

# NUMERICAL METHODS

C / KAFFY EXAM 12 / 11/19 / 2022 [20.000]

## LEAST SQUARES REGRESSION

Goal: minimize the sum of the squares of the residual errors.



$$S_r = \sum_{i=1}^n d_i = \sum_{i=1}^n (y_i - a_0 - a_1 x_i)$$

$$S_r^2 = \sum_{i=1}^n (y_i - a_0 - a_1 x_i)^2$$

$$a_0 = \frac{\sum y_i}{n} \quad a_1 = \frac{\sum x_i y_i - \frac{(\sum x_i)(\sum y_i)}{n}}{\sum x_i^2 - \frac{(\sum x_i)^2}{n}}$$

## STANDARD ERROR:

$$S_{y_1} = \sqrt{\frac{S_r}{n-2}} \quad S_{y_2} = \sqrt{\frac{S_r(y_2 - \bar{y})^2}{n-2}}$$

## STANDARD DEVIATION:

$$S_y = \sqrt{\frac{S_r}{n-1}} \quad S_x = \sqrt{\frac{2(y_2 - \bar{y})^2}{n-1}}$$

$$a_0 = \bar{y} - a_1 \bar{x}$$

## POLYNOMIAL QUADRATIC REGRESSION:



$$S_r = \sum_{i=1}^n (y_i - a_0 - a_1 x_i - a_2 x_i^2)^2$$

Take derivatives of  $S_r$  to find the error.

$$\frac{\partial S_r}{\partial a_0} = -2(\sum y_i - \sum a_0 - a_1 \sum x_i - a_2 \sum x_i^2) = 0$$

$$\frac{\partial S_r}{\partial a_1} = -2(\sum x_i y_i - \sum a_0 \sum x_i - a_1 \sum x_i^2 - a_2 \sum x_i^3) = 0$$

$$\frac{\partial S_r}{\partial a_2} = -2(\sum x_i^2 y_i - \sum a_0 \sum x_i^2 - a_1 \sum x_i^3 - a_2 \sum x_i^4) = 0$$

$$\begin{bmatrix} \sum 1 & \sum x_i & \sum x_i^2 \\ \sum x_i & \sum x_i^2 & \sum x_i^3 \\ \sum x_i^2 & \sum x_i^3 & \sum x_i^4 \end{bmatrix} \begin{bmatrix} a_0 \\ a_1 \\ a_2 \end{bmatrix} = \begin{bmatrix} \sum y_i \\ \sum x_i y_i \\ \sum x_i^2 y_i \end{bmatrix}$$

Use Gauss-Jordan elimination to solve for  $a_0, a_1, a_2$ .

## INTERPOLATION

Use a polynomial  $P(x)$



## ODE'S

### Euler's Method

$$\frac{dy}{dx} = f(x,y) \quad y_{i+1} = y_i + f(x_i, y_i) \Delta x$$

### Runge-Kutta Method

$$y' = f(x,y)$$

$$k_1 = f(x_i, y_i)$$

$$k_2 = f(x_i + \frac{1}{2}\Delta x, y_i + \frac{1}{2}\Delta x k_1)$$

$$k_3 = f(x_i + \Delta x, y_i + \Delta x k_2)$$

$$y_{i+1} = y_i + \Delta x \left( \frac{1}{6}k_1 + \frac{4}{6}k_2 + \frac{1}{6}k_3 \right)$$

Taylor Series:  
 $y(x+\Delta x) = y(x) + \Delta x y'(x) + \frac{\Delta x^2}{2} y''(x) + \dots$   
 $y(x+\Delta x) = y(x) + f(x,y) \Delta x$

### Classic 4th Order Runge-Kutta

$$y_{i+1} = y_i + \Delta x \left( \frac{1}{4}k_1 + \frac{3}{4}k_2 + \frac{3}{4}k_3 + \frac{1}{4}k_4 \right)$$

$$k_1 = f(x_i, y_i)$$

$$k_2 = f(x_i + \frac{1}{2}\Delta x, y_i + \frac{1}{2}\Delta x k_1)$$

$$k_3 = f(x_i + \Delta x, y_i + \Delta x k_2)$$

$$k_4 = f(x_i + \Delta x, y_i + \Delta x k_3)$$

## PDE'S

### Finite Difference Method



## EIGEN VALUES

$\lambda = \text{Eigen Value}$

Example:  $2 \times 2$

$$\begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} = \begin{bmatrix} \lambda x_1 \\ \lambda x_2 \end{bmatrix}$$

