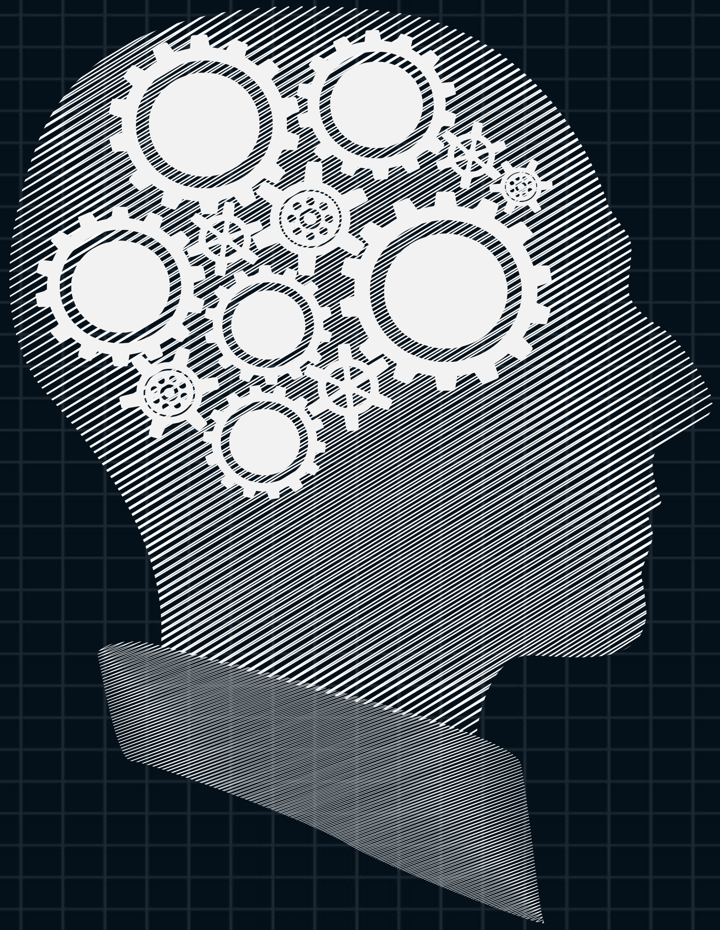


Forward Propagation of Neural Networks

Lecture.5
Conv Layers

- Image Tensors

$$X \in \mathbb{R}^{n_H \times n_W}$$

$$X = \begin{pmatrix} X[0,0] & X[0,1] & \dots & X[0,n_W-1] \\ X[1,0] & X[1,1] & \dots & X[1,n_W-1] \\ \vdots & \vdots & \ddots & \vdots \\ X[n_H-1,0] & X[n_H-1,1] & \dots & X[n_H-1,n_W-1] \end{pmatrix}$$

Lecture.5
Conv Layers

- Image Tensors

$$X \in \mathbb{R}^{n_H \times n_W}$$

$$X \in \mathbb{R}^{n_H \times n_W \times n_C}$$

$$X \in \mathbb{R}^{N \times n_H \times n_W \times n_C}$$

Classical Correlation

$X \in \mathbb{R}^{n_H \times n_W}$, $\mathcal{F} \in \mathbb{R}^{n_H \times n_W}$, $z \in \mathbb{R}$

$$z = X \otimes \mathcal{F} = \sum_{i=0}^{n_H-1} \sum_{j=0}^{n_W-1} X[i,j]\mathcal{F}[i,j]$$

$$X \otimes \mathcal{F} : \mathbb{R}^{n_H \times n_W} \times \mathbb{R}^{n_H \times n_W} \to \mathbb{R}$$

$n_H = 3$

$n_W = 3$

$X[0,0]$	$X[0,1]$	$X[0,2]$
$X[1,0]$	$X[1,1]$	$X[1,2]$
$X[2,0]$	$X[2,1]$	$X[2,2]$

$X \in \mathbb{R}^{3\times3}$

$\mathcal{F}[0,0]$	$\mathcal{F}[0,1]$	$\mathcal{F}[0,2]$
$\mathcal{F}[1,0]$	$\mathcal{F}[1,1]$	$\mathcal{F}[1,2]$
$\mathcal{F}[2,0]$	$\mathcal{F}[2,1]$	$\mathcal{F}[2,2]$

$\mathcal{F} \in \mathbb{R}^{3\times3}$

$$\begin{aligned} z &= X \otimes \mathcal{F} \\ &= \sum_{i=0}^{2} \sum_{j=0}^{2} X[i,j]\mathcal{F}[i,j] \\ &= X[0,0]\mathcal{F}[0,0] + X[0,1]\mathcal{F}[0,1] + X[0,2]\mathcal{F}[0,2] + \\ &\quad X[1,0]\mathcal{F}[1,0] + X[1,1]\mathcal{F}[1,1] + X[1,2]\mathcal{F}[1,2] + \\ &\quad X[2,0]\mathcal{F}[2,0] + X[2,1]\mathcal{F}[2,1] + X[2,2]\mathcal{F}[2,2] \end{aligned}$$

Correlation with Bias

$X \in \mathbb{R}^{n_H \times n_W}, \mathscr{F} \in \mathbb{R}^{n_H \times n_W}, b \in \mathbb{R}, z \in \mathbb{R}$

$$z = X \otimes \mathscr{F} + b = \sum_{i=0}^{n_H-1} \sum_{j=0}^{n_W-1} X[i,j]\mathscr{F}[i,j] + b$$

$$X \otimes \mathscr{F} + b : \mathbb{R}^{n_H \times n_W} \times \mathbb{R}^{n_H \times n_W} \times \mathbb{R} \to \mathbb{R}$$

$X[0,0]$	$X[0,1]$	$X[0,2]$
$X[1,0]$	$X[1,1]$	$X[1,2]$
$X[2,0]$	$X[2,1]$	$X[2,2]$

$X \in \mathbb{R}^{3\times 3}$

$\mathscr{F}[0,0]$	$\mathscr{F}[0,1]$	$\mathscr{F}[0,2]$
$\mathscr{F}[1,0]$	$\mathscr{F}[1,1]$	$\mathscr{F}[1,2]$
$\mathscr{F}[2,0]$	$\mathscr{F}[2,1]$	$\mathscr{F}[2,2]$

