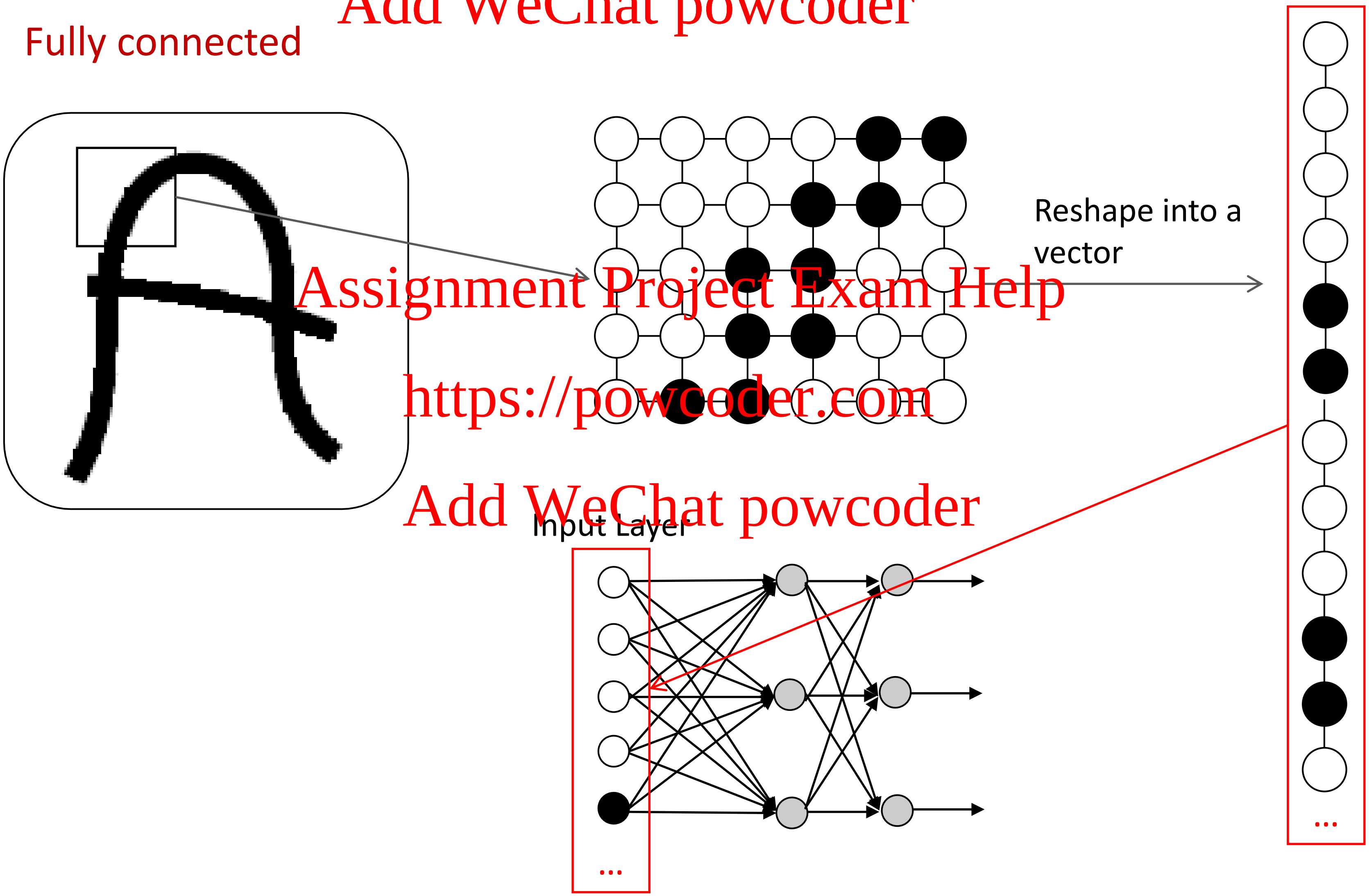
Fully connected



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2D Input: fully connected network

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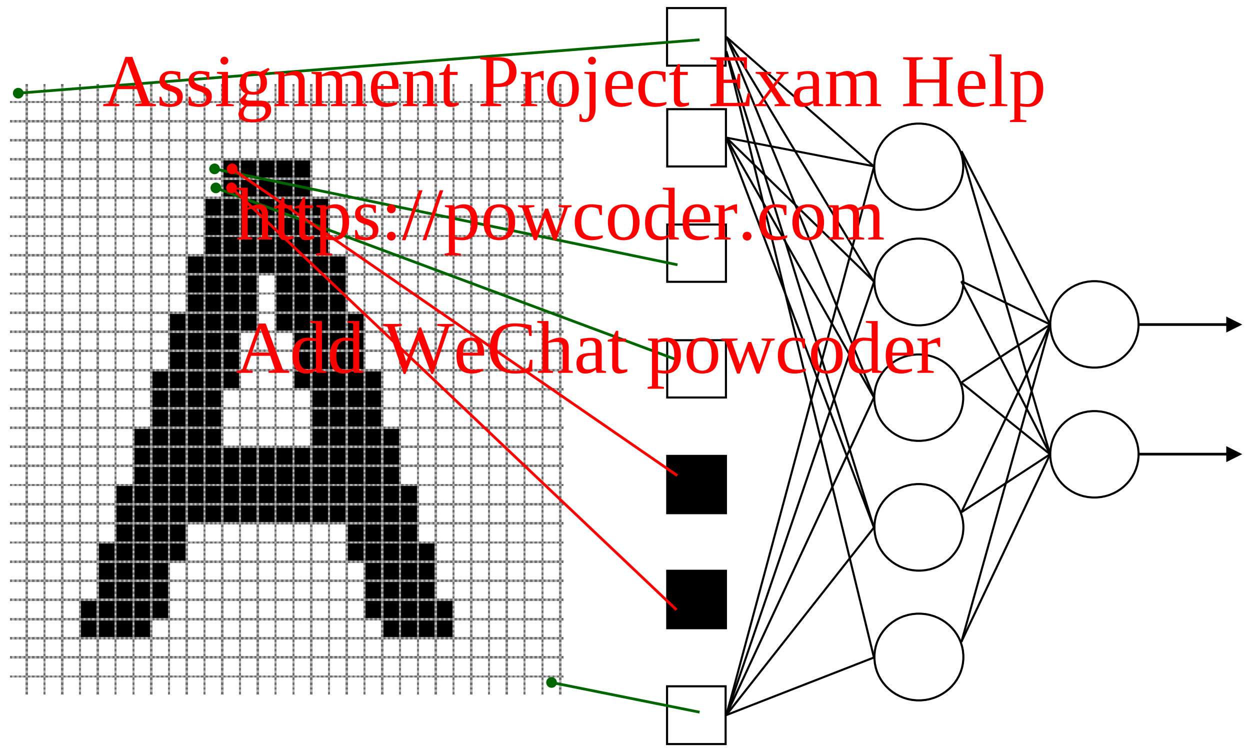
Vectorize input by copying rows into a single column



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2D Input: fully connected network

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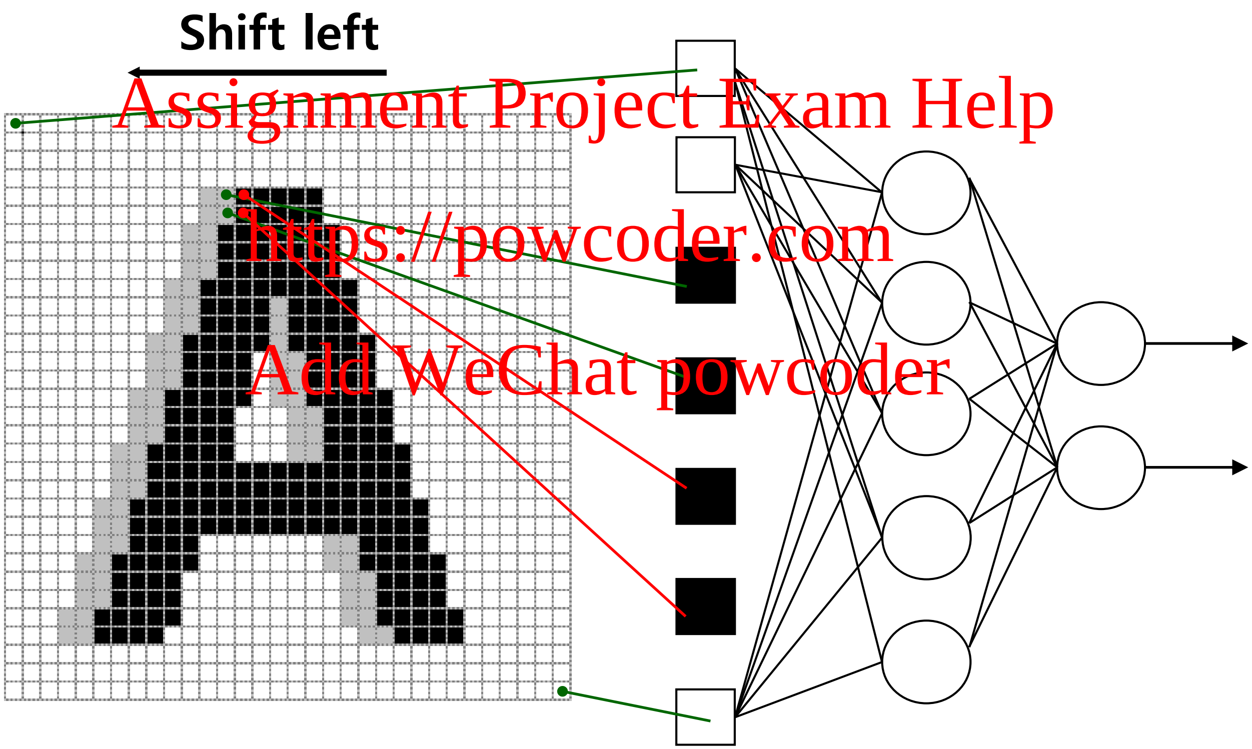
Problem: shifting, scaling, and other distortion changes location of features