The determinant:

$$\begin{bmatrix} a_{11} - \lambda & a_{12} \\ a_{21} & a_{22} - \lambda \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \end{bmatrix}$$

$$A = \begin{bmatrix} a & b \\ c & d \end{bmatrix} \begin{bmatrix} x \\ y \end{bmatrix} = \begin{bmatrix} \lambda x \\ \lambda y \end{bmatrix}$$

$$|A - \lambda I| = \det \begin{bmatrix} a-\lambda & b \\ c & d-\lambda \end{bmatrix} = 0$$

$$\lambda^2 - (a+d)\lambda + (ad-bc) = 0$$

$$\lambda = \frac{a+d \pm \sqrt{(a+d)^2 - 4(ad-bc)}}{2}$$

Find Eigen Value with given

$$\begin{bmatrix} 1 & 1 \\ 1 & 1 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} = \begin{bmatrix} \lambda x_1 \\ \lambda x_2 \end{bmatrix}$$

$$\lambda_1 = \lambda_2 = 0$$

$$x_1 = -x_2$$

$$x_1 = x_2$$

$$x_1 = 1, x_2 = 1$$

$$x_1 = [-1]$$

$$\begin{bmatrix} 1 & -1 \\ -1 & 1 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} = \begin{bmatrix} \lambda x_1 \\ \lambda x_2 \end{bmatrix}$$

$$-x_1 + x_2 = 0 \Rightarrow x_1 = x_2$$

$$x_1 + -1x_2 = 0 \Rightarrow x_1 = x_2$$

$$x_1 = 1, x_2 = 1$$

$$x_1 = 1, x_2 = 1$$

$$x_1 = 1, x_2 = 1$$

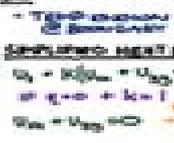
### 1D Heat Conduction



$$u_{i+1}(t) = u_i(t) - \alpha \Delta x (u_{i+1} - u_i) + \alpha \Delta x (u_i - u_{i-1})$$

$$u_{i+1}(t) = u_i(t) + \alpha \Delta x (u_{i+1} - u_i) + \alpha \Delta x (u_i - u_{i-1})$$

### 2D Heat Conduction



$$u_{i,j}(t) = u_{i,j}(t) + \alpha \Delta x (u_{i+1,j} - u_{i,j}) + \alpha \Delta x (u_{i-1,j} - u_{i,j}) + \alpha \Delta y (u_{i,j+1} - u_{i,j}) + \alpha \Delta y (u_{i,j-1} - u_{i,j})$$

### 3D Heat Conduction



$$u_{i,j,k}(t) = u_{i,j,k}(t) + \alpha \Delta x (u_{i+1,j,k} - u_{i,j,k}) + \alpha \Delta x (u_{i-1,j,k} - u_{i,j,k}) + \alpha \Delta y (u_{i,j+1,k} - u_{i,j,k}) + \alpha \Delta y (u_{i,j-1,k} - u_{i,j,k}) + \alpha \Delta z (u_{i,j,k+1} - u_{i,j,k}) + \alpha \Delta z (u_{i,j,k-1} - u_{i,j,k})$$

### Central Difference

$$\frac{\partial^2 u}{\partial x^2} = \frac{u_{i+1} - 2u_i + u_{i-1}}{\Delta x^2}$$

### Right Nominant B.C.

$$\frac{\partial u}{\partial x} = u_x = \frac{u_{i+1} - u_i}{\Delta x}$$

### Bottom Nominant B.C.

$$\frac{\partial u}{\partial x} = u_x = \frac{u_i - u_{i-1}}{\Delta x}$$

### Top Nominant B.C.

$$\frac{\partial u}{\partial x} = u_x = \frac{u_{i+1} - u_i}{\Delta x}$$

### Left Nominant B.C.

$$u_{i-1} = u_i - 2\alpha \Delta x u_x$$

[A] MATRIX:

$$-2u_{i,j} + 4u_{i,j} - u_{i,j-1} - u_{i,j+1} = -2\alpha \Delta x u_x$$

$$-2u_{i,j} + 4u_{i,j} - u_{i,j-1} - u_{i,j+1} = -2\alpha \Delta x u_x$$

$$-2u_{i,j} + 4u_{i,j} - u_{i,j-1} - u_{i,j+1} = -2\alpha \Delta x u_x$$

$$-2u_{i,j} + 4u_{i,j} - u_{i,j-1} - u_{i,j+1} = -2\alpha \Delta x u_x$$

FINITE DIFFERENCE:

$$f(x) = \frac{f(x+\Delta x) - f(x-\Delta x)}{2\Delta x}$$

$$f(x) = \frac{f(x+\Delta x) - 2f(x) + f(x-\Delta x))}{2\Delta x}$$

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