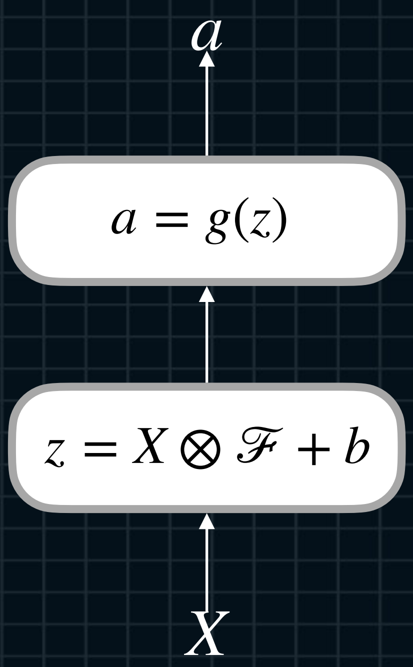
$\mathscr{F} \in \mathbb{R}^{3\times 3}$

$b \in \mathbb{R}$

$$\begin{aligned} z &= X \otimes \mathscr{F} + b \\ &= \sum_{i=0}^{2} \sum_{j=0}^{2} X[i,j]\mathscr{F}[i,j] + b \\ &= X[0,0]\mathscr{F}[0,0] + X[0,1]\mathscr{F}[0,1] + X[0,2]\mathscr{F}[0,2] + \\ &\quad X[1,0]\mathscr{F}[1,0] + X[1,1]\mathscr{F}[1,1] + X[1,2]\mathscr{F}[1,2] + \\ &\quad X[2,0]\mathscr{F}[2,0] + X[2,1]\mathscr{F}[2,1] + X[2,2]\mathscr{F}[2,2] + b \end{aligned}$$

Correlation with Activation

$X \in \mathbb{R}^{n_H \times n_W}$, $\mathcal{F} \in \mathbb{R}^{n_H \times n_W}$, $b \in \mathbb{R}$, $z \in \mathbb{R}$, $a \in \mathbb{R}$



$$
\begin{aligned}
z &= X \otimes \mathcal{F} + b \\
&= \sum_{i=0}^{2} \sum_{j=0}^{2} X[i,j]\mathcal{F}[i,j] + b \\
&= X[0,0]\mathcal{F}[0,0] + X[0,1]\mathcal{F}[0,1] + X[0,2]\mathcal{F}[0,2] + \\
&\quad\ X[1,0]\mathcal{F}[1,0] + X[1,1]\mathcal{F}[1,1] + X[1,2]\mathcal{F}[1,2] + \\
&\quad\ X[2,0]\mathcal{F}[2,0] + X[2,1]\mathcal{F}[2,1] + X[2,2]\mathcal{F}[2,2] + b
\end{aligned}
$$

$$a = g(z)$$

Correlation and Dot Product

$$\sum_{i=0}^{n_H-1}\sum_{j=0}^{n_W-1} X[i,j]\mathcal{F}[i,j] + b = \left(flattn(x)\right)^T flatten(\mathcal{F}) + b$$

$A[0,0]$	$A[0,1]$	$A[0,2]$
$A[1,0]$	$A[1,1]$	$A[1,2]$
$A[2,0]$	$A[2,1]$	$A[2,2]$

$X \in \mathbb{R}^{3\times 3}$

Flatten $\longrightarrow$

$A[0,0]$	$A[0,1]$	$A[0,2]$	$A[1,0]$	$A[1,1]$	$A[1,2]$	$A[2,0]$	$A[2,1]$	$A[2,2]$

$flatten(X) \in \mathbb{R}^9$

$\mathcal{F}[0,0]$	$\mathcal{F}[0,1]$	$\mathcal{F}[0,2]$
$\mathcal{F}[1,0]$	$\mathcal{F}[1,1]$	$\mathcal{F}[1,2]$
$\mathcal{F}[2,0]$	$\mathcal{F}[2,1]$	$\mathcal{F}[2,2]$

$\mathcal{F} \in \mathbb{R}^{3\times 3}$

Flatten $\longrightarrow$

$\mathcal{F}[0,0]$	$\mathcal{F}[0,1]$	$\mathcal{F}[0,2]$	$\mathcal{F}[1,0]$	$\mathcal{F}[1,1]$	$\mathcal{F}[1,2]$	$\mathcal{F}[2,0]$	$\mathcal{F}[2,1]$	$\mathcal{F}[2,2]$

$flatten(\mathcal{F}) \in \mathbb{R}^9$

- Window Extraction

Windows(1D)

$$\overrightarrow{x} = (x_0 \quad x_1 \quad x_2 \quad x_3 \quad x_4 \quad x_5)$$

$$\mathscr{W}_0 = X[0:3] = (x_0 \quad x_1 \quad x_2) \qquad \mathscr{W}_1 = X[1:4] = (x_1 \quad x_2 \quad x_3)$$

$$\mathscr{W}_2 = X[2:5] = (x_2 \quad x_3 \quad x_4) \qquad \mathscr{W}_3 = X[3:6] = (x_3 \quad x_4 \quad x_5)$$

$$\mathscr{W}_i = \left(\overrightarrow{x}_i \quad \overrightarrow{x}_{i+1} \quad \overrightarrow{x}_{i+2}\right)$$

