

# 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.

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

Sum of squares of residuals:  $S = \sum_{i=1}^n e_i^2 = \sum_{i=1}^n (y_i - a_0 - a_1 x_i)^2$

Normal equations:

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

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

Matrix form:  $\begin{bmatrix} n & \sum x_i \\ \sum x_i & \sum x_i^2 \end{bmatrix} \begin{bmatrix} a_0 \\ a_1 \end{bmatrix} = \begin{bmatrix} \sum y_i \\ \sum x_i y_i \end{bmatrix}$

### STANDARD ERROR:

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

$$S_{y-x} = \sqrt{\frac{\sum (y_i - \hat{y}_i)^2}{n-2}}$$

### STANDARD DEVIATION:

$$S_y = \sqrt{\frac{\sum y_i^2}{n-1}}$$

$$S_{y-x} = \sqrt{\frac{\sum (y_i - \hat{y}_i)^2}{n-1}}$$

### INTERPOLATION

Use a polynomial  $P(x)$ :

Degree 0	Degree 1	Degree 2	Degree n
1 point	2 points	3 points	n+1 points
0 nodes	1 node	2 nodes	n nodes

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

Order:  $n=1$  (line),  $n=2$  (parabola),  $n=3$  (cubic),  $n=4$  (quartic)

Turns:  $n=1$  (0),  $n=2$  (1),  $n=3$  (2),  $n=4$  (3),  $n=1$  (0)

Splices:  $P_1 = \frac{f(x_1) - f(x_0)}{x_1 - x_0}$

### POLYNOMIAL QUADRATIC REGRESSION

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

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

Sum of squares of residuals:  $S = \sum_{i=1}^n (y_i - a_0 - a_1 x_i - a_2 x_i^2)^2$

Normal equations:

$$\frac{\partial S}{\partial a_0} = -2 \sum_{i=1}^n (y_i - a_0 - a_1 x_i - a_2 x_i^2) = 0$$

$$\frac{\partial S}{\partial a_1} = -2 \sum_{i=1}^n x_i (y_i - a_0 - a_1 x_i - a_2 x_i^2) = 0$$

$$\frac{\partial S}{\partial a_2} = -2 \sum_{i=1}^n x_i^2 (y_i - a_0 - a_1 x_i - a_2 x_i^2) = 0$$

Matrix form:  $\begin{bmatrix} n & \sum x_i & \sum x_i^2 \\ \sum x_i & \sum x_i^2 & \sum x_i^3 \\ \sum x_i^2 & \sum x_i^3 & \sum x_i^4 \end{bmatrix} \begin{bmatrix} a_0 \\ a_1 \\ a_2 \end{bmatrix} = \begin{bmatrix} \sum y_i \\ \sum x_i y_i \\ \sum x_i^2 y_i \end{bmatrix}$

### ODE'S

Runge-Kutta method:

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

Heun's method:

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

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

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

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

Single 2x2:

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

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

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

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

### RIGHT BOUNDARY B.C.

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

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

### LEFT BOUNDARY B.C.

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

### PDE'S

#### FINITE DIFFERENCE METHOD

Central difference:

$$u_{xx} = \frac{u_{i+1,j} - 2u_{i,j} + u_{i-1,j}}{\Delta x^2}$$

Right boundary:

$$u_{xx} = \frac{u_{i+1,j} - 2u_{i,j} + u_{i-1,j}}{\Delta x^2}$$

Left boundary:

$$u_{xx} = \frac{u_{i+1,j} - 2u_{i,j} + u_{i-1,j}}{\Delta x^2}$$

#### TOP BOUNDARY B.C.

$$\frac{\partial u}{\partial y} = u_y = \frac{u_{i,j+1} - u_{i,j}}{\Delta y}$$

$$u_{i,j+1} = u_{i,j} + 2\Delta y u_y$$

#### BOTTOM BOUNDARY B.C.

$$\frac{\partial u}{\partial y} = u_y = \frac{u_{i,j+1} - u_{i,j}}{\Delta y}$$

$$u_{i,j+1} = u_{i,j} + 2\Delta y u_y$$

#### 5th ROW OF A MATRIX

$$\begin{bmatrix} 0 & -1 & 0 & -1 & 4 & -1 & 0 & -1 & 0 \end{bmatrix} \begin{bmatrix} u_1 \\ u_2 \\ u_3 \\ u_4 \\ u_5 \\ u_6 \\ u_7 \\ u_8 \\ u_9 \end{bmatrix} = 0$$

### [A] MATRIX

Centered finite-diff eqs:

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

$$-2u_{i,j+1} + 4u_{i,j} - 2u_{i,j-1} = -2\Delta y^2 u_{yy}$$

### FINITE DIFFS

Centered finite-diff eqs:

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

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