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

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

2.3

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

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

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

2.4

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

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

to obtain

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

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

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

to obtain

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

Notice that

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

where

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

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

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

Hence,

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

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

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

Introduction To Optimization 4th Edition Solutions

Annelies Wilder-Smith

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