- Window Extraction

Windows(2D)

$$X = \begin{pmatrix} X[0,0] & X[0,1] & X[0,2] & X[0,3] \\ X[1,0] & X[1,1] & X[1,2] & X[1,3] \\ X[2,0] & X[2,1] & X[2,2] & X[2,3] \\ X[3,0] & X[3,1] & X[3,2] & X[3,3] \end{pmatrix}$$

$$\mathscr{W}_{i,j} = \begin{pmatrix} X[i,j] & X[i,j+1] & X[i,j+2] \\ X[i+1,j] & X[i+1,j+1] & X[i+1,j+2] \\ X[i+2,j] & X[i+2,j+1] & X[i+2,j+2] \end{pmatrix}$$

$$\mathscr{W}_{0,0} = X[0:3, 0:3] = \begin{pmatrix} X[0,0] & X[0,1] & X[0,2] \\ X[1,0] & X[1,1] & X[1,2] \\ X[2,0] & X[2,1] & X[2,2] \end{pmatrix}$$

$$\mathscr{W}_{0,1} = X[0:3, 1:4] = \begin{pmatrix} X[0,1] & X[0,2] & X[0,3] \\ X[1,1] & X[1,2] & X[1,3] \\ X[2,1] & X[2,2] & X[2,3] \end{pmatrix}$$

$$\mathscr{W}_{1,0} = X[1:4, 0:3] = \begin{pmatrix} X[1,0] & X[1,1] & X[1,2] \\ X[2,0] & X[2,1] & X[2,2] \\ X[3,0] & X[3,1] & X[3,2] \end{pmatrix}$$

$$\mathscr{W}_{1,1} = X[1:4, 1:4] = \begin{pmatrix} X[1,1] & X[1,2] & X[1,3] \\ X[2,1] & X[2,2] & X[2,3] \\ X[3,1] & X[3,2] & X[3,3] \end{pmatrix}$$

- Window Extraction

Window Formularization

$X \in \mathbb{R}^{n_H \times n_W}$, $\mathscr{W}_{i,j} \in \mathbb{R}^{f \times f}$

$$X = \begin{pmatrix} X[0,0] & X[0,1] & \dots & X[0, n_W - f] & \dots & X[0, n_W - 1] \\ X[1,0] & X[1,1] & \dots & X[1, n_W - f] & \dots & X[1, n_W - 1] \\ \vdots & \vdots & \ddots & \vdots & \ddots & \vdots \\ X[n_H - f, 0] & X[n_H - f, 1] & \dots & X[n_H - f, n_W - f] & \dots & X[n_H - f, n_W - 1] \\ \vdots & \vdots & \ddots & \vdots & \ddots & \vdots \\ X[n_H - 1, 0] & X[n_H - 1, 1] & \dots & X[n_H - 1, n_W - f] & \dots & X[n_H - 1, n_W - 1] \end{pmatrix}$$

$$\mathscr{W}_{i,j} = X\big[i : i+f, j : j+f\big] = \begin{pmatrix} X[i,j] & X[i, j+1] & \dots & X[i, j+(f-1)] \\ X[i+1, j] & X[i+1, j+1] & \dots & X[i+1, j+(f-1)] \\ \vdots & \vdots & \ddots & \vdots \\ X[i+(f-1), j] & X[i+(f-1), j+1] & \dots & X[i+(f-1), j+(f-1)] \end{pmatrix}$$

$$0 \le i \le n_H - f, \quad 0 \le j \le n_W - f$$

Lecture.5
Conv Layers

- Computations of Conv Layer

$$(\vec{z})^T = (z_1 \quad z_1 \quad z_2 \quad z_3)$$

$z_0 = \mathscr{W}_0 \otimes \mathscr{K} + b$

$z_1 = \mathscr{W}_1 \otimes \mathscr{K} + b$

$z_2 = \mathscr{W}_1 \otimes \mathscr{K} + b$

$z_3 = \mathscr{W}_3 \otimes \mathscr{K} + b$

$$\mathscr{K} = \begin{pmatrix} k_0 & k_1 & k_2 \end{pmatrix}$$

$$b$$

$\mathscr{W}_0 = (x_0 \quad x_1 \quad x_2)$

$\mathscr{W}_1 = (x_1 \quad x_2 \quad x_3)$

$\mathscr{W}_2 = (x_2 \quad x_3 \quad x_4)$

$\mathscr{W}_3 = (x_3 \quad x_4 \quad x_5)$

$$\vec{x} = (\boxed{x_0 \quad x_1 \quad x_2} \quad x_3 \quad x_4 \quad x_5)$$

Lecture.5
Conv Layers

- Computations of Conv Layer

$$X = \begin{pmatrix} X[0,0] & X[0,1] & X[0,2] & X[0,3] \\ X[1,0] & X[1,1] & X[1,2] & X[1,3] \\ X[2,0] & X[2,1] & X[2,2] & X[2,3] \\ X[3,0] & X[3,1] & X[3,2] & X[3,3] \end{pmatrix}$$

$$\mathscr{W}_{0,0} = \begin{pmatrix} X[0,0] & X[0,1] & X[0,2] \\ X[1,0] & X[1,1] & X[1,2] \\ X[2,0] & X[2,1] & X[2,2] \end{pmatrix} \qquad \mathscr{W}_{0,1} = \begin{pmatrix} X[0,1] & X[0,2] & X[0,3] \\ X[1,1] & X[1,2] & X[1,3] \\ X[2,1] & X[2,2] & X[2,3] \end{pmatrix}$$

$$\mathscr{W}_{1,0} = \begin{pmatrix} X[1,0] & X[1,1] & X[1,2] \\ X[2,0] & X[2,1] & X[2,2] \\ X[3,0] & X[3,1] & X[3,2] \end{pmatrix} \qquad \mathscr{W}_{1,1} = \begin{pmatrix} X[1,1] & X[1,2] & X[1,3] \\ X[2,1] & X[2,2] & X[2,3] \\ X[3,1] & X[3,2] & X[3,3] \end{pmatrix}$$

$$\mathscr{K} = \begin{pmatrix} \mathscr{K}[0,0] & \mathscr{K}[0,1] & \mathscr{K}[0,2] \\ \mathscr{K}[1,0] & \mathscr{K}[1,1] & \mathscr{K}[1,2] \\ \mathscr{K}[2,0] & \mathscr{K}[2,1] & \mathscr{K}[2,2] \end{pmatrix} \quad b$$