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2D Input: fully connected network

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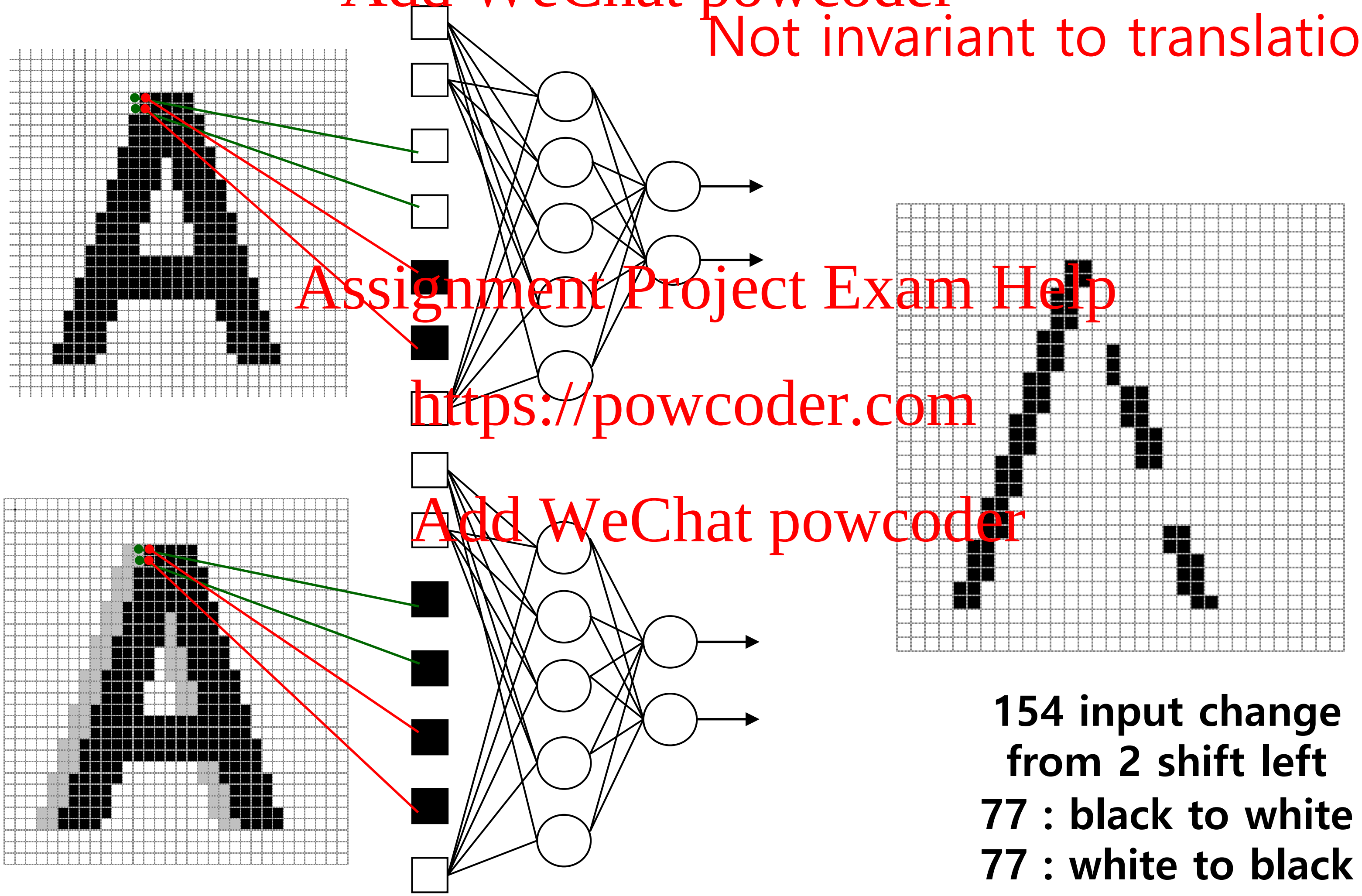
Not invariant to translation!



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154 input change from 2 shift left
77 : black to white
77 : white to black

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Convolution layer in 2D

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- detect the same feature at different positions in the input, e.g. image
- preserve input topology

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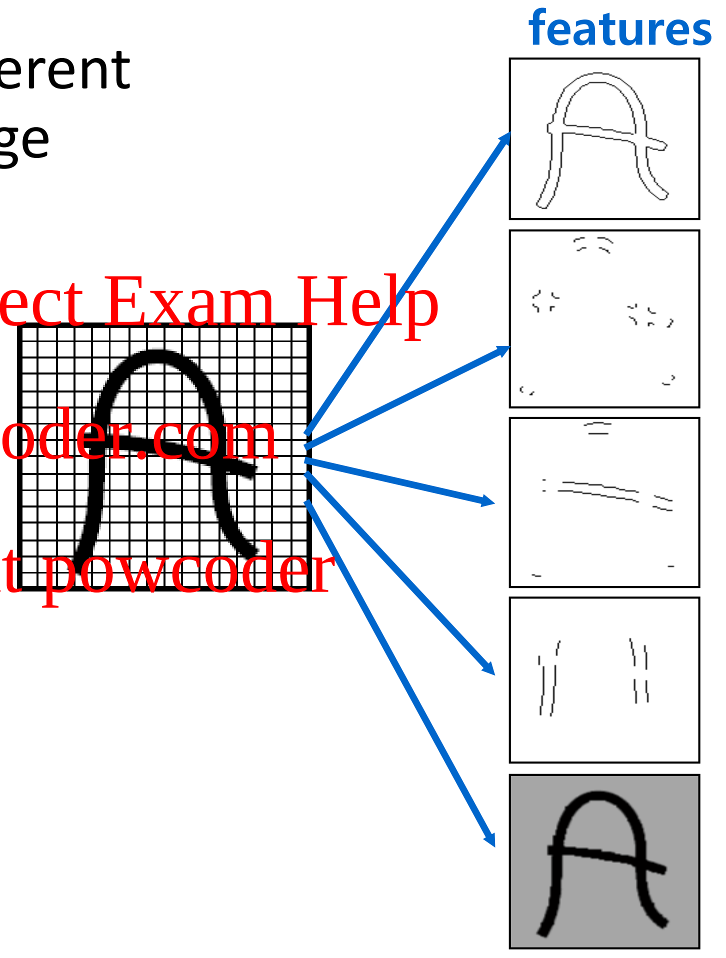

