Special Matrices

Name	Represents linear transformation	Has entries
Zero matrix, $0_{m\times n} \in \mathbb{R}^{m\times n}$	$L_0 : \mathbb{R}^n \to \mathbb{R}^m$ $L_0(x) = 0$ for all x	$0 = 0_{m\times n} = \begin{pmatrix} 0 & 0 & \cdots & 0 \\ 0 & 0 & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \cdots & 0 \end{pmatrix}$
Identity matrix, $I \in \mathbb{R}^{n\times n}$	$L_I : \mathbb{R}^n \to \mathbb{R}^n$ $L_I(x) = x$ for all x	$I = I_{n\times n} = \begin{pmatrix} 1 & 0 & \cdots & 0 \\ 0 & 1 & \cdots & 0 \\ \vdots & \ddots & \ddots & \vdots \\ 0 & 0 & \cdots & 1 \end{pmatrix}$
Diagonal matrix, $D \in \mathbb{R}^{n\times n}$	$L_D : \mathbb{R}^n \to \mathbb{R}^n$ if $y = L_D(x)$ then $\psi_i = \delta_i \chi_i$	$D = \begin{pmatrix} \delta_0 & 0 & \cdots & 0 \\ 0 & \delta_1 & \cdots & 0 \\ \vdots & \ddots & \ddots & \vdots \\ 0 & 0 & \cdots & \delta_{n-1} \end{pmatrix}$

Triangular matrices

$A \in \mathbb{R}^{n\times n}$ is said to be...	if ...	
lower triangular	$\alpha_{i,j} = 0$ if $i < j$	$\begin{pmatrix} \alpha_{0,0} & 0 & \cdots & 0 & 0 \\ \alpha_{1,0} & \alpha_{1,1} & \cdots & 0 & 0 \\ \vdots & \vdots & \ddots & \vdots & \vdots \\ \alpha_{n-2,0} & \alpha_{n-2,1} & \cdots & \alpha_{n-2,n-2} & 0 \\ \alpha_{n-1,0} & \alpha_{n-1,1} & \cdots & \alpha_{n-1,n-2} & \alpha_{n-1,n-1} \end{pmatrix}$
strictly lower triangular	$\alpha_{i,j} = 0$ if $i \leq j$	$\begin{pmatrix} 0 & 0 & \cdots & 0 & 0 \\ \alpha_{1,0} & 0 & \cdots & 0 & 0 \\ \vdots & \vdots & \ddots & \vdots & \vdots \\ \alpha_{n-2,0} & \alpha_{n-2,1} & \cdots & 0 & 0 \\ \alpha_{n-1,0} & \alpha_{n-1,1} & \cdots & \alpha_{n-1,n-2} & 0 \end{pmatrix}$
unit lower triangular	$\alpha_{i,j} = \begin{cases} 0 & \text{if } i < j \\ 1 & \text{if } i = j \end{cases}$	$\begin{pmatrix} 1 & 0 & \cdots & 0 & 0 \\ \alpha_{1,0} & 1 & \cdots & 0 & 0 \\ \vdots & \vdots & \ddots & \vdots & \vdots \\ \alpha_{n-2,0} & \alpha_{n-2,1} & \cdots & 1 & 0 \\ \alpha_{n-1,0} & \alpha_{n-1,1} & \cdots & \alpha_{n-1,n-2} & 1 \end{pmatrix}$
upper triangular	$\alpha_{i,j} = 0$ if $i > j$	$\begin{pmatrix} \alpha_{0,0} & \alpha_{0,1} & \cdots & \alpha_{0,n-2} & \alpha_{0,n-1} \\ 0 & \alpha_{1,1} & \cdots & \alpha_{1,n-2} & \alpha_{1,n-1} \\ \vdots & \vdots & \ddots & \vdots & \vdots \\ 0 & 0 & \cdots & \alpha_{n-2,n-2} & \alpha_{n-2,n-1} \\ 0 & 0 & \cdots & 0 & \alpha_{n-1,n-1} \end{pmatrix}$
strictly upper triangular	$\alpha_{i,j} = 0$ if $i \geq j$	$\begin{pmatrix} 0 & \alpha_{0,1} & \cdots & \alpha_{0,n-2} & \alpha_{0,n-1} \\ 0 & 0 & \cdots & \alpha_{1,n-2} & \alpha_{1,n-1} \\ \vdots & \vdots & \ddots & \vdots & \vdots \\ 0 & 0 & \cdots & 0 & \alpha_{n-2,n-1} \\ 0 & 0 & \cdots & 0 & 0 \end{pmatrix}$
unit upper triangular	$\alpha_{i,j} = \begin{cases} 0 & \text{if } i > j \\ 1 & \text{if } i = j \end{cases}$	$\begin{pmatrix} 1 & \alpha_{0,1} & \cdots & \alpha_{0,n-2} & \alpha_{0,n-1} \\ 0 & 1 & \cdots & \alpha_{1,n-2} & \alpha_{1,n-1} \\ \vdots & \vdots & \ddots & \vdots & \vdots \\ 0 & 0 & \cdots & 1 & \alpha_{n-2,n-1} \\ 0 & 0 & \cdots & 0 & 1 \end{pmatrix}$

