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Theorem 13. For an $n \times n$ matrix A , the following are equivalent.

- (i) A is invertible.
- (ii) The homogeneous system $AX = 0$ has only the trivial solution $X = 0$.
- (iii) The system of equations $AX = Y$ has a solution X for each $n \times 1$ matrix Y .

Proof. According to Theorem 7, condition (ii) is equivalent to the fact that A is row-equivalent to the identity matrix. By Theorem 12, (i) and (ii) are therefore equivalent. If A is invertible, the solution of $AX = Y$ is $X = A^{-1}Y$. Conversely, suppose $AX = Y$ has a solution for each given Y . Let R be a row-reduced echelon matrix which is row-

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Solution Hoffman Kunze Linear Algebra

equivalent to A . We wish to show that $R = I$. That amounts to showing that the last row of R is not (identically) 0. Let

$$E = \begin{bmatrix} 0 \\ 0 \\ \vdots \\ 0 \\ 1 \end{bmatrix}$$

If the system $RX = E$ can be solved for X , the last row of R cannot be 0. We know that $R = PA$, where P is invertible. Thus $RX = E$ if and only if $AX = P^{-1}E$. According to (iii), the latter system has a solution. ■