$$Z[0,0] = \mathscr{W}_{0,0} \otimes \mathscr{K} + b \qquad Z[0,1] = \mathscr{W}_{0,1} \otimes \mathscr{K} + b$$

$$Z[1,0] = \mathscr{W}_{0,1} \otimes \mathscr{K} + b \qquad Z[1,1] = \mathscr{W}_{1,1} \otimes \mathscr{K} + b$$

$$Z = \begin{pmatrix} Z[0,0] & Z[0,1] \\ Z[1,0] & Z[1,1] \end{pmatrix}$$

- Computations of Conv Layer

$$X \in \mathbb{R}^{n_H \times n_W}$$
$$\mathscr{W}_{i,j} \in \mathbb{R}^{f \times f}$$

$$\mathscr{K} \in \mathbb{R}^{f \times f}, b \in \mathbb{R}$$

$$Z[i,j] = \mathscr{W}_{i,j} \otimes \mathscr{K} + b$$

$$Z = Conv2D(X; \mathscr{K}, b) = \begin{pmatrix} \mathscr{W}_{0,0} \otimes \mathscr{K} + b & \mathscr{W}_{0,1} \otimes \mathscr{K} + b & \dots & \mathscr{W}_{0,n_W-f} \otimes \mathscr{K} + b \\ \mathscr{W}_{1,0} \otimes \mathscr{K} + b & \mathscr{W}_{1,1} \otimes \mathscr{K} + b & \dots & \mathscr{W}_{1,n_W-f} \otimes \mathscr{K} + b \\ \vdots & \vdots & \ddots & \vdots \\ \mathscr{W}_{n_H-f,0} \otimes \mathscr{K} + b & \mathscr{W}_{n_H-f,1} \otimes \mathscr{K} + b & \dots & \mathscr{W}_{n_H-f,n_W-f} \otimes \mathscr{K} + b \end{pmatrix}$$

$$n'_H = n_H - f + 1$$
$$n'_W = n_W - f + 1$$

- Computations of Conv Layer

$$Z[i,j] = \mathscr{W}_{i,j} \otimes \mathscr{K} + b$$

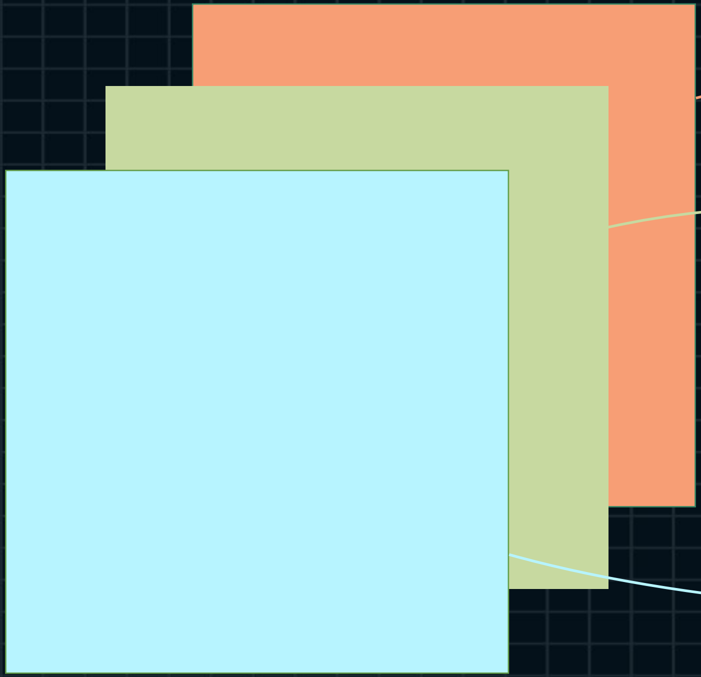
$$A[i,j] = \sigma\big(Z[i,j]\big)$$

$$A = Conv2D(X;\ \mathscr{K}, b;\ \sigma) = \begin{pmatrix} \sigma\big(\mathscr{W}_{0,0} \otimes \mathscr{K} + b\big) & \sigma\big(\mathscr{W}_{0,1} \otimes \mathscr{K} + b\big) & \dots & \sigma\big(\mathscr{W}_{0,n_W-f} \otimes \mathscr{K} + b\big) \\ \sigma\big(\mathscr{W}_{1,0} \otimes \mathscr{K} + b\big) & \sigma\big(\mathscr{W}_{1,1} \otimes \mathscr{K} + b\big) & \dots & \sigma\big(\mathscr{W}_{1,n_W-f} \otimes \mathscr{K} + b\big) \\ \vdots & \vdots & \ddots & \vdots \\ \sigma\big(\mathscr{W}_{n_H-f,0} \otimes \mathscr{K} + b\big) & \sigma\big(\mathscr{W}_{n_H-f,1} \otimes \mathscr{K} + b\big) & \dots & \sigma\big(\mathscr{W}_{n_H-f,n_W-f} \otimes \mathscr{K} + b\big) \end{pmatrix}$$

Lecture.5
Conv Layers

- n-Channel Input

$$X \in \mathbb{R}^{n_H \times n_W \times n_C}$$



$$X[:,:,0] = \begin{pmatrix} X[0,0,0] & X[0,1,0] & \dots & X[0,n_W-1,0] \\ X[1,0,0] & X[1,1,0] & \dots & X[1,n_W-1,0] \\ \vdots & \vdots & \ddots & \vdots \\ X[n_H-1,0,0] & X[n_H-1,1,0] & \dots & X[n_H-1,n_W-1,0] \end{pmatrix}$$

$$X[:,:,1] = \begin{pmatrix} X[0,0,1] & X[0,1,1] & \dots & X[0,n_W-1,1] \\ X[1,0,1] & X[1,1,1] & \dots & X[1,n_W-1,1] \\ \vdots & \vdots & \ddots & \vdots \\ X[n_H-1,0,1] & X[n_H-1,1,1] & \dots & X[n_H-1,n_W-1,1] \end{pmatrix}$$