Transpose matrix

$$\left(\begin{array}{ccccc} \alpha_{0,0} & \alpha_{0,1} & \cdots & \alpha_{0,n-2} & \alpha_{0,n-1} \\ \alpha_{1,0} & \alpha_{1,1} & \cdots & \alpha_{1,n-2} & \alpha_{1,n-1} \\ \vdots & \vdots & & \vdots & \vdots \\ \alpha_{m-2,0} & \alpha_{m-2,1} & \cdots & \alpha_{m-2,n-2} & \alpha_{m-2,n-1} \\ \alpha_{m-1,0} & \alpha_{m-1,1} & \cdots & \alpha_{m-1,n-2} & \alpha_{m-1,n-1} \end{array}\right)^T = \left(\begin{array}{ccccc} \alpha_{0,0} & \alpha_{1,0} & \cdots & \alpha_{m-2,0} & \alpha_{m-1,0} \\ \alpha_{0,1} & \alpha_{1,1} & \cdots & \alpha_{m-2,1} & \alpha_{m-1,1} \\ \vdots & \vdots & & \vdots & \vdots \\ \alpha_{0,n-2} & \alpha_{1,n-2} & \cdots & \alpha_{m-2,n-2} & \alpha_{m-1,n-2} \\ \alpha_{0,n-1} & \alpha_{1,n-1} & \cdots & \alpha_{m-2,n-1} & \alpha_{m-1,n-1} \end{array}\right)$$

Symmetric matrix

Matrix $A \in \mathbb{R}^{n\times n}$ is symmetric if and only if $A = A^T$:

$$A = \left(\begin{array}{ccccc} \alpha_{0,0} & \alpha_{0,1} & \cdots & \alpha_{0,n-2} & \alpha_{0,n-1} \\ \alpha_{1,0} & \alpha_{1,1} & \cdots & \alpha_{1,n-2} & \alpha_{1,n-1} \\ \vdots & \vdots & & \vdots & \vdots \\ \alpha_{n-2,0} & \alpha_{n-2,1} & \cdots & \alpha_{n-2,n-2} & \alpha_{n-2,n-1} \\ \alpha_{n-1,0} & \alpha_{n-1,1} & \cdots & \alpha_{n-1,n-2} & \alpha_{n-1,n-1} \end{array}\right) = \left(\begin{array}{ccccc} \alpha_{0,0} & \alpha_{1,0} & \cdots & \alpha_{n-2,0} & \alpha_{n-1,0} \\ \alpha_{0,1} & \alpha_{1,1} & \cdots & \alpha_{n-2,1} & \alpha_{n-1,1} \\ \vdots & \vdots & \ddots & \vdots & \vdots \\ \alpha_{0,n-2} & \alpha_{1,n-2} & \cdots & \alpha_{n-2,n-2} & \alpha_{n-1,n-2} \\ \alpha_{0,n-1} & \alpha_{1,n-1} & \cdots & \alpha_{n-2,n-1} & \alpha_{n-1,n-1} \end{array}\right) = A^T$$

Scaling a matrix

Let $\beta \in \mathbb{R}$ and $A \in \mathbb{R}^{m\times n}$. Then

$$\begin{array}{rcl} \beta A & = & \beta \left(\begin{array}{c|c|c|c} a_0 & a_1 & \cdots & a_{n-1} \end{array} \right) = \left(\begin{array}{c|c|c|c} \beta a_0 & \beta a_1 & \cdots & \beta a_{n-1} \end{array} \right) \\ & = & \beta \left(\begin{array}{cccc} \alpha_{0,0} & \alpha_{0,1} & \cdots & \alpha_{0,n-1} \\ \alpha_{1,0} & \alpha_{1,1} & \cdots & \alpha_{1,n-1} \\ \vdots & \vdots & & \vdots \\ \alpha_{m-1,0} & \alpha_{m-1,1} & \cdots & \alpha_{m-1,n-1} \end{array}\right) = \left(\begin{array}{cccc} \beta\alpha_{0,0} & \beta\alpha_{0,1} & \cdots & \beta\alpha_{0,n-1} \\ \beta\alpha_{1,0} & \beta\alpha_{1,1} & \cdots & \beta\alpha_{1,n-1} \\ \vdots & \vdots & & \vdots \\ \beta\alpha_{m-1,0} & \beta\alpha_{m-1,1} & \cdots & \beta\alpha_{m-1,n-1} \end{array}\right) \end{array}$$

