

## Systems Review

### QUESTION ONE

For each of the following matrices A find two independent solutions of

$$\dot{\vec{x}}' = A \vec{x}$$

Note that answers are not unique.

a)  $A = \begin{bmatrix} -7 & -6 \\ 4 & 7 \end{bmatrix}$       b)  $A = \begin{bmatrix} -4 & 6 \\ -3 & 5 \end{bmatrix}$

c)  $A = \begin{bmatrix} 0 & 3 \\ -3 & 0 \end{bmatrix}$       d)  $A = \begin{bmatrix} -8 & 4 \\ -10 & 4 \end{bmatrix}$

e)  $A = \begin{bmatrix} 5 & 2 \\ -2 & 1 \end{bmatrix}$       f)  $A = \begin{bmatrix} 1 & \frac{1}{2} \\ -\frac{1}{2} & 2 \end{bmatrix}$

### ANSWER OUTLINE

a)  $P(\lambda) = \det(A - \lambda I) = \lambda^2 - 25 = 0$        $\lambda = \pm 5$

$\lambda_1 = 5$        $(A - \lambda_1 I) \vec{x}_1 = \vec{0}$        $\vec{x}_1 = \begin{pmatrix} 1 \\ -2 \end{pmatrix}$

$\lambda_2 = -5$        $(A - \lambda_2 I) \vec{x}_2 = \vec{0}$        $\vec{x}_2 = \begin{pmatrix} -3 \\ 1 \end{pmatrix}$

$\vec{x}_1(t) = e^{5t} \begin{pmatrix} 1 \\ -2 \end{pmatrix}$        $\vec{x}_2(t) = e^{-5t} \begin{pmatrix} -3 \\ 1 \end{pmatrix}$

b)  $P(\lambda) = (\lambda+1)(\lambda-2)$        $\lambda_1 = -1$ ,  $\lambda_2 = 2$

$\vec{x}_1(t) = e^{-t} \begin{pmatrix} 2 \\ 1 \end{pmatrix}$        $\vec{x}_2(t) = e^{2t} \begin{pmatrix} 1 \\ 1 \end{pmatrix}$

c)  $P(\lambda) = \det(A - \lambda I) = \lambda^2 + 9$        $\lambda = \pm 3i$  (Complex)

$(A - 3iI) \vec{x} = \begin{bmatrix} -3i & 3 \\ -3 & -3i \end{bmatrix} \vec{x} = \vec{0}$

$\vec{x} = \vec{a} + i\vec{b} = \begin{pmatrix} 1 \\ i \end{pmatrix} = \begin{pmatrix} 1 \\ 0 \end{pmatrix} + i \begin{pmatrix} 0 \\ 1 \end{pmatrix}$

$\vec{x}(t) = e^{\lambda t} \vec{x} = e^{3it} (\vec{a} + i\vec{b})$

Take real/imaginary parts ( $e^{i\theta} = \cos\theta + i\sin\theta$ )

$\vec{x}_1(t) = \begin{pmatrix} \cos 3t \\ -\sin 3t \end{pmatrix}$        $\vec{x}_2(t) = \begin{pmatrix} \sin 3t \\ \cos 3t \end{pmatrix}$

d)  $P(\lambda) = \lambda^2 + 4\lambda + 8 = 0 \Rightarrow \lambda = -2 \pm 2i$  (Complex)

$(A - \lambda I) \vec{x} = \begin{bmatrix} -6-2i & 4 \\ * & * \end{bmatrix} \vec{x} = \vec{0}$

$\vec{x} = \begin{pmatrix} 2 \\ 3+i \end{pmatrix} = \begin{pmatrix} 2 \\ 3 \end{pmatrix} + i \begin{pmatrix} 0 \\ 1 \end{pmatrix} = \vec{a} + i\vec{b}$

$\vec{x}(t) = e^{\lambda t} \vec{x}$

$\vec{x}(t) = e^{-2t} (\cos 2t + i\sin 2t) (\vec{a} + i\vec{b})$

Take real and imaginary parts

$\vec{x}_1 = e^{-2t} \begin{pmatrix} 2\cos 2t \\ 3\cos 2t - \sin 2t \end{pmatrix}$

$\vec{x}_2 = e^{-2t} \begin{pmatrix} 2\sin 2t \\ 3\sin 2t + \cos 2t \end{pmatrix}$

e)  $P(\lambda) = \det(A - \lambda I) = (\lambda - 3)^2$   $\lambda = 3$  repeated

$$(A - \lambda I) \vec{\eta}_0 = \begin{bmatrix} a & a \\ -a & -a \end{bmatrix} \vec{\eta}_0 = \vec{0} \quad \vec{\eta}_0 = \begin{pmatrix} 1 \\ -1 \end{pmatrix}$$

Next find a soln (not unique) of

$$(A - \lambda I) \vec{\eta}_1 = \begin{bmatrix} a & a \\ -a & -a \end{bmatrix} \vec{\eta}_1 = \vec{\eta}_0 = \begin{pmatrix} 1 \\ -1 \end{pmatrix}$$

