# Lecture 1

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## Contents



# 1 Invertible Matrix Theorem

## 1.1 Definition

Let A be a square n x n matrix. Then the following statements are equivalent. That is, for a given A, the statements are either all true or all false.

1. A is invertible.
2. A is row equivalent to I.
3. A has n pivot positions.
4. The equation $A\mathbf{x} = \mathbf{0}$ has only the trivial solution.
5. The columns of A are linearly independent.
6. The linear transformation $\mathbf{x} \mapsto A\mathbf{x}$ is one-to-one.
7. The equation $A\mathbf{x} = \mathbf{b}$ has at least one solution for each $\mathbf{b}$ in $\mathbb{R}^n$.
8. The columns of A span $\mathbb{R}^n$

9. The linear transformation $\mathbf{x} \mapsto A\mathbf{x}$ maps $\mathbb{R}^n$ onto $\mathbb{R}^n$.
10. There is an n x n matrix C such that CA = I.
11. There is an n x n matrix D such that AD = I.
12. $A^T$ is invertible.
13. The columns of A form a basis of $\mathbb{R}^n$.
14. Col A = $\mathbb{R}^n$.
15. dim Col A = n.
16. rank A = n
17. Nul A = 0
18. dim Nul A = 0
19. The number 0 is *not* an eigenvalue of A.
20. det A $\neq$ 0.
21. $(\text{Col A})^\perp = \mathbf{0}$
22. $(\text{Nul A})^\perp = \mathbb{R}^n$
23. Row A = $\mathbb{R}^n$

## 1.2 Exercise

**Thm 9.1.16** Let $A \in M_n$ and let $\lambda \in \mathbb{C}$. Then the following statements are equivalent:

(a) $\lambda$ is an eigenvalue of A.

(b) $A\mathbf{x} = \lambda\mathbf{x}$ for some nonzero $\mathbf{x} \in \mathbb{C}^n$.

(c) $(A - \lambda I)\mathbf{x} = \mathbf{0}$ has a nontrivial solution, that is, nullity$(A-\lambda I) > 0$.

(d) rank$(A - \lambda I) < n$.

(e) $A - \lambda I$ is not invertible.

(f) $A^\top - \lambda I$ is not invertible.

(g) $\lambda$ is an eigenvalue of $A^\top$.

**Proof**

(a) $\Leftrightarrow$ (b) is true by definition of eigenvalue.

(b) $\Leftrightarrow$ (c)

(c) $\Leftrightarrow$ (d)

(d) $\Leftrightarrow$ (e)

(e) $\Leftrightarrow$ (f)

(f) $\Leftrightarrow$ (g)