Convolution layer in 2D

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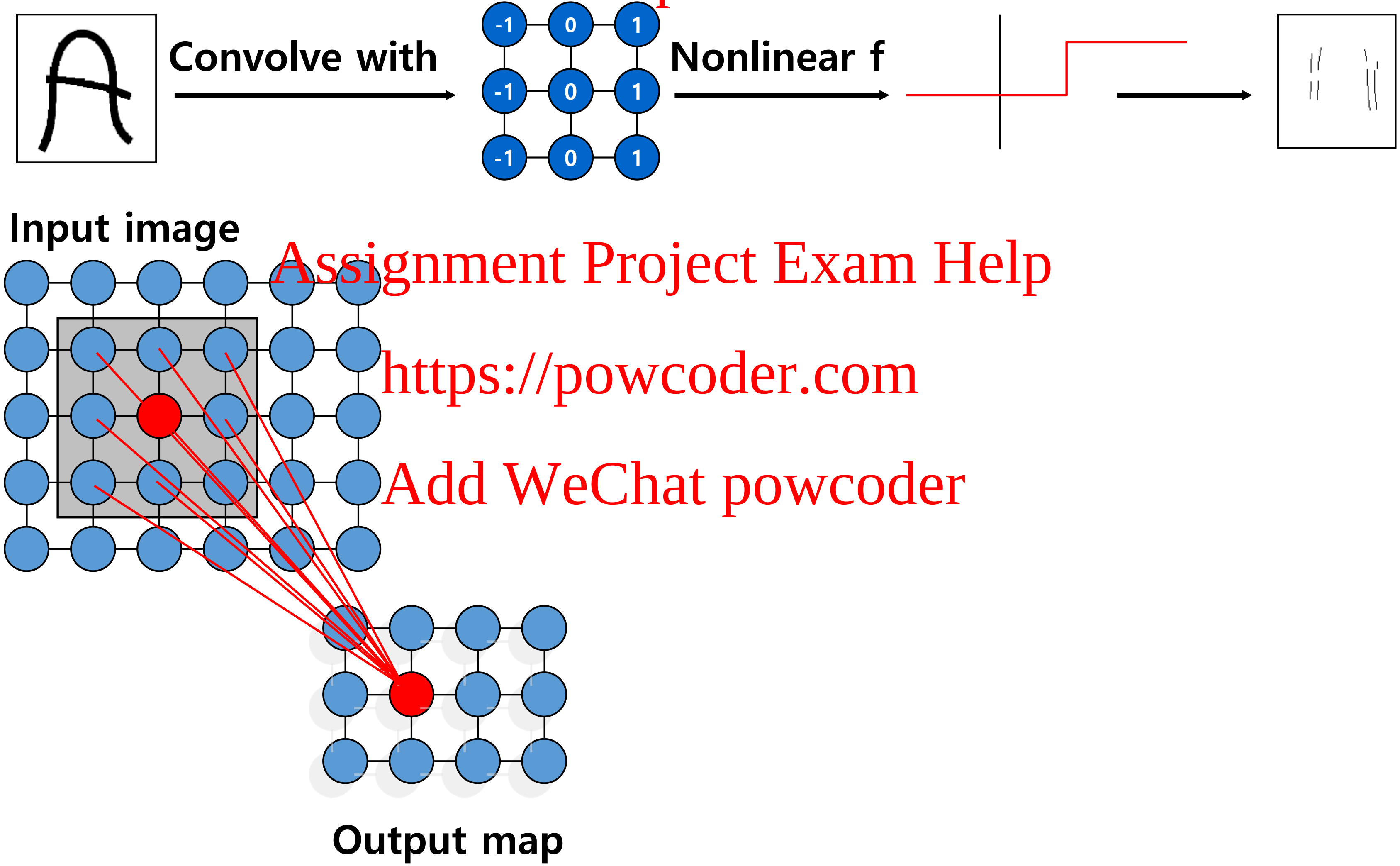

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Convolution layer in 2D

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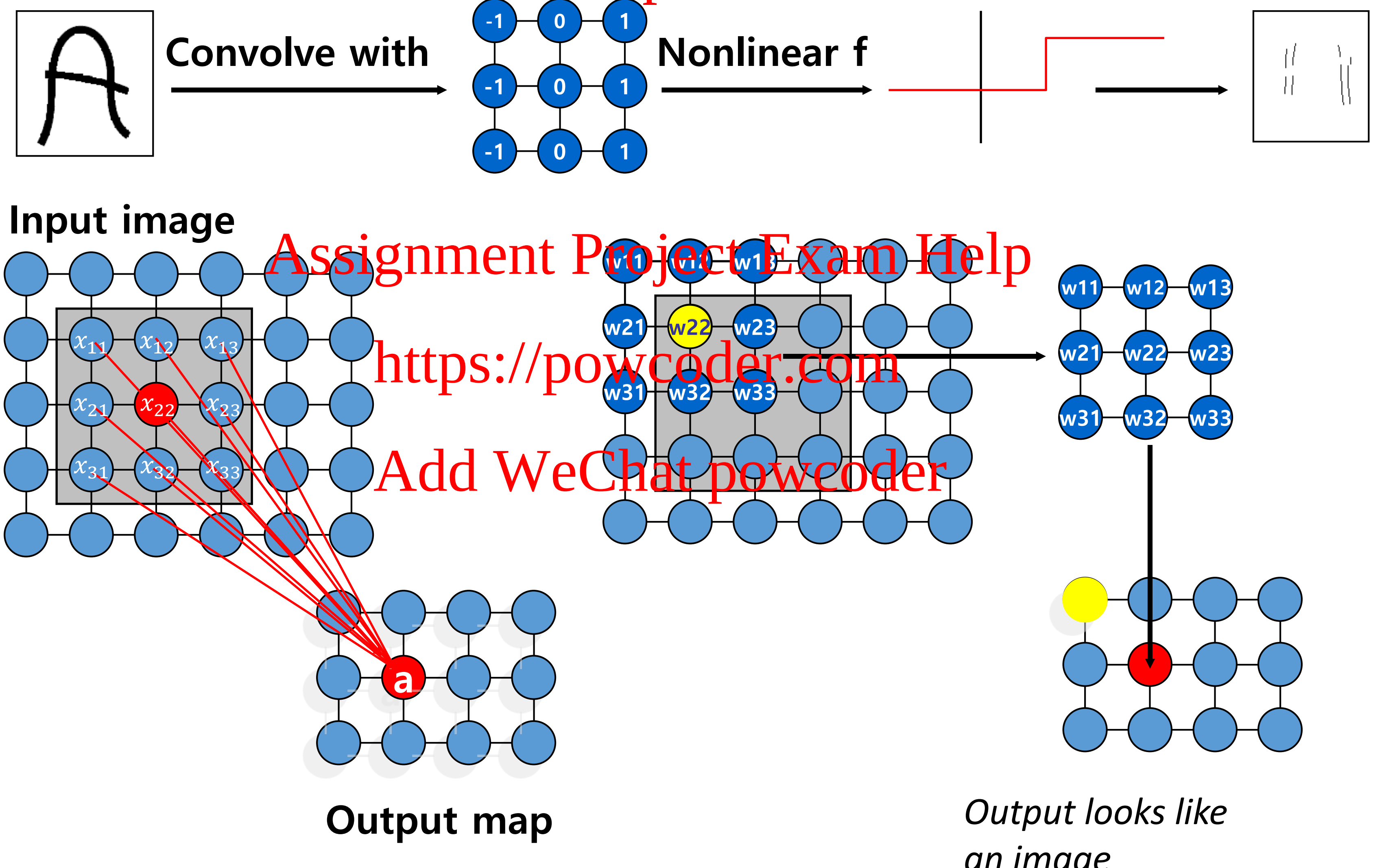

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$$a = f(w_{11}x_{11} + w_{12}x_{12} + w_{13}x_{13} + \cdots w_{33}x_{33})$$

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What weights correspond to these output maps?

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These are output maps before thresholding

Hint: filters look like the input they fire on

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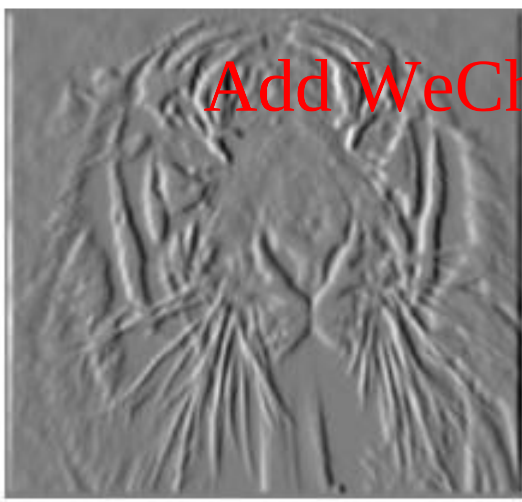
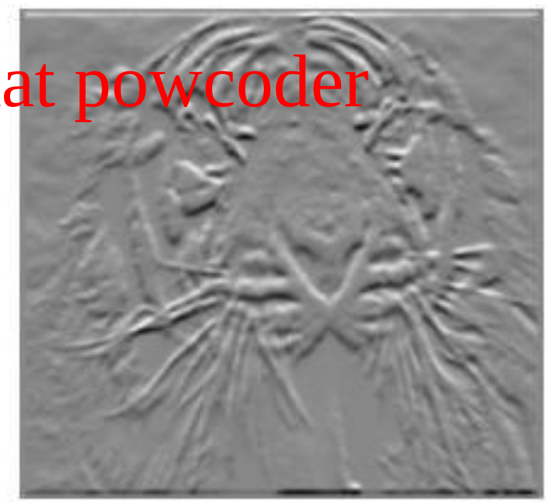
$$\frac{\partial f(x,y)}{\partial x}$$

$$\begin{bmatrix} -1 & 0 & 1 \\ -1 & 0 & 1 \\ -1 & 0 & 1 \end{bmatrix}$$





$$\frac{\partial f(x,y)}{\partial y}$$

$$\begin{bmatrix} -1 & -1 & -1 \\ 0 & 0 & 0 \\ 1 & 1 & 1 \end{bmatrix}$$

What will the output map look like?

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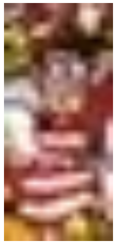
Input



filter

What will the output map look like?