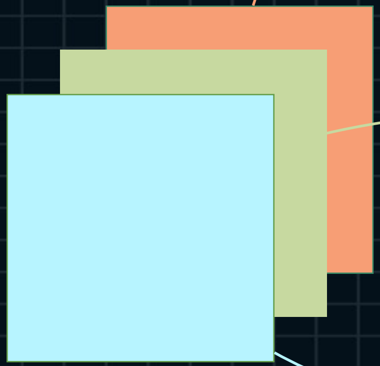
$$X[:,:,2] = \begin{pmatrix} X[0,0,2] & X[0,1,2] & \dots & X[0,n_W-1,2] \\ X[1,0,2] & X[1,1,2] & \dots & X[1,n_W-1,2] \\ \vdots & \vdots & \ddots & \vdots \\ X[n_H-1,0,2] & X[n_H-1,1,2] & \dots & X[n_H-1,n_W-1,2] \end{pmatrix}$$

Lecture.5
Conv Layers

- n-Channel Input

$$f = 3,\ n_C = 3$$

$$\mathscr{W}_{i,\,j} \in \mathbb{R}^{3\times3\times3}$$



$$\mathscr{W}_{i,j} = X[i:i+f, j:j+f, 0]$$

$$= \begin{pmatrix} X[i,\,j,\,0] & X[i,\,j+1,\,0] & X[i,\,j+2,\,0] \\ X[i+1,\,j,\,0] & X[i+1,\,j+1,\,0] & X[i+1,\,j+2,\,0] \\ X[i+2,\,j,\,0] & X[i+2,\,j+1,\,0] & X[i+2,\,j+2,\,0] \end{pmatrix}$$

$$\mathscr{W}_{i,j} = X[i:i+f, j:j+f, 1]$$

$$= \begin{pmatrix} X[i,\,j,\,1] & X[i,\,j+1,\,1] & X[i,\,j+2,\,1] \\ X[i+1,\,j,\,1] & X[i+1,\,j+1,\,1] & X[i+1,\,j+2,\,1] \\ X[i+2,\,j,\,1] & X[i+2,\,j+1,\,1] & X[i+2,\,j+2,\,1] \end{pmatrix}$$

$$\mathscr{W}_{i,j} = X[i:i+f, j:j+f, 2]$$

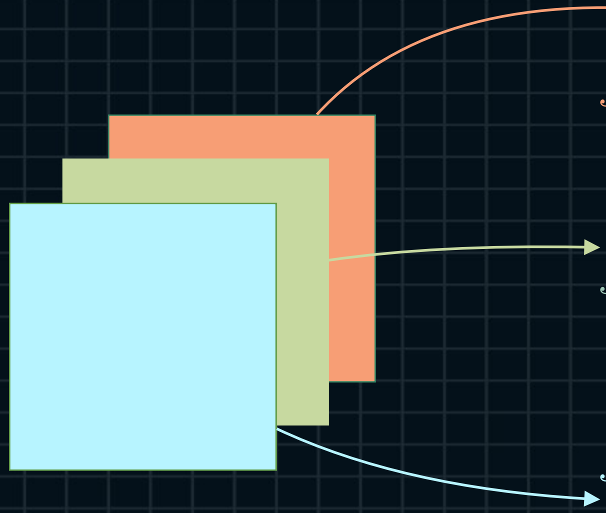
$$= \begin{pmatrix} X[i,\,j,\,2] & X[i,\,j+1,\,2] & X[i,\,j+2,\,2] \\ X[i+1,\,j,\,2] & X[i+1,\,j+1,\,2] & X[i+1,\,j+2,\,2] \\ X[i+2,\,j,\,2] & X[i+2,\,j+1,\,2] & X[i+2,\,j+2,\,2] \end{pmatrix}$$

Lecture.5
Conv Layers

- n-Channel Input

$$f = 3,\ n_C = 3$$

$$\mathscr{K}_{i,j} \in \mathbb{R}^{3\times3\times3}$$



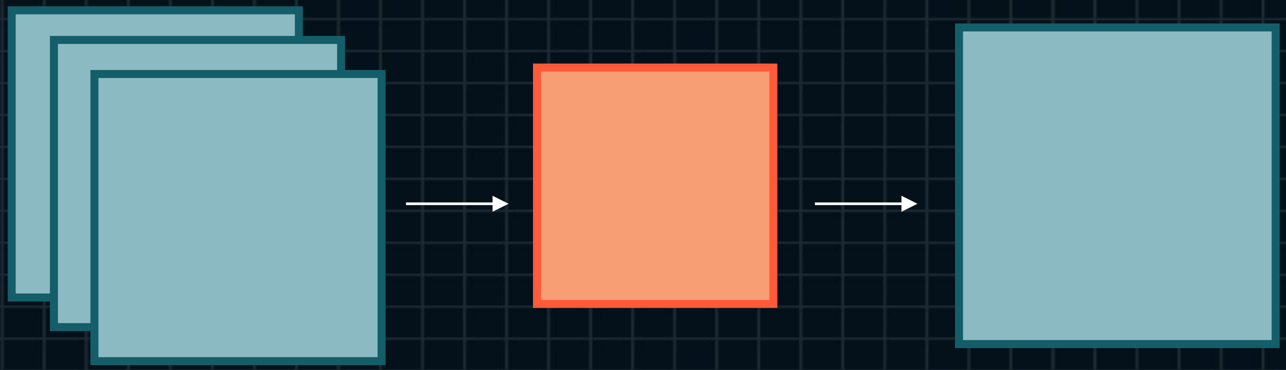
$$\mathscr{K}[:,:,0] = \begin{pmatrix} \mathscr{K}[0,0,0] & \mathscr{K}[0,1,0] & \mathscr{K}[0,2,0] \\ \mathscr{K}[1,0,0] & \mathscr{K}[1,1,0] & \mathscr{K}[1,2,0] \\ \mathscr{K}[2,0,0] & \mathscr{K}[2,1,0] & \mathscr{K}[2,2,0] \end{pmatrix}$$