Adding matrices

Let $A, B \in \mathbb{R}^{m\times n}$. Then

$$\begin{array}{rcl} A + B & = & \left(\begin{array}{c|c|c|c} a_0 & a_1 & \cdots & a_{n-1} \end{array} \right) + \left(\begin{array}{c|c|c|c} b_0 & b_1 & \cdots & b_{n-1} \end{array} \right) = \left(\begin{array}{c|c|c|c} a_0 + b_0 & a_1 + b_1 & \cdots & a_{n-1} + b_{n-1} \end{array} \right) \\ & = & \left(\begin{array}{cccc} \alpha_{0,0} & \alpha_{0,1} & \cdots & \alpha_{0,n-1} \\ \alpha_{1,0} & \alpha_{1,1} & \cdots & \alpha_{1,n-1} \\ \vdots & \vdots & & \vdots \\ \alpha_{m-1,0} & \alpha_{m-1,1} & \cdots & \alpha_{m-1,n-1} \end{array}\right) + \left(\begin{array}{cccc} \beta_{0,0} & \beta_{0,1} & \cdots & \beta_{0,n-1} \\ \beta_{1,0} & \beta_{1,1} & \cdots & \beta_{1,n-1} \\ \vdots & \vdots & & \vdots \\ \beta_{m-1,0} & \beta_{m-1,1} & \cdots & \beta_{m-1,n-1} \end{array}\right) \end{array}$$

$$
= \begin{pmatrix} \alpha_{0,0}+\beta_{0,0} & \alpha_{0,1}+\beta_{0,1} & \cdots & \alpha_{0,n-1}+\beta_{0,n-1} \\ \alpha_{1,0}+\beta_{1,0} & \alpha_{1,1}+\beta_{1,1} & \cdots & \alpha_{1,n-1}+\beta_{1,n-1} \\ \vdots & \vdots & & \vdots \\ \alpha_{m-1,0}+\beta_{m-1,0} & \alpha_{m-1,1}+\beta_{m-1,1} & \cdots & \alpha_{m-1,n-1}+\beta_{m-1,n-1} \end{pmatrix}
$$

- Matrix addition commutes: $A+B=B+A$.
- Matrix addition is associative: $(A+B)+C=A+(B+C)$.
- $(A+B)^T = A^T + B^T$.

Matrix-vector multiplication

$$
\begin{aligned}
Ax &= \begin{pmatrix} \alpha_{0,0} & \alpha_{0,1} & \cdots & \alpha_{0,n-1} \\ \alpha_{1,0} & \alpha_{1,1} & \cdots & \alpha_{1,n-1} \\ \vdots & \vdots & \vdots & \vdots \\ \alpha_{m-1,0} & \alpha_{m-1,1} & \cdots & \alpha_{m-1,n-1} \end{pmatrix} \begin{pmatrix} \chi_0 \\ \chi_1 \\ \vdots \\ \chi_{n-1} \end{pmatrix} = \begin{pmatrix} \alpha_{0,0}\chi_0 + & \alpha_{0,1}\chi_1 + & \cdots + & \alpha_{0,n-1}\chi_{n-1} \\ \alpha_{1,0}\chi_0 + & \alpha_{1,1}\chi_1 + & \cdots + & \alpha_{1,n-1}\chi_{n-1} \\ \vdots & \vdots & \vdots & \vdots \\ \alpha_{m-1,0}\chi_0 + & \alpha_{m-1,1}\chi_1 + & \cdots + & \alpha_{m-1,n-1}\chi_{n-1} \end{pmatrix} \\
&= \left(a_0 \,\middle|\, a_1 \,\middle|\, \cdots \,\middle|\, a_{n-1} \right) \begin{pmatrix} \chi_0 \\ \chi_1 \\ \vdots \\ \chi_{n-1} \end{pmatrix} = \chi_0 a_0 + \chi_1 a_1 + \cdots + \chi_{n-1} a_{n-1} \\
&= \begin{pmatrix} \widetilde{a}_0^T \\ \widetilde{a}_1^T \\ \vdots \\ \widetilde{a}_{m-1}^T \end{pmatrix} x = \begin{pmatrix} \widetilde{a}_0^T x \\ \widetilde{a}_1^T x \\ \vdots \\ \widetilde{a}_{m-1}^T x \end{pmatrix}
\end{aligned}
$$