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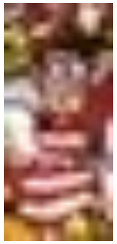
Output



filter

Stacking convolutional layers

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- Each layer outputs multi-channel feature maps (like images)
- Next layer learns filters on previous layer's feature maps

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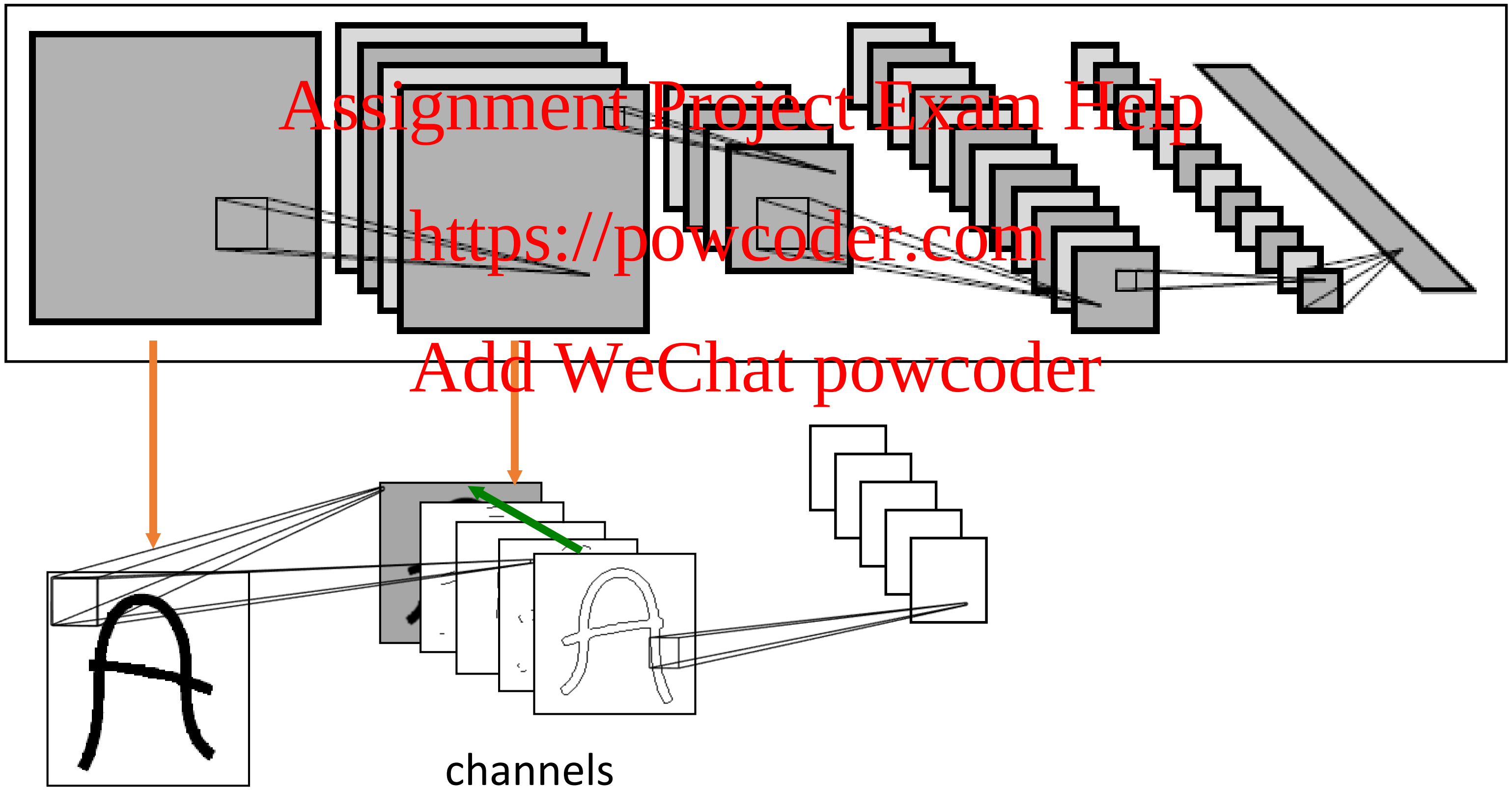

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Pooling layers

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- Convolution with stride > 1 reduces the size of the input
- Another way to downsize the feature map is with pooling
- A pooling layer subsamples the input in each sub-window
  - max-pooling: chose the max in a window
  - mean-pooling: take the average

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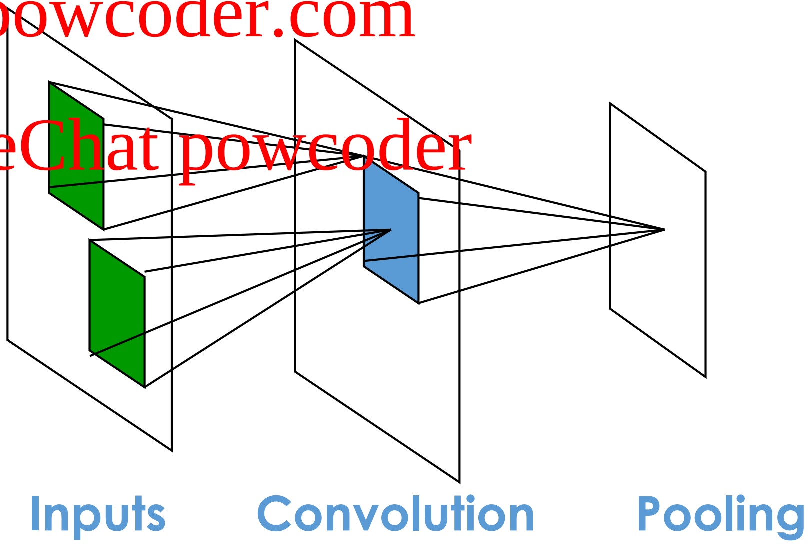

Pooling layer

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- the pooling layers reduce the spatial resolution of each feature map
- Goal is to get a certain degree of shift and distortion invariance

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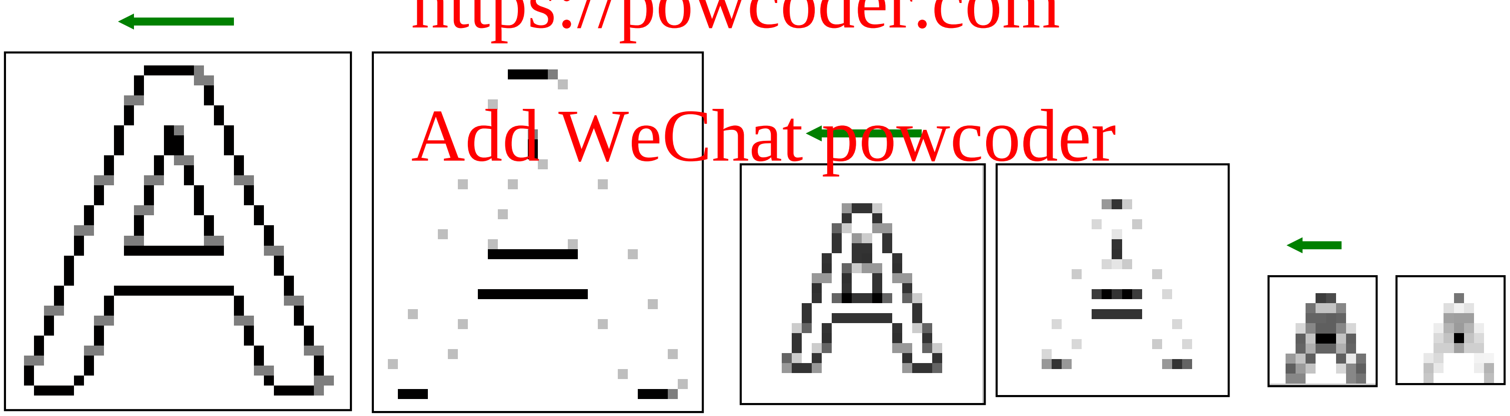