$$\mathscr{K}[:,:,1] = \begin{pmatrix} \mathscr{K}[0,0,1] & \mathscr{K}[0,1,1] & \mathscr{K}[0,2,1] \\ \mathscr{K}[1,0,1] & \mathscr{K}[1,1,1] & \mathscr{K}[1,2,1] \\ \mathscr{K}[2,0,1] & \mathscr{K}[2,1,1] & \mathscr{K}[2,2,1] \end{pmatrix}$$

$$\mathscr{K}[:,:,2] = \begin{pmatrix} \mathscr{K}[0,0,2] & \mathscr{K}[0,1,2] & \mathscr{K}[0,2,2] \\ \mathscr{K}[1,0,2] & \mathscr{K}[1,1,2] & \mathscr{K}[1,2,2] \\ \mathscr{K}[2,0,2] & \mathscr{K}[2,1,2] & \mathscr{K}[2,2,2] \end{pmatrix}$$

Lecture.5
Conv Layers

- Conv Layers



$X \in \mathbb{R}^{n_H^{[l]} \times n_W^{[l]} \times 3}$

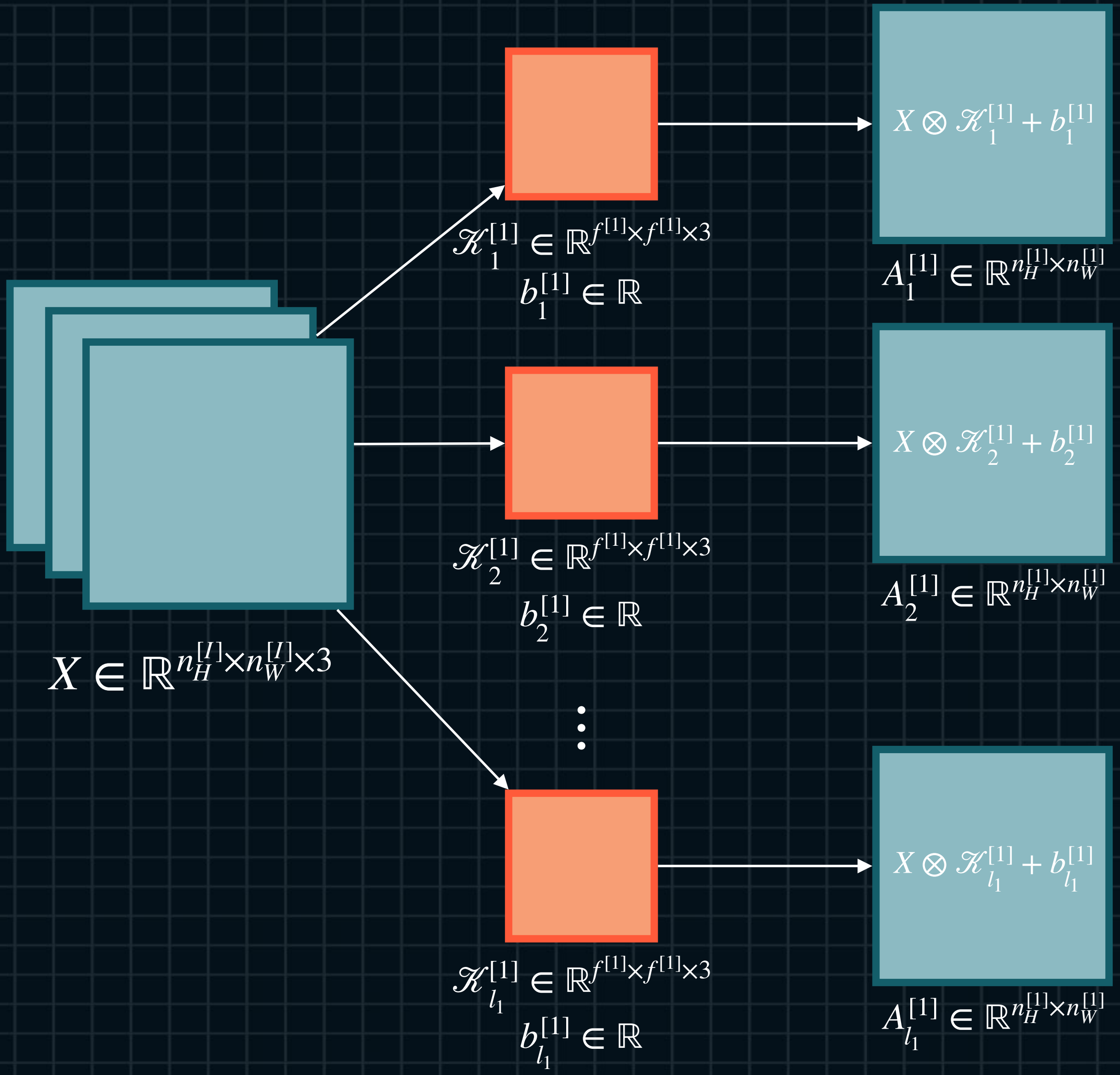
$\mathscr{K}^{[1]} \in \mathbb{R}^{f^{[1]} \times f^{[1]} \times 3}$