One such soln  $\vec{\eta}_1 = \begin{pmatrix} 0 \\ 1/2 \end{pmatrix}$

$$\vec{x}_1 = e^{\lambda t} \vec{\eta}_0 = e^{3t} \begin{pmatrix} 1 \\ -1 \end{pmatrix}$$

$$\vec{x}_2 = e^{\lambda t} (\vec{\eta}_0 t + \vec{\eta}_1) = e^{3t} \begin{pmatrix} t \\ -t + 1/2 \end{pmatrix}$$

f)  $P(\lambda) = \det(A - \lambda I) = \lambda^2 - 3\lambda + \frac{9}{4}$   $\lambda = \frac{3}{2}$  repeated

$$(A - \lambda I) \vec{\eta}_0 = \begin{bmatrix} -1/2 & 1/2 \\ -1/2 & 1/2 \end{bmatrix} \vec{\eta}_0 = \vec{0} \quad \vec{\eta}_0 = \begin{pmatrix} 1 \\ 1 \end{pmatrix}$$

Then  $(A - \lambda I) \vec{\eta}_1 = \vec{\eta}_0$  is

$$\begin{bmatrix} -1/2 & 1/2 \\ * & * \end{bmatrix} \vec{\eta}_1 = \begin{pmatrix} 1 \\ 1 \end{pmatrix} \quad \vec{\eta}_1 = \begin{pmatrix} 0 \\ 2 \end{pmatrix}$$

$$\vec{x}_1 = e^{\lambda t} \vec{\eta}_0 = e^{\frac{3}{2}t} \begin{pmatrix} 1 \\ 1 \end{pmatrix}$$

$$\vec{x}_2 = e^{\lambda t} (\vec{\eta}_0 t + \vec{\eta}_1) = e^{\frac{3}{2}t} \begin{pmatrix} t \\ t+2 \end{pmatrix}$$

QUESTION TWO

Find a particular soln for

$$\vec{x}' = A\vec{x} + \vec{f}(t) \quad A = \begin{bmatrix} 1 & 4 \\ a & -1 \end{bmatrix} \quad \vec{f} = \begin{pmatrix} e^{3t} \\ \frac{1}{2}e^{3t} \end{pmatrix}$$

Answer One can find two independent solns of the homogeneous problem

$$\vec{x}_1 = \begin{pmatrix} 2e^{3t} \\ e^{3t} \end{pmatrix} \quad \vec{x}_2 = \begin{pmatrix} -e^{-3t} \\ e^{-3t} \end{pmatrix}$$

Use variation of parameters to find  $\vec{x}_p(t)$

$$\vec{x}_p(t) = \mathbf{X}(t) \vec{v}(t) \quad \vec{v}(t) = \int \mathbf{X}^{-1}(s) \vec{f}(s) ds$$

Here  $\mathbf{X}$  = fund matrix. Wronskian  $W = \det \mathbf{X} = 3 \Rightarrow$

$$\mathbf{X} = \begin{bmatrix} 2e^{3t} & -e^{-3t} \\ e^{3t} & e^{-3t} \end{bmatrix} \quad \mathbf{X}^{-1} = \begin{bmatrix} \frac{1}{3}e^{-3t} & \frac{1}{3}e^{-3t} \\ -\frac{1}{3}e^{3t} & \frac{1}{3}e^{3t} \end{bmatrix}$$

Then

$$\vec{v}(t) = \int \mathbf{X}^{-1} \vec{f} ds = \int \begin{pmatrix} 1/2 \\ 0 \end{pmatrix} ds = \begin{pmatrix} t/2 \\ 0 \end{pmatrix}$$

Having found  $\vec{v}(t)$

$$\vec{x}_p(t) = \mathbf{X}(t) \vec{v}(t) = \begin{bmatrix} 2e^{3t} & -e^{-3t} \\ e^{3t} & e^{-3t} \end{bmatrix} \begin{bmatrix} t/2 \\ 0 \end{bmatrix}$$

$$\vec{x}_p(t) = e^{3t} \begin{pmatrix} t \\ t/2 \end{pmatrix}$$

QUESTION THREE Find a particular soln of

$$\vec{x}' = A(t)\vec{x} + \vec{f}(t) \quad \vec{f} = \begin{pmatrix} 1 \\ 1 \end{pmatrix}$$

given the fundamental matrix is

$$X(t) = \begin{bmatrix} 2t & t^2 \\ t & t^2 \end{bmatrix}$$

ANSWER (Don't need to know  $A(t)$ )

Apply variation of parameters method

$$\vec{x}_p = X(t)\vec{v}(t) \quad \vec{v}(t) = \int^t X^{-1}(s)\vec{f}(s)ds$$

The Wronskian  $W(t) = \det X(t) = t^3$  hence

$$X^{-1} = \frac{1}{t^3} \begin{bmatrix} t^2 & -t^2 \\ -t & 2t \end{bmatrix} = \begin{bmatrix} t^{-1} & -t^{-1} \\ -t^{-2} & 2t^{-2} \end{bmatrix}$$

$$X^{-1}\vec{f} = \begin{pmatrix} 0 \\ t^{-2} \end{pmatrix}$$

$$\text{Hence } \vec{v}(t) = \int^t \begin{pmatrix} 0 \\ s^{-2} \end{pmatrix} ds = \begin{pmatrix} 0 \\ -\frac{1}{s} \end{pmatrix}$$

