

# NUMERICAL METHODS

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

### LEAST SQUARES REGRESSION

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

Residuals are the vertical distances between the data points and the fitted line.

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

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

Minimize  $S_r^2$  by setting partial derivatives to zero:

$$\frac{\partial S_r^2}{\partial a_0} = -2 \sum_{i=1}^n (y_i - a_0 - a_1 x_i) = 0$$

$$\frac{\partial S_r^2}{\partial a_1} = -2 \sum_{i=1}^n x_i (y_i - a_0 - a_1 x_i) = 0$$

### STANDARD ERROR:

$$S_{y_1} = \sqrt{\frac{\sum y_i^2}{n-2}}$$

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

### STANDARD DEVIATION:

$$S_y = \sqrt{\frac{\sum y_i^2}{n}}$$

$$S_x = \sqrt{\frac{\sum x_i^2}{n}}$$

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

### INTERPOLATION

Use a 4th order polynomial

Order	Nodes	Degree	Nodes	Degree
1st	2	1	2	1
2nd	3	2	3	2
3rd	4	3	4	3
4th	5	4	5	4

$P_n(x) = a_0 + a_1 x + a_2 x^2 + \dots + a_n x^n$   
 Order:  $n=1, 2, 3, 4, 5$   
 Turns:  $0, 1, 2, 3, 4$

### SPINES:

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

### 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 best fit.  
 $\frac{\partial S_r}{\partial a_0} = -2 \sum_{i=1}^n (y_i - a_0 - a_1 x_i - a_2 x_i^2) = 0$   
 $\frac{\partial S_r}{\partial a_1} = -2 \sum_{i=1}^n x_i (y_i - a_0 - a_1 x_i - a_2 x_i^2) = 0$   
 $\frac{\partial S_r}{\partial a_2} = -2 \sum_{i=1}^n x_i^2 (y_i - a_0 - a_1 x_i - a_2 x_i^2) = 0$

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

### ODE'S

#### Runge-Kutta Method

$$y_{i+1} = y_i + f(x_i, y_i) \Delta x$$

#### Heun's Method

$$y_{i+1} = y_i + f(x_i, y_i) \Delta x + \frac{1}{2} (f(x_i, y_i) - f(x_{i+1}, y_{i+1})) \Delta x^2$$

#### Taylor Series

$$y(x+\Delta x) = y(x) + \Delta x y'(x) + \frac{\Delta x^2}{2} y''(x) + \dots$$

### CLASSIC 4th ORDER RUNGE-KUTTA:

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

$k_1 = f(x_i, y_i)$   
 $k_2 = f(x_i + \frac{1}{2} \Delta x, y_i + \frac{1}{2} \Delta x k_1)$   
 $k_3 = f(x_i + \frac{1}{2} \Delta x, y_i + \Delta x k_2)$   
 $k_4 = f(x_i + \Delta x, y_i + \Delta x k_3)$

## EIGEN VALUES

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

$\det(A - \lambda I) = \det \begin{bmatrix} a-\lambda & b \\ c & d-\lambda \end{bmatrix} = (a-\lambda)(d-\lambda) - bc = 0$   
 $\lambda^2 - (a+d)\lambda + (ad-bc) = 0$   
 $\lambda = \frac{(a+d) \pm \sqrt{(a+d)^2 - 4(ad-bc)}}{2}$

$[A - \lambda I] \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \end{bmatrix}$   
 $(a-\lambda)x_1 + bx_2 = 0$   
 $cx_1 + (d-\lambda)x_2 = 0$

### PDE'S

#### FINITE DIFFERENCE METHOD:

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

### HEAT CONDUCTION

$\frac{\partial^2 u}{\partial x^2} = 0$   
 Central Difference:  $\frac{u_{i+1} - 2u_i + u_{i-1}}{\Delta x^2} = 0$   
 $u_{i+1} + u_{i-1} = 2u_i$

Boundary conditions:  
 Left:  $u_0 = 0$   
 Right:  $u_N = 0$

### RIGHT BOUNDARY B.C.

$\frac{\partial u}{\partial x} = 0$  at  $x = L$   
 Central Difference:  $\frac{u_{i+1} - u_i}{\Delta x} = 0$   
 $u_{i+1} = u_i$

### LEFT BOUNDARY B.C.

$\frac{\partial u}{\partial x} = 0$  at  $x = 0$   
 Central Difference:  $\frac{u_1 - u_0}{\Delta x} = 0$   
 $u_1 = u_0$

### TOP BOUNDARY B.C.

$\frac{\partial u}{\partial y} = 0$  at  $y = 0$   
 Central Difference:  $\frac{u_{i,j+1} - u_{i,j}}{\Delta y} = 0$   
 $u_{i,j+1} = u_{i,j}$

### LEFT BOUNDARY B.C.

$u_{i,j} = u_{i,j+1} - 2 \Delta x g_j$

### [A] MATRIX:

$u_{i,j+1} = u_{i,j} + \Delta x g_j$   
 $-2u_{i,j} + u_{i,j+1} + u_{i,j-1} = -2 \Delta x g_j$   
 $u_{i,j-1} = u_{i,j} - \Delta x g_j$   
 $-2u_{i,j} + u_{i,j-1} + u_{i,j+1} = -2 \Delta x g_j$

### FINITE DIFFERENCE:

Centered Finite-Difference Error:  
 $f(x) = \frac{f(x+\Delta x) - f(x-\Delta x)}{2\Delta x}$   
 $f(x) = \frac{f(x+\Delta x) + 3f(x) - 3f(x-\Delta x) + f(x)}{4\Delta x}$

### FINITE DIFFERENCE:

Error analysis for various schemes.  
 $f(x) = \frac{f(x+\Delta x) - f(x-\Delta x)}{2\Delta x}$   
 $f(x) = \frac{f(x+\Delta x) + 3f(x) - 3f(x-\Delta x) + f(x)}{4\Delta x}$

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**Rosina Ehmann**



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