

# NUMERICAL METHODS

C / RAPPY 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:

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

## STANDARD DEVIATION:

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

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

## 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.

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

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

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

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

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

## INTERPOLATION

Use a polynomial  $P(x)$

LAGRANGE	DEGREE 1	DEGREE 2	DEGREE n
2 Pts 1 unknown $P(x) = a_0 + a_1 x$	3 Pts 2 unknown $P(x) = a_0 + a_1 x + a_2 x^2$	4 Pts 3 unknown	n+1 Pts n unknown
<b>ORDER</b> n=1 n=2 n=3 n=4			
	<b>TURNS</b> 0 1 2 n-1		
		<b>SPINES:</b> $P_n = \frac{f(x_{i+1}) - f(x_i)}{x_{i+1} - x_i}$	

## ODE'S

### EULER METHOD

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

### HEUN'S METHOD

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

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

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

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

### CLASSIC 4th ORDER RUNGE-KUTTA

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

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

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

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

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

## PDE'S

### FINITE DIFFERENCE METHOD



## EIGEN VALUES

$\lambda = \text{eigen value}$

Example:  $2 \times 2$

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

The determinant:

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

$$A = \begin{bmatrix} a & b \\ c & d \end{bmatrix} \begin{bmatrix} x \\ y \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \end{bmatrix}$$

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

$$\begin{bmatrix} a-\lambda & b \\ c & d-\lambda \end{bmatrix} \begin{bmatrix} x \\ y \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \end{bmatrix}$$

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

Find eigen value using

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

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

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

$$x_1 = \begin{bmatrix} 1 \\ -1 \end{bmatrix}$$

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

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

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

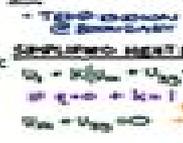
$$x_2 = \begin{bmatrix} 1 \\ 1 \end{bmatrix}$$

### 1D Heat Conduction



$$u_{i+1}(t) = u_i(t) - \alpha \Delta x \frac{u_i(t) - u_{i-1}(t)}{\Delta x} + u_i(t) + \alpha \Delta x^2 \frac{u_{i+1}(t) - 2u_i(t) + u_{i-1}(t)}{\Delta x^2}$$

### 2D Heat Conduction



$$u_{i,j}(t) = u_{i,j}(t) - \alpha \Delta x \frac{u_{i,j}(t) - u_{i-1,j}(t)}{\Delta x} - \alpha \Delta y \frac{u_{i,j}(t) - u_{i,j-1}(t)}{\Delta y} + u_{i,j}(t) + \alpha \Delta x^2 \frac{u_{i+1,j}(t) - 2u_{i,j}(t) + u_{i-1,j}(t)}{\Delta x^2} + \alpha \Delta y^2 \frac{u_{i,j+1}(t) - 2u_{i,j}(t) + u_{i,j-1}(t)}{\Delta y^2}$$

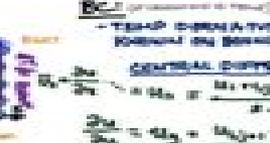
### 1D Heat Conduction



$$\frac{\partial u}{\partial t} = \alpha \frac{\partial^2 u}{\partial x^2}$$

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

### 2D Heat Conduction



$$\frac{\partial u}{\partial t} = \alpha \frac{\partial^2 u}{\partial x^2} + \alpha \frac{\partial^2 u}{\partial y^2}$$

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

### 5th Rank of a Matrix



$$\frac{\partial u}{\partial t} = \alpha \frac{\partial^2 u}{\partial x^2} + \alpha \frac{\partial^2 u}{\partial y^2}$$

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

### 5th Rank of a Matrix



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

[A] MATRIX:

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

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

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

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

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

FINITE DIFFERENCE:

$$f(x) = \frac{f(x_1) - f(x_2)}{\Delta x}$$

$$f(x) = \frac{f(x_1) - 3f(x_2) + 3f(x_3) - f(x_4)}{12 \Delta x}$$

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**Renato de Leone, Almerico Murli, Panos  
M. Pardalos, Gerardo Toraldo**

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## **Table of Contents Numerical Analysis Lecture Notes Math User Home Pages**

1. Understanding the eBook Numerical Analysis Lecture Notes Math User Home Pages
  - The Rise of Digital Reading Numerical Analysis Lecture Notes Math User Home Pages
  - Advantages of eBooks Over Traditional Books
2. Identifying Numerical Analysis Lecture Notes Math User Home Pages
  - Exploring Different Genres
  - Considering Fiction vs. Non-Fiction
  - Determining Your Reading Goals
3. Choosing the Right eBook Platform
  - Popular eBook Platforms
  - Features to Look for in an Numerical Analysis Lecture Notes Math User Home Pages
  - User-Friendly Interface
4. Exploring eBook Recommendations from Numerical Analysis Lecture Notes Math User Home Pages
  - Personalized Recommendations
  - Numerical Analysis Lecture Notes Math User Home Pages User Reviews and Ratings
  - Numerical Analysis Lecture Notes Math User Home Pages and Bestseller Lists
5. Accessing Numerical Analysis Lecture Notes Math User Home Pages Free and Paid eBooks
  - Numerical Analysis Lecture Notes Math User Home Pages Public Domain eBooks
  - Numerical Analysis Lecture Notes Math User Home Pages eBook Subscription Services
  - Numerical Analysis Lecture Notes Math User Home Pages Budget-Friendly Options
6. Navigating Numerical Analysis Lecture Notes Math User Home Pages eBook Formats
  - ePub, PDF, MOBI, and More
  - Numerical Analysis Lecture Notes Math User Home Pages Compatibility with Devices
  - Numerical Analysis Lecture Notes Math User Home Pages Enhanced eBook Features

7. Enhancing Your Reading Experience
  - Adjustable Fonts and Text Sizes of Numerical Analysis Lecture Notes Math User Home Pages
  - Highlighting and Note-Taking Numerical Analysis Lecture Notes Math User Home Pages
  - Interactive Elements Numerical Analysis Lecture Notes Math User Home Pages
8. Staying Engaged with Numerical Analysis Lecture Notes Math User Home Pages
  - Joining Online Reading Communities
  - Participating in Virtual Book Clubs
  - Following Authors and Publishers Numerical Analysis Lecture Notes Math User Home Pages
9. Balancing eBooks and Physical Books Numerical Analysis Lecture Notes Math User Home Pages
  - Benefits of a Digital Library
  - Creating a Diverse Reading Collection Numerical Analysis Lecture Notes Math User Home Pages
10. Overcoming Reading Challenges
  - Dealing with Digital Eye Strain
  - Minimizing Distractions
  - Managing Screen Time
11. Cultivating a Reading Routine Numerical Analysis Lecture Notes Math User Home Pages
  - Setting Reading Goals Numerical Analysis Lecture Notes Math User Home Pages
  - Carving Out Dedicated Reading Time
12. Sourcing Reliable Information of Numerical Analysis Lecture Notes Math User Home Pages
  - Fact-Checking eBook Content of Numerical Analysis Lecture Notes Math User Home Pages
  - Distinguishing Credible Sources
13. Promoting Lifelong Learning
  - Utilizing eBooks for Skill Development
  - Exploring Educational eBooks
14. Embracing eBook Trends
  - Integration of Multimedia Elements
  - Interactive and Gamified eBooks

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