Distortion invariance

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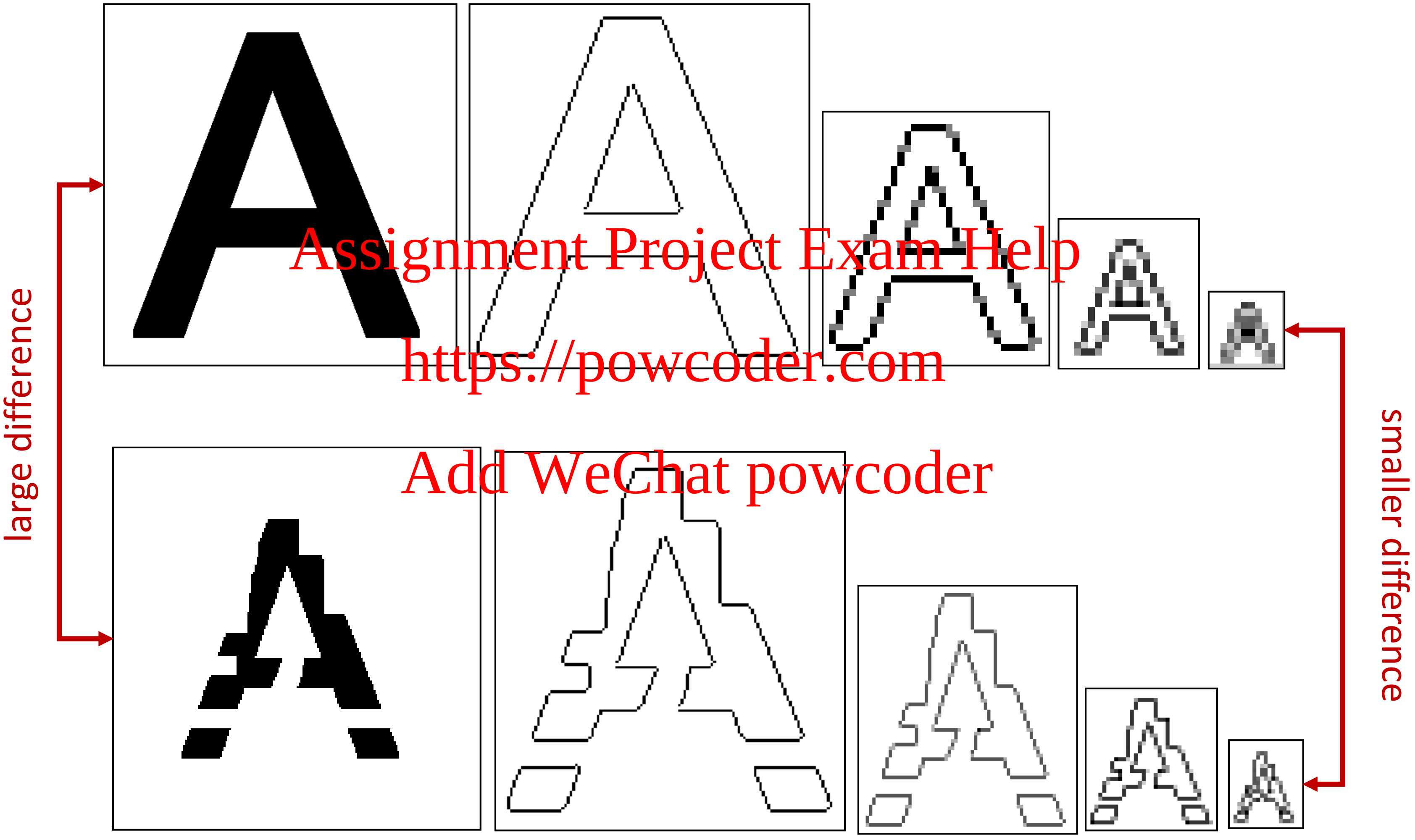

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Pooling layer

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- the weight sharing is also applied in pooling layers
- for mean/max pooling, no weights are needed

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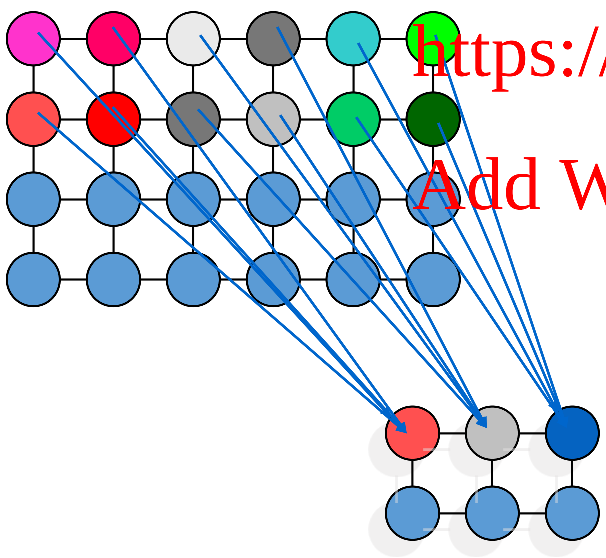
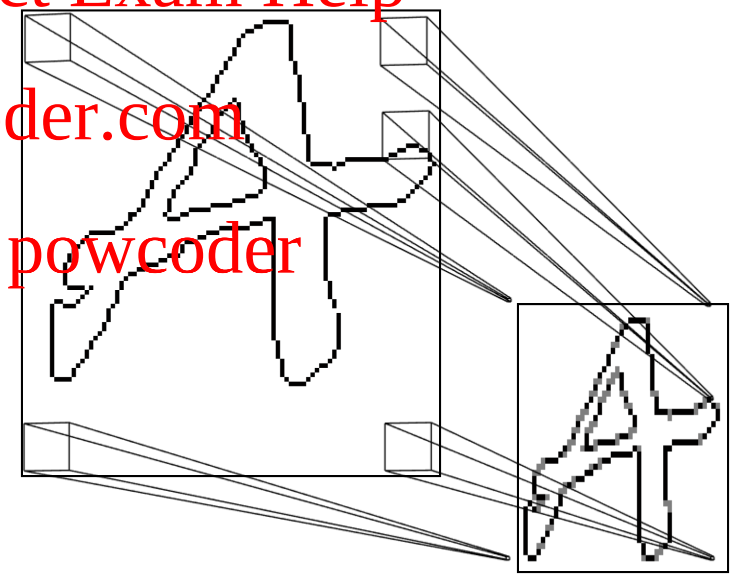
Feature map



Pooled output



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Putting it all together...

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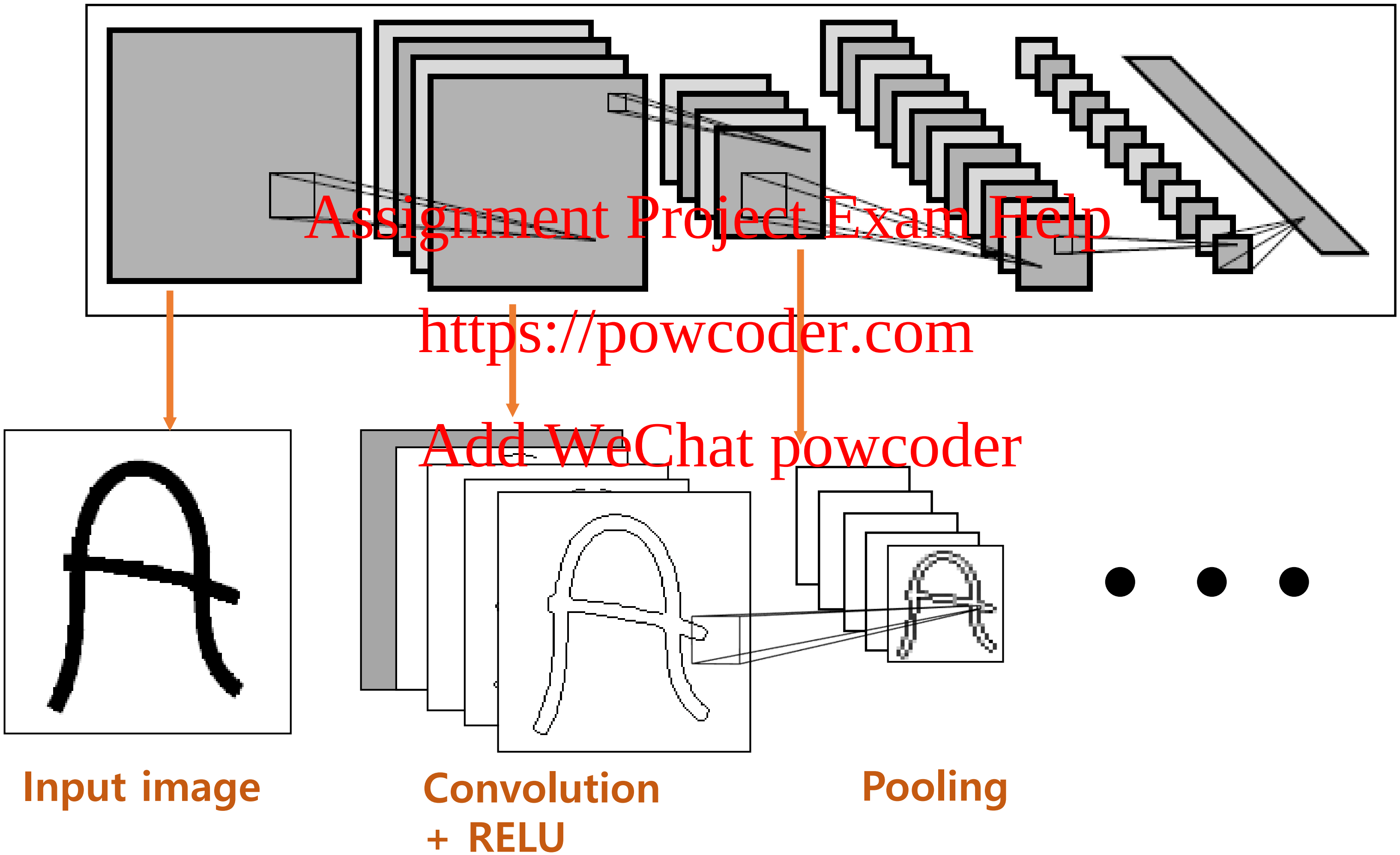

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Convolutional Neural Network

