

# NUMERICAL METHODS

C / KAPPA EXAM 12 / 11/19 / 2022 / 20.000

## LEAST SQUARES REGRESSION

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



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

1. sum of the square errors.  
2. minimize the square of the errors.

$$a_0 = \frac{\sum y_i - a_1 \sum x_i}{n}$$

$$a_0 = \frac{\sum y_i}{n} - a_1 \frac{\sum x_i}{n} \Rightarrow a_0 = 5 - 0.8$$

## STANDARD ERROR:

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

## STANDARD DEVIATION:

$$S_y = \sqrt{\frac{\sum y_i^2}{n-1}} \quad S_x = \sqrt{\frac{\sum (x_i - \bar{x})^2}{n-1}}$$

$$a_0 = 5 - 0.8x$$

## POLYNOMIAL QUADRATIC REGRESSION:



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

Take derivative of  $S_r$  to find the error.

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

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

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

$$\begin{bmatrix} \sum x_i^0 & \sum x_i^1 & \sum x_i^2 \\ \sum x_i^1 & \sum x_i^2 & \sum x_i^3 \\ \sum x_i^2 & \sum x_i^3 & \sum x_i^4 \end{bmatrix} \begin{bmatrix} a_0 \\ a_1 \\ a_2 \end{bmatrix} = \begin{bmatrix} \sum y_i \\ \sum y_i x_i \\ \sum y_i x_i^2 \end{bmatrix}$$

COEFFICIENT OF DETERMINATION  
 $R^2 = \frac{S_{y_1}^2}{S_y^2}$

## INTERPOLATION

Use a polynomial  $P(x)$



$$P(x) = a_0 + a_1 x + a_2 x^2 + \dots + a_n x^n$$



## ODE'S

### Euler's Method

$$\frac{dy}{dx} = f(x,y) \quad y_{n+1} = y_n + f(x_n, y_n) \Delta x$$

### Runge-Kutta Method

$$\frac{dy}{dx} = f(x,y)$$

$$y' = \frac{y^2 + 2x - f(x,y)}{2}$$

$$y' = \frac{y^2 + 2x - f(x,y) + f(2x, y)}{2}$$

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

$$y_{n+1} = y_n + \frac{\Delta x}{4} (k_1 + 2k_2 + 2k_3 + k_4)$$

$$k_1 = f(x_n, y_n)$$

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

$$k_3 = f(x_n + \frac{1}{2}\Delta x, y_n + k_2 \Delta x)$$

$$k_4 = f(x_n + \Delta x, y_n + k_3 \Delta x)$$

## PDE'S

### Finite Difference Method



## EIGEN VALUES

$\lambda = \text{Eigen Value}$

### Example 2x2

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

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

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

### Single 2x2

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

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

### 2x2 matrix with zero

$$\begin{bmatrix} a & b \\ c & d \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \end{bmatrix}$$

$$ax_1 + bx_2 = 0 \Rightarrow x_1 = -\frac{b}{a}x_2$$

$$cx_1 + dx_2 = 0 \Rightarrow x_1 = -\frac{d}{c}x_2$$

$$x_1 = \begin{bmatrix} -b \\ d \end{bmatrix}$$

### 3x3 matrix

$$\begin{bmatrix} a & b & c \\ d & e & f \\ g & h & i \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ x_3 \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ 0 \end{bmatrix}$$

$$-bx_1 + ex_2 = 0 \Rightarrow x_1 = \frac{e}{b}x_2$$

$$ax_1 - dx_2 + fx_3 = 0 \Rightarrow x_1 = \frac{d-fx_3}{a}$$

$$x_1 = \begin{bmatrix} e \\ a \end{bmatrix} x_2$$

### 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



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

### 5th Rank of a Matrix



$$\begin{bmatrix} 0 & -1 & 0 & -1 & 0 \\ 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} u_1 \\ u_2 \\ u_3 \\ u_4 \\ u_5 \end{bmatrix} = 0$$

### Right Boundary B.C.

$$\frac{\partial u}{\partial x} = 0 = \frac{u_{i+1} - u_i}{\Delta x}$$

$$u_{i+1} = u_i$$

### Left Boundary B.C.

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

### [A] MATRIX

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

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

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

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

### 5th Rank

$$\text{CENTERED FINITE-DIFFERENCE EQUATIONS}$$

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

$$f(x) = \frac{f(x+\Delta x) + 3f(x) - 3f(x-\Delta x) + f(x)}{4\Delta x}$$

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**M Lipman**



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