Then

$$\vec{x}_p = X\vec{v} = \begin{bmatrix} 2t & t^2 \\ t & t^2 \end{bmatrix} \begin{bmatrix} 0 \\ -\frac{1}{t} \end{bmatrix} = \begin{pmatrix} -t \\ -t \end{pmatrix}$$

QUESTION FOUR Solve the initial value problem

$$\vec{x}' = A\vec{x} \quad \vec{x}(0) = \begin{pmatrix} 1 \\ 2 \end{pmatrix}^*$$

given two independent solutions are

$$\vec{x}_1(t) = \begin{pmatrix} e^t \\ e^t \end{pmatrix} \quad \vec{x}_2(t) = \begin{pmatrix} e^{2t} \\ 2e^{2t} \end{pmatrix}$$

Soln The general solution is

$$\vec{x}(t) = X(t)\vec{c} \quad X(t) = \begin{bmatrix} e^t & e^{2t} \\ e^t & 2e^{2t} \end{bmatrix}$$

Given  $\vec{c}$  determines  $\vec{c}$

$$\vec{x}(0) = X(0)\vec{c} \quad X(0) = \begin{bmatrix} 1 & 1 \\ 1 & 2 \end{bmatrix}$$

Thus  $(\det X(0) = 1)$

$$\vec{c} = X(0)^{-1}\vec{x}(0) = \begin{bmatrix} 2 & -1 \\ -1 & 1 \end{bmatrix}^* \begin{bmatrix} 1 \\ 2 \end{bmatrix} = \begin{pmatrix} 0 \\ 1 \end{pmatrix}$$

Hence

$$\vec{x}(t) = X(t) \begin{pmatrix} 0 \\ 1 \end{pmatrix} = \begin{pmatrix} e^{2t} \\ 2e^{2t} \end{pmatrix}$$

is the unique soln of the IVP

QUESTION FIVE Solve the initial value problem

$$\vec{x}' = A\vec{x} + \vec{f}(t) \quad \vec{x}(0) = \begin{pmatrix} 3 \\ 4 \end{pmatrix}$$

Given two independent homogeneous solns  
 $\vec{x}_1(t), \vec{x}_2(t)$  and the particular soln:

$$\vec{x}_1(t) = \begin{pmatrix} \cos t \\ \cos t \end{pmatrix} \quad \vec{x}_2(t) = \begin{pmatrix} e^t \\ 2e^t \end{pmatrix} \quad \vec{x}_p(t) = \begin{pmatrix} t+1 \\ 2e^t \end{pmatrix}$$

Soln

$$\vec{x}(t) = \Sigma(t)\vec{c} + \vec{x}_p(t) \quad \Sigma(t) = \begin{bmatrix} \vec{x}_1 & \vec{x}_2 \end{bmatrix}$$

$$\vec{x}(0) = \Sigma(0)\vec{c} + \vec{x}_p(0)$$

$$\begin{pmatrix} 3 \\ 4 \end{pmatrix} = \begin{bmatrix} 1 & 1 \\ 1 & 2 \end{bmatrix} \vec{c} + \begin{pmatrix} 1 \\ 2 \end{pmatrix}$$

Thus

$$\begin{bmatrix} 1 & 1 \\ 1 & 2 \end{bmatrix} \vec{c} = \begin{pmatrix} 2 \\ 2 \end{pmatrix}$$

$$\vec{c} = \begin{bmatrix} 1 & 1 \\ 1 & 2 \end{bmatrix}^{-1} \begin{pmatrix} 2 \\ 2 \end{pmatrix}$$

$$\vec{c} = \begin{bmatrix} 2 & -1 \\ -1 & 1 \end{bmatrix} \begin{pmatrix} 2 \\ 2 \end{pmatrix} = \begin{pmatrix} 2 \\ 0 \end{pmatrix}$$

Initial value problem soln

$$\vec{x}(t) = \begin{bmatrix} \cos t & e^t \\ \cos t & 2e^t \end{bmatrix} \begin{pmatrix} 2 \\ 0 \end{pmatrix} + \begin{pmatrix} t+1 \\ 2e^t \end{pmatrix} = \begin{pmatrix} 2\cos t + t + 1 \\ 2\cos t + 2e^t \end{pmatrix}$$

QUESTION SIX If  $A = \begin{bmatrix} 1 & 2 \\ 1 & 3 \end{bmatrix}$  above, what is  $\vec{f}(t)$ ?

$$\vec{f}(t) = \vec{x}_p' - A\vec{x}_p = \begin{pmatrix} 1 \\ 2e^t \end{pmatrix} - \begin{bmatrix} 1 & 2 \\ 1 & 3 \end{bmatrix} \begin{pmatrix} t+1 \\ 2e^t \end{pmatrix} = \text{etc.}$$