
PROBLEM #1.

Calculate the expression $\frac{df}{dt} = \frac{\partial f}{\partial x} \frac{dx}{dt}$ in matrix form.

$$\begin{aligned} f(x) &= f(x_1, x_2) \\ &= x_1^2 x_2^2 + x_1 x_2 \end{aligned}$$

$$\begin{aligned} x_1(t) &= 1 - t^2 \\ x_2(t) &= 1 + t^2 \end{aligned}$$

Calculate the vector derivative of x ,

$$\frac{dx}{dt} = \begin{bmatrix} -2t \\ 2t \end{bmatrix}$$

Calculate the Jacobian row-vector of f ,

$$\begin{aligned} J_f &= \frac{\partial f}{\partial x} \\ &= \left[\frac{\partial f}{\partial x_1}, \frac{\partial f}{\partial x_2} \right] \\ &= [2x_1 x_2^2 + x_2, 2x_2 x_1^2 + x_1] \end{aligned}$$

The total derivative formed by the matrix representation chain rule,

$$\frac{df}{dt} = [2x_1 x_2^2 + x_2, 2x_2 x_1^2 + x_1] \begin{bmatrix} -2t \\ 2t \end{bmatrix}$$

PROBLEM #2.

Calc the total derivative in matrix form,

$$\begin{aligned} f(x) &= f(x_1, x_2, x_3) \\ &= x_1^3 \cos(x_2) e^{x_3} \end{aligned}$$

$$\begin{aligned} x_1(t) &= 2t \\ x_2(t) &= 1 - t^2 \end{aligned}$$

$$x_3(t) = e^t$$

The total derivative is equal to,

$$\frac{df}{dt} = \frac{\partial f}{\partial x} \frac{dx}{dt}, \text{ where } \frac{\partial f}{\partial x} \text{ is the Jacobian row vector of } f$$

and $\frac{dx}{dt}$ is the vector derivative of \underline{x}
relative to \underline{t} .

The Jacobian row vector is equal to,

$$J_f = [3x_1^2 \cos(x_2) e^{x_3}, -\sin(x_2) x_1^3 e^{x_3}, e^{x_3} \cos x_2 x_1^3]$$

$$= \frac{\partial f}{\partial x}$$

The vector derivative of \underline{x} -to- \underline{t} is,

$$\frac{dx}{dt} = \begin{bmatrix} 2 \\ -2t \\ e^t \end{bmatrix}$$

The total derivative,

$$\frac{df}{dt} = [3x_1^2 \cos(x_2) e^{x_3}, -\sin(x_2) x_1^3 e^{x_3}, e^{x_3} \cos x_2 x_1^3] \begin{bmatrix} 2 \\ -2t \\ e^t \end{bmatrix}$$

PROBLEM #3.

Calculate the total derivative in matrix form.

$$f(x) = f(x_1, x_2)$$

$$= x_1^2 - x_2^2$$

$$x_1(u_1, u_2) = 2u_1 + 3u_2$$

$$x_2(u_1, u_2) = 2u_1 - 3u_2$$

$$u_1(t) = \cos(t/2)$$

$$u_2(t) = \sin(2t)$$

The total derivative can be expressed,

$$\frac{df}{dt} = \frac{\partial f}{\partial x} \frac{\partial x}{\partial u} \frac{du}{dt}$$

$= J_f J_x \frac{du}{dt}$, can be re-expressed in terms of Jacobian.

The Jacobian of f is,

$$J_f = [2x_1, -2x_2]$$

The Jacobian of x is,

$$J_x = \begin{bmatrix} J_{x_1} \\ J_{x_2} \end{bmatrix} = \begin{bmatrix} \frac{\partial x_1}{\partial u_1} & \frac{\partial x_1}{\partial u_2} \\ \frac{\partial x_2}{\partial u_1} & \frac{\partial x_2}{\partial u_2} \end{bmatrix}$$

$$= \begin{bmatrix} 2 & 3 \\ 2 & -3 \end{bmatrix}$$

The vector derivative of u is,

$$\frac{du}{dt} = \begin{bmatrix} -\sin(t/2) \cdot \frac{1}{2} \\ \cos(2t) \cdot 2 \end{bmatrix}$$

The total derivative is,

$$\frac{df}{dt} = [2x_1, -2x_2] \begin{bmatrix} 2 & 3 \\ 2 & -3 \end{bmatrix} \begin{bmatrix} -\sin(t/2) \cdot \frac{1}{2} \\ \cos(2t) \cdot 2 \end{bmatrix}$$

PROBLEM # 4.

