## Advanced Differential Equations

## Chapter 1. Systems of Linear Differential Equations

## Section 1.5. The Constant Coefficient Case: Real and Distinct

 Eigenvalues-Proofs of Theorems

## Table of contents

(1) Theorem 1.5.1
(2) Theorem 1.5.2
(3) Theorem 1.5.3

## Theorem 1.5.1

Theorem 1.5.1. Let $A$ be a constant matrix. A fundamental matrix $\Phi$ for $y^{\prime}=A y$ is $\Phi=e^{A t}$.

Proof. We have $\frac{d}{d t}\left[e^{A t}\right]=A e^{A t}$ and $\operatorname{det}\left(e^{A t}\right) \neq 0$ by Theorem 1.4.4.

## Theorem 1.5.1

Theorem 1.5.1. Let $A$ be a constant matrix. A fundamental matrix $\Phi$ for $y^{\prime}=A y$ is $\Phi=e^{A t}$.

Proof. We have $\frac{d}{d t}\left[e^{A t}\right]=A e^{A t}$ and $\operatorname{det}\left(e^{A t}\right) \neq 0$ by Theorem 1.4.4. $\square$

## Theorem 1.5.2

Theorem 1.5.2. If $B=T A T^{-1}$, then $A$ and $B$ have the same eigenvalues.
Proof. First, $B-\lambda I=T A T^{-1}-\lambda T T^{-1}=T(A-\lambda \mathcal{I}) T^{-1}$. By Theorem 1.2.3,

$$
\operatorname{det}(B-\lambda \mathcal{I})=\operatorname{det}(T) \operatorname{det}(A-\lambda \mathcal{I}) \operatorname{det}\left(T^{-1}\right) .
$$

## Theorem 1.5.2

Theorem 1.5.2. If $B=T A T^{-1}$, then $A$ and $B$ have the same eigenvalues.
Proof. First, $B-\lambda \mathcal{I}=T A T^{-1}-\lambda T T^{-1}=T(A-\lambda \mathcal{I}) T^{-1}$. By Theorem 1.2.3,

$$
\operatorname{det}(B-\lambda \mathcal{I})=\operatorname{det}(T) \operatorname{det}(A-\lambda \mathcal{I}) \operatorname{det}\left(T^{-1}\right) .
$$

Since $T$ (and $T^{-1}$ ) are invertible, then $\operatorname{det}(T) \neq 0$ and $\operatorname{det}\left(T^{-1}\right) \neq 0$ by Theorem 1.2.4. So $\operatorname{det}(B-\lambda \mathcal{I})=0$ if and only if $\operatorname{det}(A-\lambda \mathcal{I})=0$, so that $A$ and $B$ have the same eigenvalues, as claimed.

## Theorem 1.5.2

Theorem 1.5.2. If $B=T A T^{-1}$, then $A$ and $B$ have the same eigenvalues.
Proof. First, $B-\lambda \mathcal{I}=T A T^{-1}-\lambda T T^{-1}=T(A-\lambda \mathcal{I}) T^{-1}$. By Theorem 1.2.3,

$$
\operatorname{det}(B-\lambda \mathcal{I})=\operatorname{det}(T) \operatorname{det}(A-\lambda \mathcal{I}) \operatorname{det}\left(T^{-1}\right)
$$

Since $T$ (and $T^{-1}$ ) are invertible, then $\operatorname{det}(T) \neq 0$ and $\operatorname{det}\left(T^{-1}\right) \neq 0$ by Theorem 1.2.4. So $\operatorname{det}(B-\lambda \mathcal{I})=0$ if and only if $\operatorname{det}(A-\lambda \mathcal{I})=0$, so that $A$ and $B$ have the same eigenvalues, as claimed.

## Theorem 1.5.3

Theorem 1.5.3. If $A$ is a constant matrix, $\lambda$ is an eigenvalue of $A$ and $\vec{c}$ a corresponding eigenvector, then $\vec{y}=e^{\lambda t} \vec{c}$ is a solution of $\vec{y}^{\prime}=A \vec{y}$.

## Proof. First,

$$
A \vec{y}=A e^{\lambda t} \vec{c}=e^{\lambda t}(A \vec{c})=e^{\lambda t}(\lambda \vec{c})=\lambda e^{\lambda t} \vec{c} .
$$

## Secondly,

$$
\vec{y}^{\prime}=\frac{d}{d t}\left[e^{\lambda t} \vec{c}\right]=\lambda e^{\lambda t} \vec{c} .
$$

So the claim holds.

## Theorem 1.5.3

Theorem 1.5.3. If $A$ is a constant matrix, $\lambda$ is an eigenvalue of $A$ and $\vec{c}$ a corresponding eigenvector, then $\vec{y}=e^{\lambda t} \vec{c}$ is a solution of $\vec{y}^{\prime}=A \vec{y}$.

Proof. First,

$$
A \vec{y}=A e^{\lambda t} \vec{c}=e^{\lambda t}(A \vec{c})=e^{\lambda t}(\lambda \vec{c})=\lambda e^{\lambda t} \vec{c} .
$$

Secondly,

$$
\vec{y}^{\prime}=\frac{d}{d t}\left[e^{\lambda t} \vec{c}\right]=\lambda e^{\lambda t} \vec{c} .
$$

So the claim holds.