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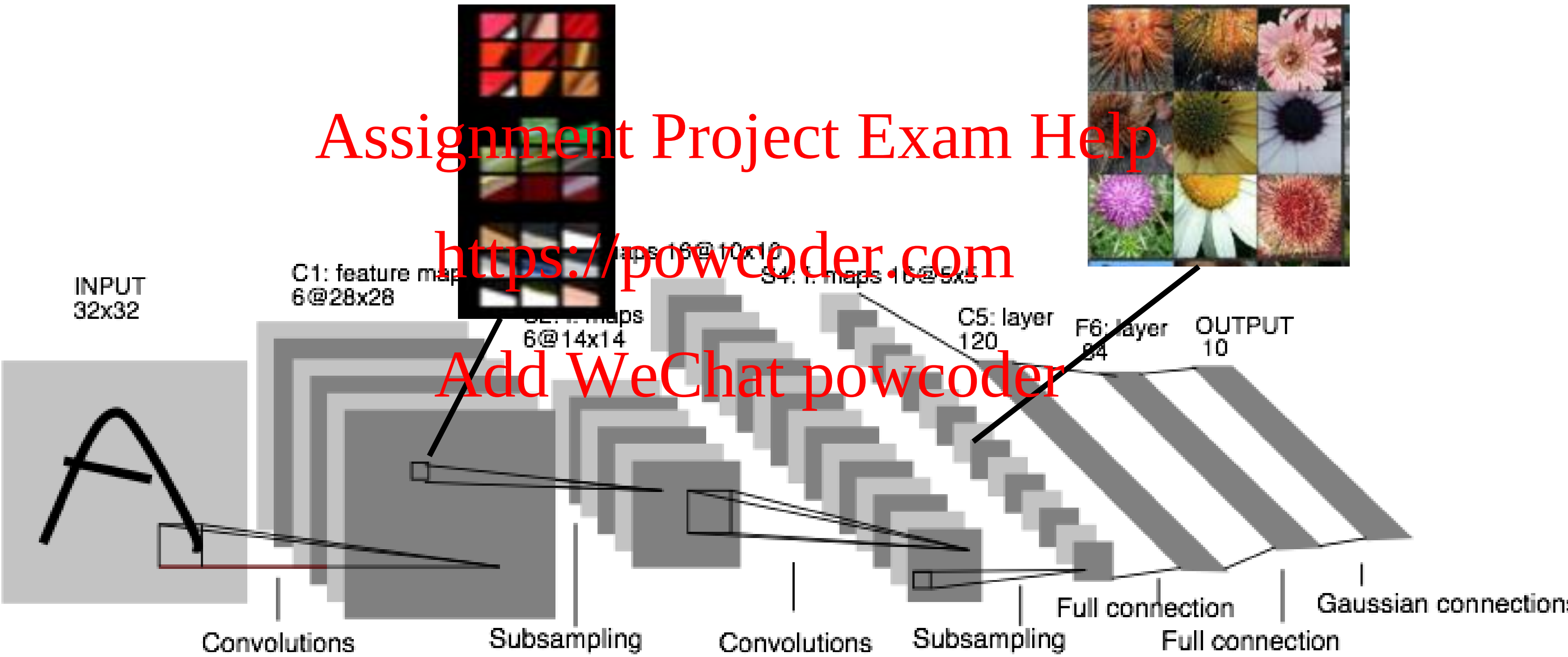
A better architecture for 2d signals



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LeNet

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Deep Convolutional Networks

The Unreasonable Effectiveness of Deep Features

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Maximal activations of pool_5 units [R-CNN]

conv_5 DeConv visualization [Zeiler-Fergus]

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Rich visual structure of features deep in hierarchy.

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Convolutional Neural Nets

Why they rule

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Why CNNs rule: Sparsity

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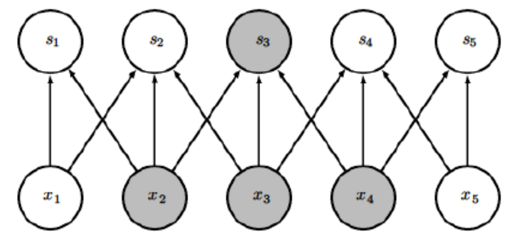
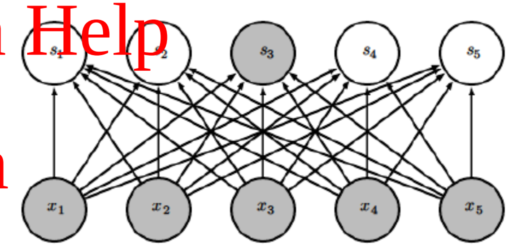
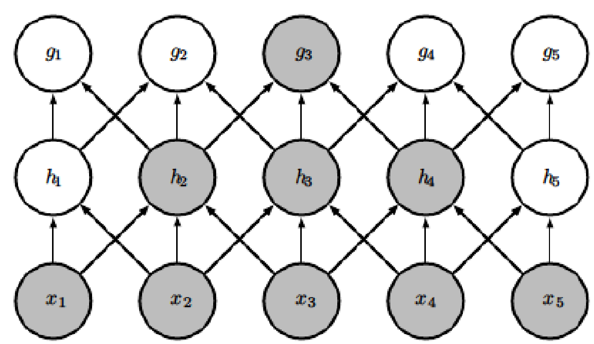
- CNNs have sparse interactions, because the kernel is smaller than the input
- E.g. in thousands or millions pixel image, can detect small meaningful features such as edges
- Very efficient computation!
  - For *m* inputs and *n* outputs, matrix multiplication requires $O(m \times n)$ runtime (per example)
  - For *k* connections to each output, need only $O(k \times n)$ runtime
- Deep layers have larger effective inputs, or receptive fields







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Why CNNs rule: Parameter sharing

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- Kernel weights are shared across all locations
- Statistically efficient – learn from more data
- Memory efficient – store only *k* parameters, since *k*<<*m*, this is much smaller than *m*×*n*.

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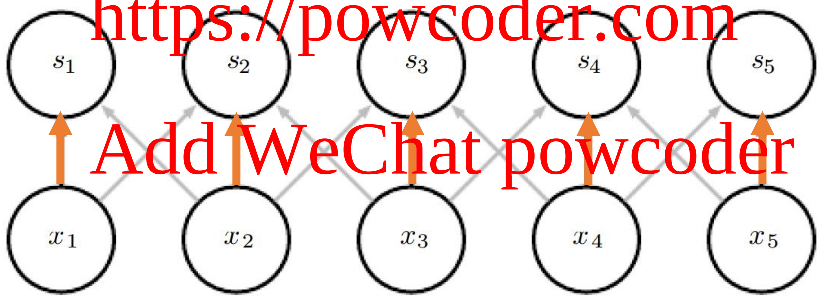
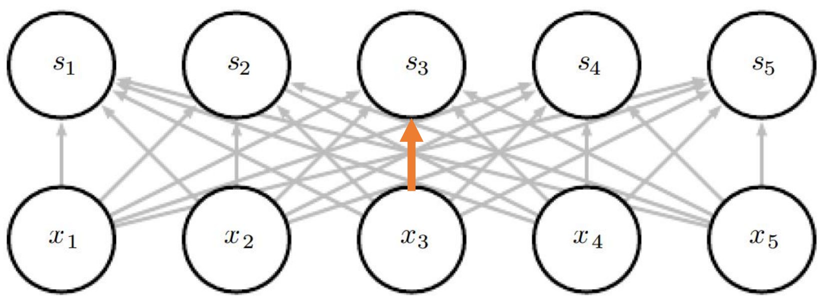


parameter used multiple times



parameter used only once

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Why CNNs rule: Translation invariance

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- Output is invariant to translation of input
  - spatial translation for images
  - temporal translation for time sequences
- useful when some function of a small local window is useful when applied to multiple input locations
- Note, not invariant to other transformations of input, such as large image rotation
- Pooling provides additional invariance to distortions

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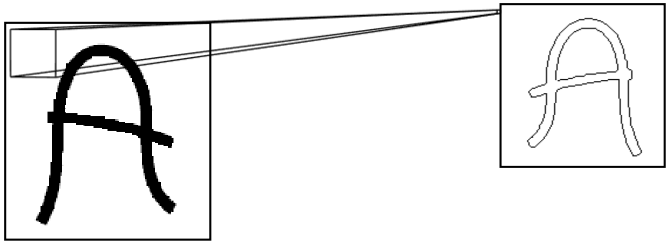

Convolutional Neural Nets

Example

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CIFAR-10 Demo ConvJS Network

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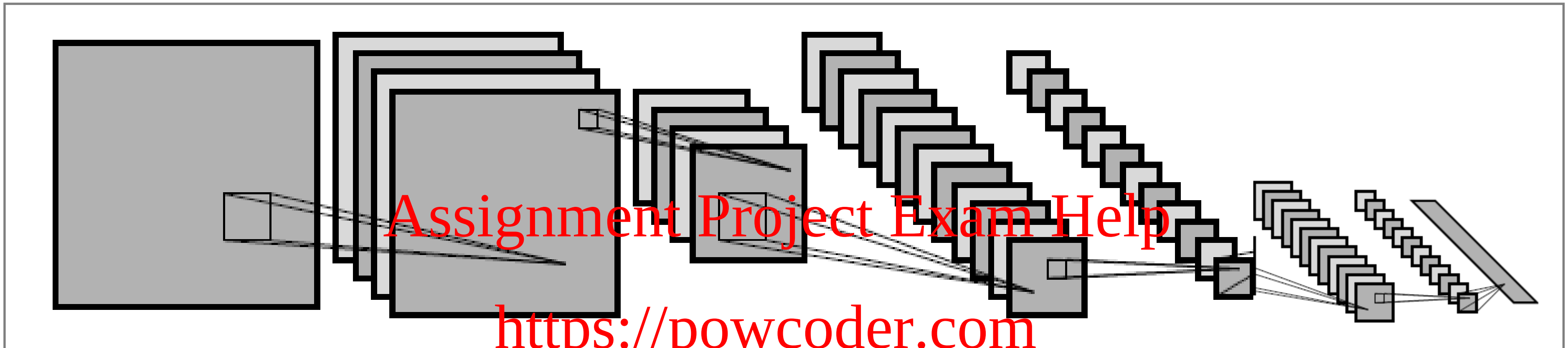
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input image conv RELU pool conv RELU pool conv RELU pool fc