$b^{[1]} \in \mathbb{R}$

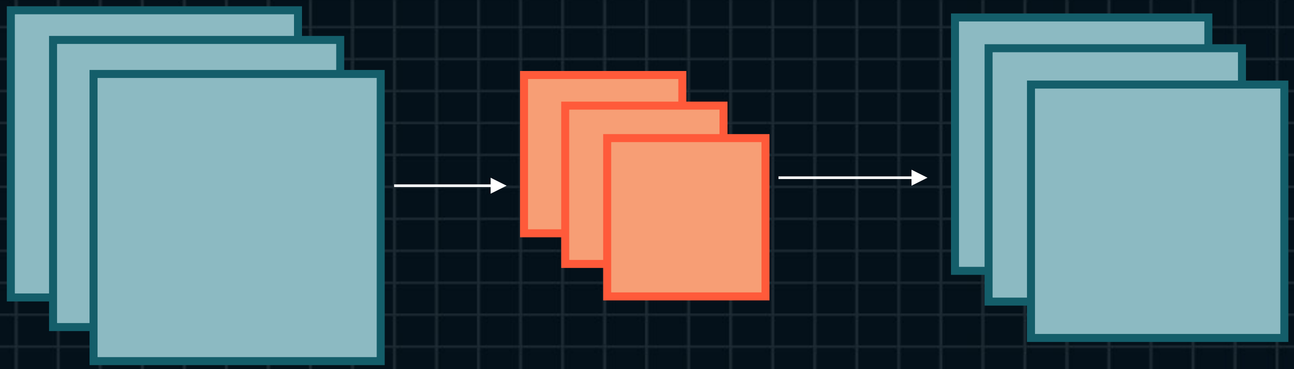
$A^{[1]} \in \mathbb{R}^{n_H^{[1]} \times n_W^{[1]}}$

Lecture.5
Conv Layers

- Conv Layers



- Conv Layers



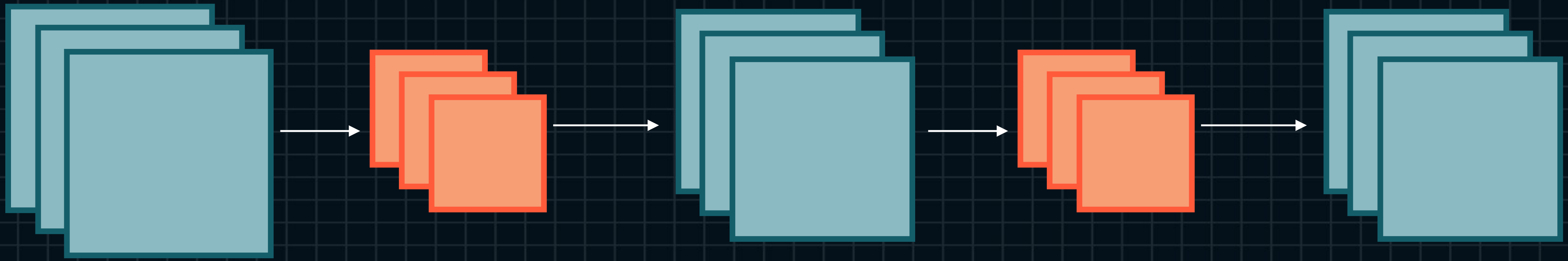
$X \in \mathbb{R}^{n_H^{[I]} \times n_W^{[I]} \times l_I}$

$\mathscr{K}^{[1]} \in \mathbb{R}^{f^{[1]} \times f^{[1]} \times l_I \times l_1}$
$b^{[1]} \in \mathbb{R}^{l_1}$

$A^{[1]} \in \mathbb{R}^{n_H^{[1]} \times n_W^{[1]} \times l_1}$

Lecture.5 Conv Layers

- Conv Layers



$X \in \mathbb{R}^{n_H^{[l]} \times n_W^{[l]} \times l_l}$

$\mathscr{K}^{[1]} \in \mathbb{R}^{f^{[1]} \times f^{[1]} \times l_l \times l_1}$

$b^{[1]} \in \mathbb{R}^{l_1}$

$A^{[1]} \in \mathbb{R}^{n_H^{[1]} \times n_W^{[1]} \times l_1}$

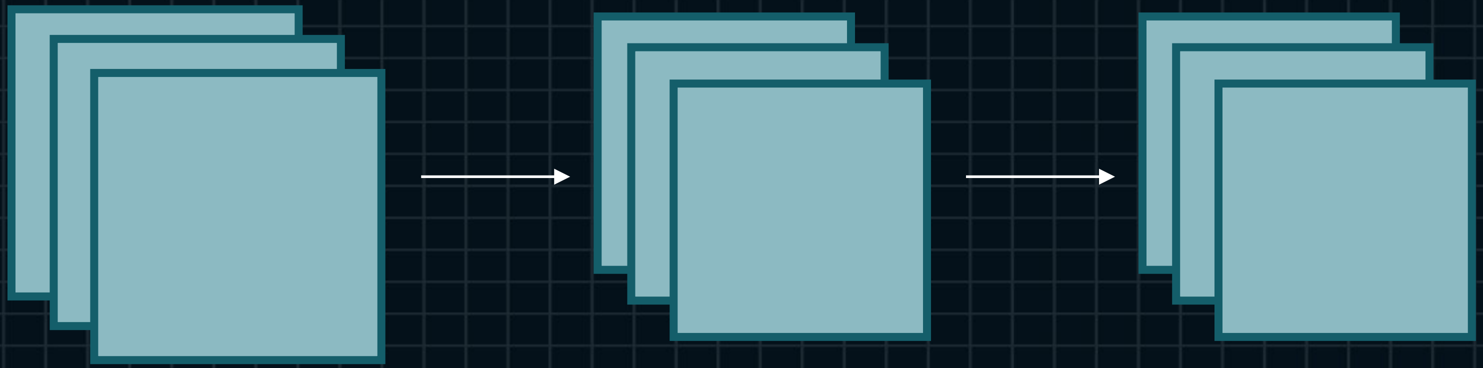
$\mathscr{K}^{[2]} \in \mathbb{R}^{f^{[2]} \times f^{[2]} \times l_1 \times l_2}$

