

# NUMERICAL METHODS

C / KAFFY EXAM 12 / 11/19 / 2022 [20.00]

### LEAST SQUARES REGRESSION

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

Residual:  $e_i = y_i - \hat{y}_i$

Sum of Squares Error (SSE):  $S_e = \sum_{i=1}^n e_i^2 = \sum_{i=1}^n (y_i - a_0 - a_1 x_i)^2$

Normal Equations:

$$\begin{cases} \sum y_i = n a_0 + a_1 \sum x_i \\ \sum x_i y_i = a_0 \sum x_i + a_1 \sum x_i^2 \end{cases}$$

Solving for  $a_0$  and  $a_1$ .

**STANDARD ERROR:**

$$S_{y_1} = \sqrt{\frac{S_e}{n-2}} \quad S_{y_2} = \sqrt{\frac{S_e (1-x^2)}{n-2}}$$

**STANDARD DEVIATION:**

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

$a_0 = \bar{y} - a_1 \bar{x}$   
 $a_1 = \frac{\sum (x_i - \bar{x})(y_i - \bar{y})}{\sum (x_i - \bar{x})^2}$

### INTERPOLATION

Use a 4th order polynomial

Order	Nodes	Degree	Nodes	Degree
1	2	1	3	2
2	3	2	4	3
3	4	3	5	4
4	5	4	6	5

Polynomial form:  $P_n(x) = a_0 + a_1 x + a_2 x^2 + \dots + a_n x^n$

**LAGRANGE:**  $L_i(x) = \prod_{j \neq i} \frac{x - x_j}{x_i - x_j}$

**NEWTON:**  $P(x) = f(x_0) + f'(x_0)(x-x_0) + \dots$

**SPRINGS:**  $P_n = \frac{f(x_{i+1}) - f(x_i)}{x_{i+1} - x_i}$

### POLYNOMIAL QUADRATIC REGRESSION

Goal: find the best fit quadratic curve to a set of data points.

Model:  $y = a_0 + a_1 x + a_2 x^2$

Normal Equations:

$$\begin{cases} \sum y_i = n a_0 + a_1 \sum x_i + a_2 \sum x_i^2 \\ \sum x_i y_i = a_0 \sum x_i + a_1 \sum x_i^2 + a_2 \sum x_i^3 \\ \sum x_i^2 y_i = a_0 \sum x_i^2 + a_1 \sum x_i^3 + a_2 \sum x_i^4 \end{cases}$$

Matrix form:  $[X^T X]^{-1} X^T Y$

### ODE'S

**Euler's Method:**  $y_{i+1} = y_i + f(x_i, y_i) \Delta x$

**Runge-Kutta Method:**  $y_{i+1} = y_i + f(x_i, y_i) \Delta x$

**Series Solution:**  $y = \sum_{n=0}^{\infty} a_n x^n$

**Taylor Series:**  $y(x) = y_0 + y_0' x + \frac{y_0''}{2!} x^2 + \dots$

**Classic 4th Order Runge-Kutta:**

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

where  $k_1 = f(x_i, y_i)$ ,  $k_2 = f(x_i + \frac{\Delta x}{2}, y_i + \frac{\Delta x}{2} k_1)$ ,  $k_3 = f(x_i + \frac{\Delta x}{2}, y_i + \Delta x k_2)$ ,  $k_4 = f(x_i + \Delta x, y_i + \Delta x k_3)$

## EIGEN VALUES

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

**Characteristic Equation:**  $\det(A - \lambda I) = 0 \Rightarrow \lambda^2 - (a+d)\lambda + (ad-bc) = 0$

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

**Eigenvectors:**  $(A - \lambda I)v = 0$

## PDE'S

### FINITE DIFFERENCE METHOD

Central Difference:  $\frac{\partial^2 u}{\partial x^2} \approx \frac{u_{i+1} - 2u_i + u_{i-1}}{\Delta x^2}$

### HEAT CONDUCTION

1D Heat Conduction:  $\frac{\partial^2 T}{\partial x^2} = \frac{1}{\alpha} \frac{\partial T}{\partial t}$

Steady State:  $\frac{d^2 T}{dx^2} = 0$

Boundary Conditions:  $T(0) = T_0, T(L) = T_L$

### HEAT CONDUCTION (2D)

Central Difference:  $\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2} = -\frac{q}{k}$

### 5th ROW OF A MATRIX

Matrix  $A$  and vector  $b$ .

Row 5:  $0 \cdot u_1 - 1 \cdot u_2 + 0 \cdot u_3 - 1 \cdot u_4 + 0 \cdot u_5 - 1 \cdot u_6 + 0 \cdot u_7 = 0$

### LEFT BOUNDARY B.C.

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

### [A] MATRIX

Matrix elements for finite difference method.

Interior nodes:  $u_{i,j} - u_{i+1,j} - u_{i-1,j} - u_{i,j+1} - u_{i,j-1} = -2 \Delta x G_{i,j}$

Top boundary:  $u_{i,0} - u_{i,1} + 9u_{i,1} - 2u_{i,2} = -2 \Delta x G_{i,0}$

### FINITE DIFFERENCE

Centered Finite-Difference Equations:

$$f(x) = \frac{f(x_0) - f(x_1)}{\Delta x}$$

$$f(x) = \frac{f(x_0) - 3f(x_1) + 3f(x_2) - f(x_3)}{12 \Delta x}$$

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**Yicheng Fang**



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