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RELU: rectified linear unit

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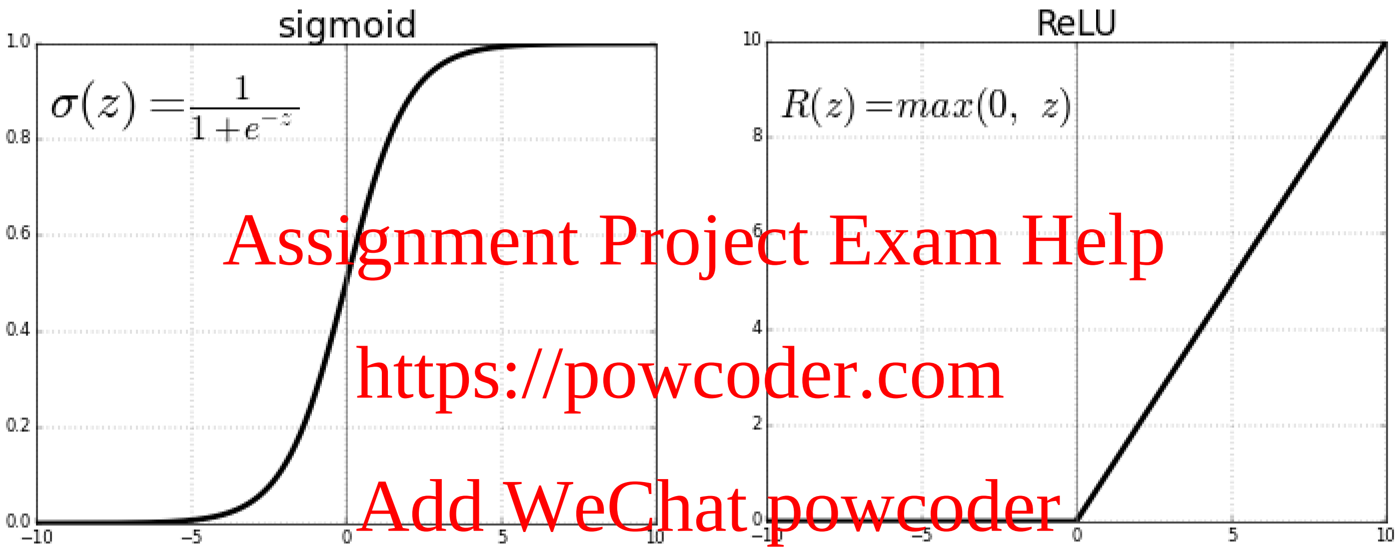

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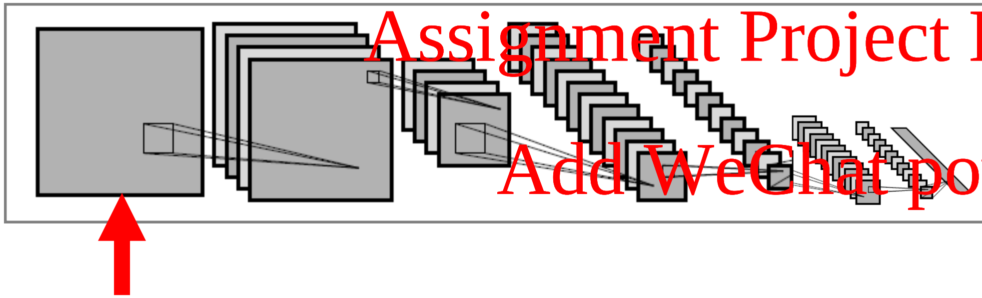
RELU function $\quad g(x) = \max(0, x)$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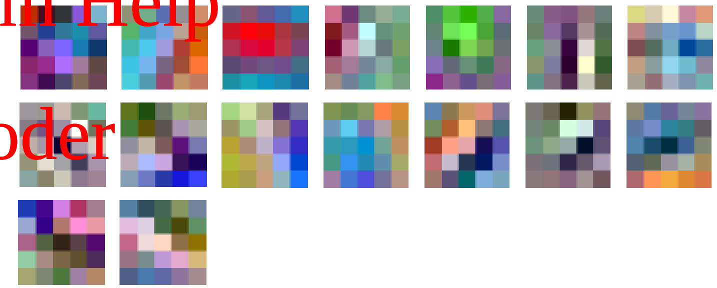
filter size 5x5x3, stride 1



input (32x32x3)

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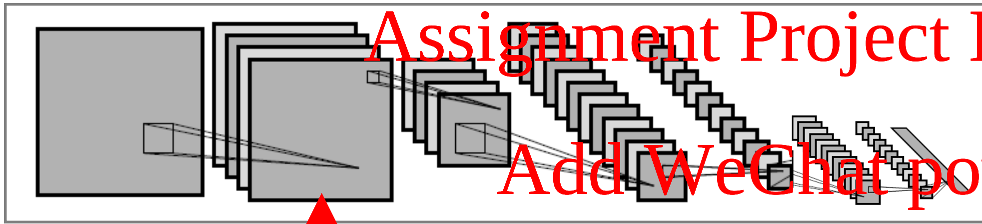
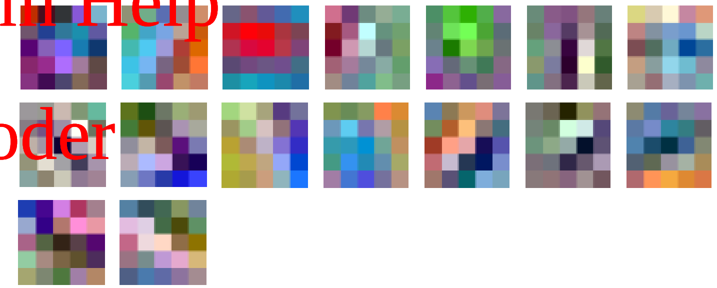


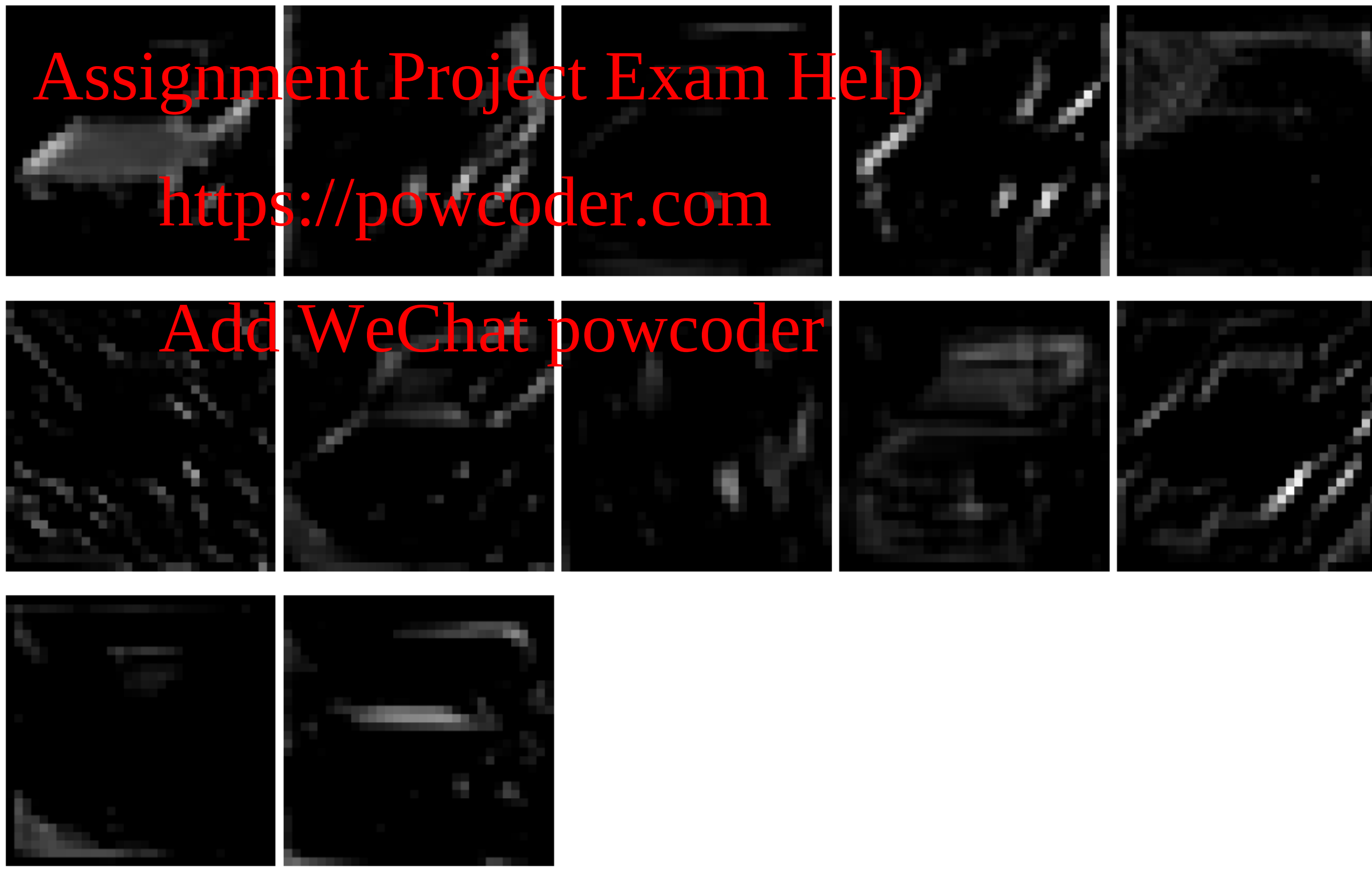
filter size 5x5x3, stride 1



input (32x32x3)