$b^{[2]} \in \mathbb{R}^{l_2}$

$A^{[2]} \in \mathbb{R}^{n_H^{[2]} \times n_W^{[2]} \times l_2}$

Lecture.5
Conv Layers

- Conv Layers



$X \in \mathbb{R}^{n_H^{[I]} \times n_W^{[I]} \times l_I}$

$A^{[1]} \in \mathbb{R}^{n_H^{[1]} \times n_W^{[1]} \times l_1}$

$A^{[2]} \in \mathbb{R}^{n_H^{[2]} \times n_W^{[2]} \times l_2}$

Lecture.5 Conv Layers

- Cascaded Conv Layers

$$A^{[2]} \in \mathbb{R}^{n_H^{[2]} \times n_W^{[2]} \times l_2}$$

$$Conv2D(A^{[1]};\ \mathscr{K}^{[2]}, \overrightarrow{b}^{[2]})$$

$$\mathscr{K}^{[2]} \in \mathbb{R}^{f^{[2]} \times f^{[2]} \times l_1 \times l_2}$$
$$\overrightarrow{b}^{[2]} \in \mathbb{R}^{l_2}$$

$$n_H^{[2]} = n_H^{[1]} - f^{[2]} + 1$$
$$n_W^{[2]} = n_W^{[1]} - f^{[2]} + 1$$

$$A^{[1]} \in \mathbb{R}^{n_H^{[1]} \times n_W^{[1]} \times l_1}$$

$$Conv2D(X;\ \mathscr{K}^{[1]}, \overrightarrow{b}^{[1]})$$

$$\mathscr{K}^{[1]} \in \mathbb{R}^{f^{[1]} \times f^{[1]} \times l_I \times l_1}$$
$$\overrightarrow{b}^{[1]} \in \mathbb{R}^{l_1}$$

$$n_H^{[1]} = n_H^{[I]} - f^{[1]} + 1$$
$$n_W^{[1]} = n_W^{[I]} - f^{[1]} + 1$$

$$X \in \mathbb{R}^{n_H^{[I]} \times n_W^{[I]} \times l_I}$$

Lecture.5 Conv Layers

- Minibatch in Conv Layers

$A^{[2]} \in \mathbb{R}^{N \times n_H^{[2]} \times n_W^{[2]} \times l_2}$

$Conv2D(A^{[1]};\ \mathscr{K}^{[2]}, \overrightarrow{b}^{[2]})$

$\mathscr{K}^{[2]} \in \mathbb{R}^{f^{[2]} \times f^{[2]} \times l_1 \times l_2}$

$\overrightarrow{b}^{[2]} \in \mathbb{R}^{l_2}$

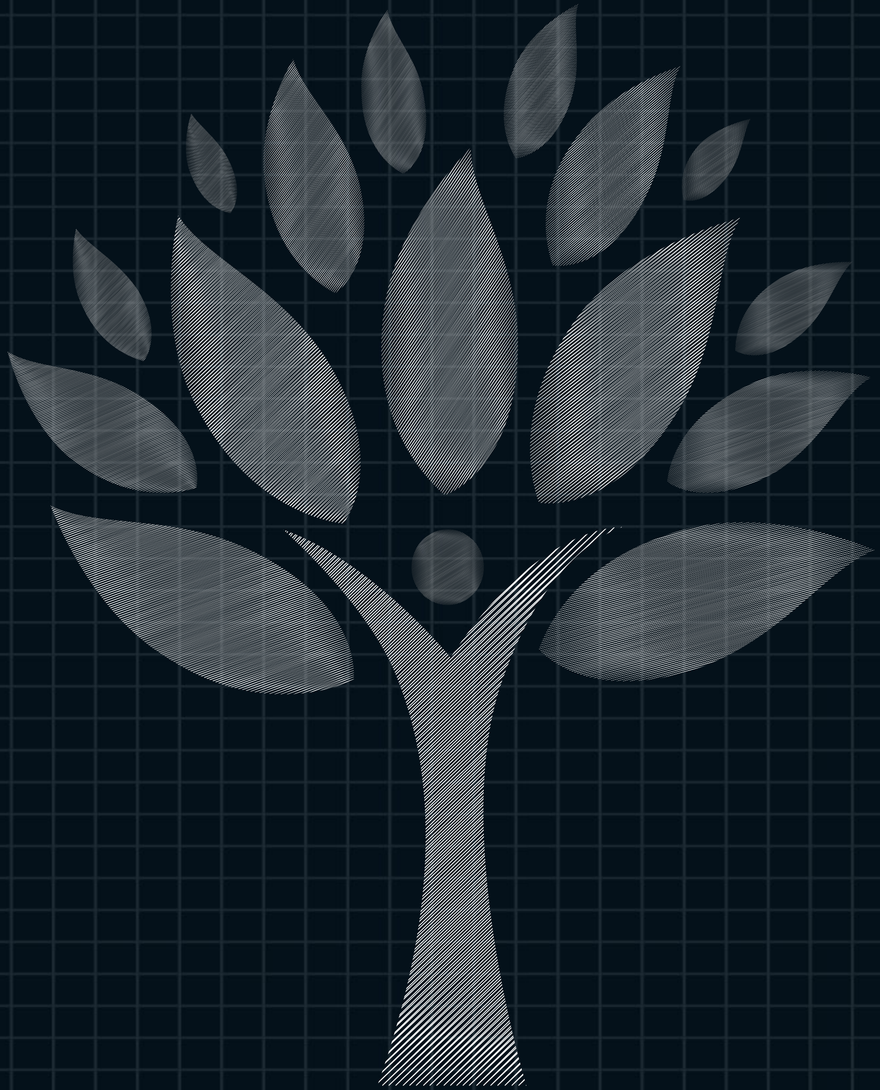
$A^{[1]} \in \mathbb{R}^{N \times n_H^{[1]} \times n_W^{[1]} \times l_1}$

$Conv2D(X;\ \mathscr{K}^{[1]}, \overrightarrow{b}^{[1]})$

$\mathscr{K}^{[1]} \in \mathbb{R}^{f^{[1]} \times f^{[1]} \times l_I \times l_1}$

$\overrightarrow{b}^{[1]} \in \mathbb{R}^{l_1}$

$X \in \mathbb{R}^{N \times n_H^{[I]} \times n_W^{[I]} \times l_I}$



Forward Propagation of Neural Networks

Lecture.5
Conv Layers