

$\mathbf{A}$ are linearly dependent, and $\mathbf{A}\mathbf{y}$ is a linear combination of the columns of $\mathbf{A}$). Let $\mathbf{x}$ be a solution to $\mathbf{A}\mathbf{x} = \mathbf{b}$. Then clearly $\mathbf{x} + \mathbf{y} \neq \mathbf{x}$ is also a solution. This contradicts the uniqueness of the solution. Hence, $\text{rank } \mathbf{A} = n$.

⇐: By Theorem 2.1, a solution exists. It remains to prove that it is unique. For this, let $\mathbf{x}$ and $\mathbf{y}$ be solutions, i.e., $\mathbf{A}\mathbf{x} = \mathbf{b}$ and $\mathbf{A}\mathbf{y} = \mathbf{b}$. Subtracting, we get $\mathbf{A}(\mathbf{x} - \mathbf{y}) = \mathbf{0}$. Since $\text{rank } \mathbf{A} = n$ and $\mathbf{A}$ has n columns, then $\mathbf{x} - \mathbf{y} = \mathbf{0}$ and hence $\mathbf{x} = \mathbf{y}$, which shows that the solution is unique.

2.3

Consider the vectors $\mathbf{a}_i = [1, \mathbf{a}_i^\top]^\top \in \mathbb{R}^{n+1}$, $i = 1, \dots, k$. Since $k \geq n + 2$, then the vectors $\mathbf{a}_1, \dots, \mathbf{a}_k$ must be linearly independent in $\mathbb{R}^{n+1}$. Hence, there exist $\alpha_1, \dots, \alpha_k$, not all zero, such that

$$\sum_{i=1}^k \alpha_i \mathbf{a}_i = \mathbf{0}.$$

The first component of the above vector equation is $\sum_{i=1}^k \alpha_i = 0$, while the last n components have the form $\sum_{i=1}^k \alpha_i \mathbf{a}_i = \mathbf{0}$, completing the proof.

2.4

a. We first postmultiply $\mathbf{M}$ by the matrix

$$\begin{bmatrix} \mathbf{I}_k & \mathbf{O} \\ -\mathbf{M}_{m-k,k} & \mathbf{I}_{m-k} \end{bmatrix}$$

to obtain

$$\begin{bmatrix} \mathbf{M}_{m-k,k} & \mathbf{I}_{m-k} \\ \mathbf{M}_{k,k} & \mathbf{O} \end{bmatrix} \begin{bmatrix} \mathbf{I}_k & \mathbf{O} \\ -\mathbf{M}_{m-k,k} & \mathbf{I}_{m-k} \end{bmatrix} = \begin{bmatrix} \mathbf{O} & \mathbf{I}_{m-k} \\ \mathbf{M}_{k,k} & \mathbf{O} \end{bmatrix}.$$

Note that the determinant of the postmultiplying matrix is 1. Next we postmultiply the resulting product by

$$\begin{bmatrix} \mathbf{O} & \mathbf{I}_k \\ \mathbf{I}_{m-k} & \mathbf{O} \end{bmatrix}$$

to obtain

$$\begin{bmatrix} \mathbf{O} & \mathbf{I}_{m-k} \\ \mathbf{M}_{k,k} & \mathbf{O} \end{bmatrix} \begin{bmatrix} \mathbf{O} & \mathbf{I}_k \\ \mathbf{I}_{m-k} & \mathbf{O} \end{bmatrix} = \begin{bmatrix} \mathbf{I}_k & \mathbf{O} \\ \mathbf{O} & \mathbf{M}_{k,k} \end{bmatrix}.$$

Notice that

$$\det \mathbf{M} = \det \left(\begin{bmatrix} \mathbf{I}_k & \mathbf{O} \\ \mathbf{O} & \mathbf{M}_{k,k} \end{bmatrix} \right) \det \left(\begin{bmatrix} \mathbf{O} & \mathbf{I}_k \\ \mathbf{I}_{m-k} & \mathbf{O} \end{bmatrix} \right),$$

where

$$\det \left(\begin{bmatrix} \mathbf{O} & \mathbf{I}_k \\ \mathbf{I}_{m-k} & \mathbf{O} \end{bmatrix} \right) = \pm 1.$$

The above easily follows from the fact that the determinant changes its sign if we interchange columns, as discussed in Section 2.2. Moreover,

$$\det \left(\begin{bmatrix} \mathbf{I}_k & \mathbf{O} \\ \mathbf{O} & \mathbf{M}_{k,k} \end{bmatrix} \right) = \det(\mathbf{I}_k) \det(\mathbf{M}_{k,k}) = \det(\mathbf{M}_{k,k}).$$

Hence,

$$\det \mathbf{M} = \pm \det \mathbf{M}_{k,k}.$$

b. We can see this on the following examples. We assume, without loss of generality that $\mathbf{M}_{m-k,k} = \mathbf{O}$ and let $\mathbf{M}_{k,k} = 2$. Thus $k = 1$. First consider the case when $m = 2$. Then we have

$$\mathbf{M} = \begin{bmatrix} \mathbf{O} & \mathbf{I}_{m-k} \\ \mathbf{M}_{k,k} & \mathbf{O} \end{bmatrix} = \begin{bmatrix} 0 & 1 \\ 2 & 0 \end{bmatrix}.$$

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