RELU

conv (32x32x16) params: 16x5x5x3+16 = 1216



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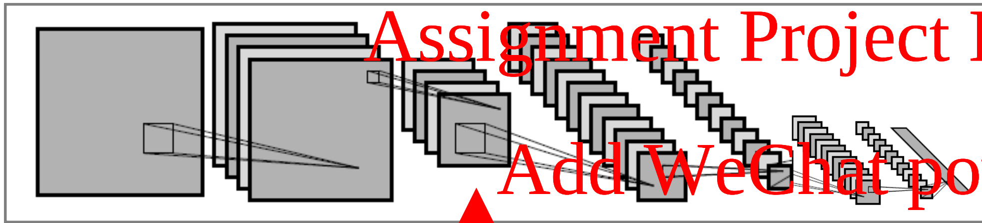
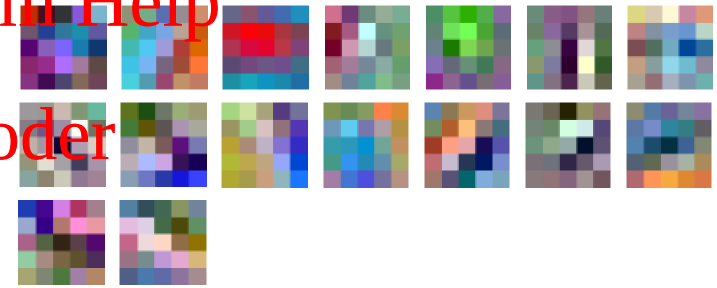
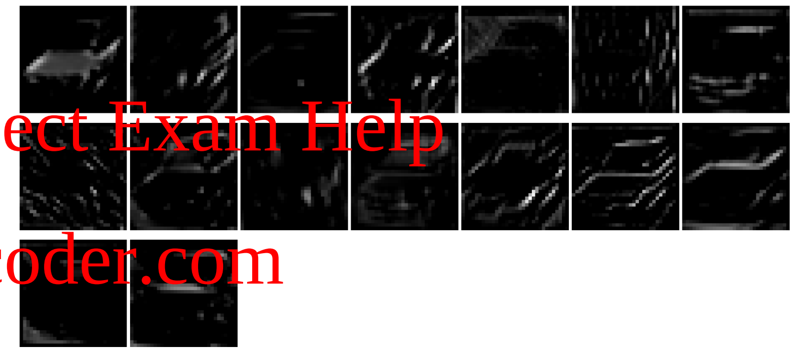


filter size 5x5x3, stride 1



input (32x32x3)

conv (32x32x16) params: 16x5x5x3+16 = 1216



pool (16x16x16)
pooling size 2x2, stride 2

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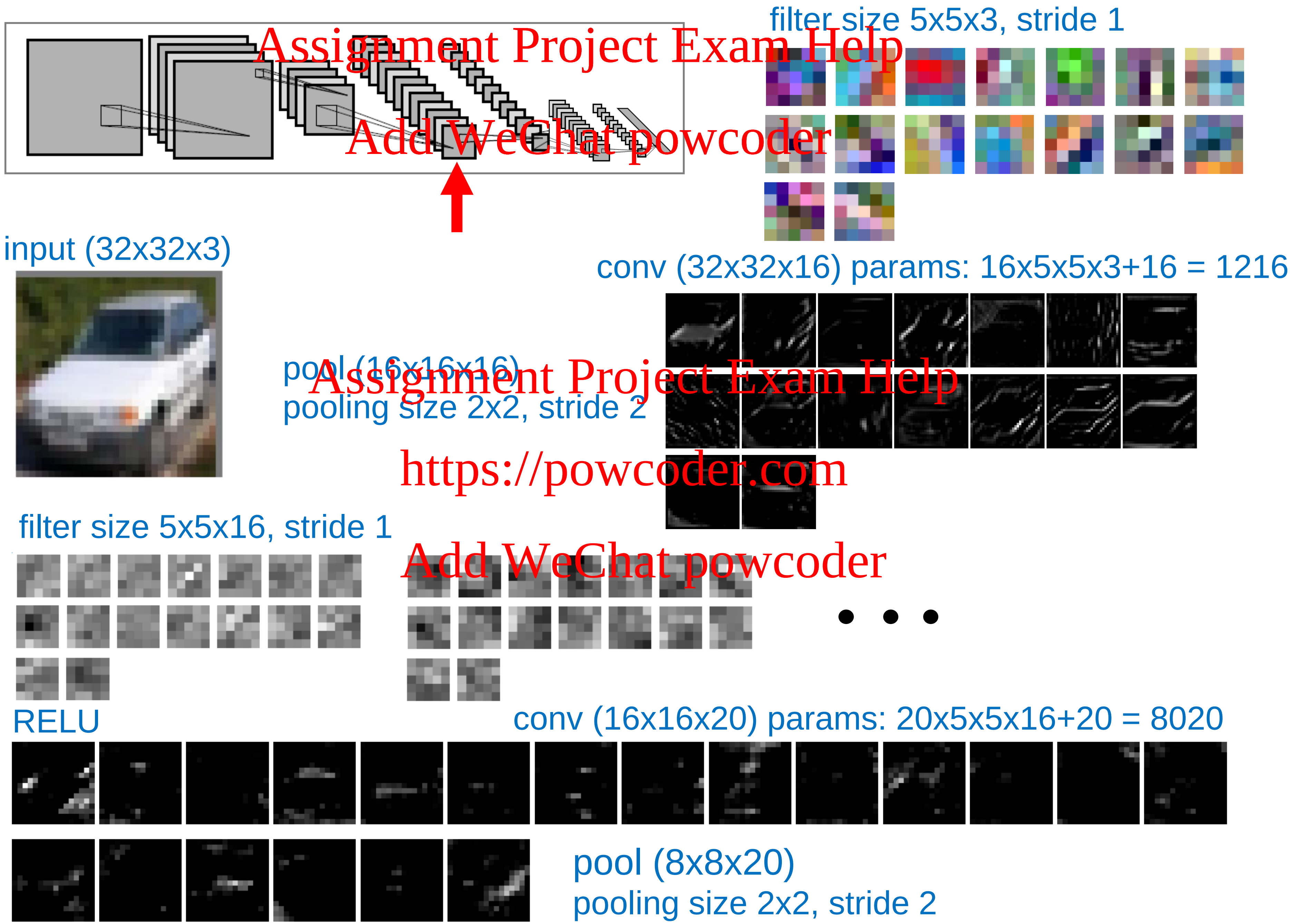

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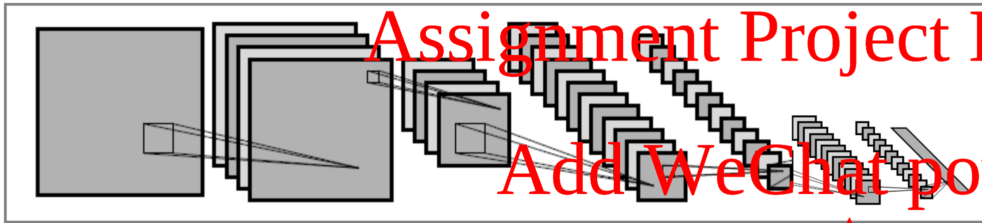

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One more conv+RELU+pool:

conv (8x8x20)
filter size 5x5x20, stride 1
relu (8x8x20)
pool (4x4x20)
pooling size 2x2, stride 2
parameters: 20x5x5x20+20 = 10020

input (32x32x3)

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fc (1x1x10); parameters: 10x320+10 = 3210

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softmax (1x1x10)

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dog car cat ⋮

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Testing the network

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- Show top three most likely classes

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http://cs.stanford.edu/people/karpathy/convnetjs/demo/cifar10.html

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Neural Networks IV: Recurrent Nets:

recurrent networks; training strategies

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