Calculate the total derivative in matrix form,

$$\begin{aligned} f(x) &= f(x_1, x_2) \\ &= \cos x_1 \sin x_2 \end{aligned}$$

$$x_1(u_1, u_2) = 2u_1^3 + 3u_2^2 - u_2$$

$$x_2(u_1, u_2) = 2u_1 - 5u_2^3$$

$$u_1(t) = e^{t/2}$$

$$u_2(t) = e^{-2t}$$

The total derivative can be expressed in terms of the Jacobian,

$$\begin{aligned}\frac{df}{dt} &= \frac{\partial f}{\partial x} \frac{\partial x}{\partial u} \frac{du}{dt} \\ &= J_f J_x \frac{du}{dt}.\end{aligned}$$

The Jacobian of f -relative-to- x ,

$$J_f = [-\sin x, \sin x_2, \cos x, \cos x_2]$$

The Jacobian of x -relative-to- u ,

$$\begin{aligned}J_x &= \begin{bmatrix} J_{x_1} \\ J_{x_2} \end{bmatrix} \\ &= \begin{bmatrix} \frac{\partial x_1}{\partial u_1} & \frac{\partial x_1}{\partial u_2} \\ \frac{\partial x_2}{\partial u_1} & \frac{\partial x_2}{\partial u_2} \end{bmatrix} = \begin{bmatrix} 4u_1, 6u_2 - 1 \\ 2, -15u_2^2 \end{bmatrix}\end{aligned}$$

The vector derivative of u ,

$$\frac{du}{dt} = \begin{bmatrix} e^{t/2} \cdot \frac{1}{2} \\ e^{-2t} \cdot (-2) \end{bmatrix}$$

The total derivative is,

$$\frac{df}{dt} = [-\sin x, \sin x_2, \cos x, \cos x_2] \begin{bmatrix} 4u_1, 6u_2 - 1 \\ 2, -15u_2^2 \end{bmatrix} \begin{bmatrix} e^{t/2} \cdot \frac{1}{2} \\ e^{-2t} \cdot (-2) \end{bmatrix}$$

PROBLEM # 5.

Calculate the total derivative in matrix form.

$$\begin{aligned} f(x) &= f(x_1, x_2, x_3) \\ &= \sin x_1 \cos x_2 e^{x_3} \end{aligned}$$

$$x_1(u_1, u_2) = \sin(u_1) + \cos u_2$$

$$x_2(u_1, u_2) = \cos u_1 - \sin u_2$$

$$x_3(u_1, u_2) = e^{u_1+u_2}$$

$$u_1(t) = 1 + t/2$$

$$u_2(t) = 1 - t/2$$

The total derivative can be expressed as Jacobian products,

$$\begin{aligned} \frac{df}{dt} &= \frac{\partial f}{\partial x} \frac{\partial x}{\partial u} \frac{du}{dt} \\ &= J_f J_x \frac{du}{dt} \end{aligned}$$

The Jacobian of f is

$$J_f = [\cos x_1 \cos x_2 e^{x_3}, -\sin x_1 \sin x_2 e^{x_3}, \sin x_1 \cos x_2 e^{x_3}]$$

The Jacobian of x ,

$$\begin{aligned} J_x &= \begin{bmatrix} J_{x_1} \\ J_{x_2} \\ J_{x_3} \end{bmatrix} \\ &= \begin{bmatrix} \frac{\partial x_1}{\partial u_1} & \frac{\partial x_1}{\partial u_2} \\ \frac{\partial x_2}{\partial u_1} & \frac{\partial x_2}{\partial u_2} \\ \frac{\partial x_3}{\partial u_1} & \frac{\partial x_3}{\partial u_2} \end{bmatrix} = \begin{bmatrix} \cos u_1, & -\sin u_2 \\ -\sin u_1, & -\cos u_2 \\ e^{u_1+u_2}, & e^{u_1+u_2} \end{bmatrix} \end{aligned}$$

The vector derivative of u ,

$$\frac{du}{dt} = \begin{bmatrix} \frac{1}{2} \\ -\frac{1}{2} \end{bmatrix}$$

The total derivative in matrix form,

$$\frac{df}{dt} = [\cos x_1 \cos x_2 e^{x_3}, -\sin x_1 \sin x_2 e^{x_3}, \sin x_1 \cos x_2 e^{x_3}]$$

$$\times \begin{bmatrix} \cos u_1, & -\sin u_2 \\ -\sin u_1, & -\cos u_2 \\ e^{u_1+u_2}, & e^{u_1+u_2} \end{bmatrix} \begin{bmatrix} \frac{1}{2} \\ -\frac{1}{2} \end{bmatrix}$$