

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:

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

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.

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

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

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

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

Matrix inversion to find coefficients.

INTERPOLATION

Use a polynomial $P(x)$



ODE'S

Euler's Method

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

Runge-Kutta Method

$$y' = f(x,y)$$

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

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

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

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

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

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

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

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

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

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

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

PDE'S

Finite Difference Method



EIGEN VALUES

$\lambda = \text{Eigen Value}$

Example: 2×2

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

The determinant

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

$$A = \begin{bmatrix} a & b \\ c & d \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} = \frac{1}{\det(A)} \begin{bmatrix} a & b \\ c & d \end{bmatrix} \begin{bmatrix} a-\lambda & b \\ c & d-\lambda \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix}$$

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

Find Eigen Value with given

$$\begin{bmatrix} 1 & 1 \\ 1 & 1 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} = \begin{bmatrix} \lambda x_1 \\ \lambda x_2 \end{bmatrix}$$

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

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

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

$$\begin{bmatrix} 1 & -1 \\ -1 & 1 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \end{bmatrix}$$

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

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

$$C_1 \begin{bmatrix} 1 \\ 1 \end{bmatrix}$$

1D Heat Conduction



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

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

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

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

2D Heat Conduction



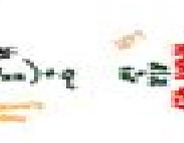
$$u_{i,j+1}(t) = u_{i,j}(t) + \alpha \Delta x (u_{i,j+1} - u_{i,j}) + \alpha \Delta y (u_{i,j} - u_{i-1,j})$$

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

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

3D Heat Conduction



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

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

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

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

Steady State



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

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

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

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

Central Difference



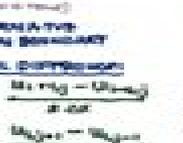
$$\frac{\partial^2 u}{\partial x^2} = \frac{u_{i+1} - 2u_i + u_{i-1}}{\Delta x^2}$$

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

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

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

5th Rank of a Matrix



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

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

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

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

Right Boundary B.C.



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

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

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

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

Top Boundary B.C.



$$\frac{\partial u}{\partial y} = 0 = \frac{u_{i,j} - u_{i,j-1}}{\Delta y}$$

$$\frac{\partial u}{\partial y} = 0 = \frac{u_{i,j} - u_{i,j-1}}{\Delta y}$$

$$\frac{\partial u}{\partial y} = 0 = \frac{u_{i,j} - u_{i,j-1}}{\Delta y}$$

$$\frac{\partial u}{\partial y} = 0 = \frac{u_{i,j} - u_{i,j-1}}{\Delta y}$$

Left Boundary B.C.



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

TRUNCATION ERROR

Centered Finite-Difference Error

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

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

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Léo Pomar



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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
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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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