

\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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**Dipti Singh,Amit K. Awasthi,Ivan
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parameters we change the behaviour of the flow determined by the equations. For some parameter values numerically computed solutions of the equations oscillate apparently forever in the pseudo random way we now call chaotic; this is the main reason for the immense amount of interest generated by the equations in the eighteen years since Lorenz first presented them. In addition there are some parameter values for which we see preturbulence, a phenomenon in which trajectories oscillate chaotically for long periods of time before finally settling down to stable stationary or stable periodic behaviour; others in which we see intermittent chaos where trajectories alternate between chaotic and apparently stable periodic behaviours; and yet others in which we see noisy periodicity where trajectories appear chaotic though they stay very close to a non stable periodic orbit. Though the Lorenz equations were not much studied in the years between 1963 and 1975, the number of man, woman and computer hours spent on them in recent years since they came to the general attention of mathematicians and other researchers must be truly immense.

Symmetries and Differential Equations George W. Bluman, Sukeyuki Kumei, 2013-03-14. A major portion of this book discusses work which has appeared since the publication of the book *Similarity Methods for Differential Equations* Springer Verlag 1974 by the first author and J D Cole. The present book also includes a thorough and comprehensive treatment of Lie groups of transformations and their various uses for solving ordinary and partial differential equations. No knowledge of group theory is assumed. Emphasis is placed on explicit computational algorithms to discover symmetries admitted by differential equations and to construct solutions resulting from symmetries. This book should be particularly suitable for physicists, applied mathematicians and engineers. Almost all of the examples are taken from physical and engineering problems including those concerned with heat conduction, wave propagation and fluid flows. A preliminary version was used as lecture notes for a two semester course taught by the first author at the University of British Columbia in 1987-88 to graduate and senior undergraduate students in applied mathematics and physics. Chapters 1 to 4 encompass basic material. More specialized topics are covered in Chapters 5 to 7.

Infinite-Dimensional Dynamical Systems in Mechanics and Physics Roger Temam, 2013-12-11. In this book the author presents the dynamical systems in infinite dimension, especially those generated by dissipative partial differential equations. This book attempts a systematic study of infinite dimensional dynamical systems generated by dissipative evolution partial differential equations arising in mechanics and physics and in other areas of sciences and technology. This second edition has been updated and extended.

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