

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.



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

1. sum of the square errors.
2. minimize the square of the errors.

$$a_0 = \frac{\sum y_i - a_1 \sum x_i}{n}$$

$$a_0 = \frac{\sum y_i}{n} - a_1 \frac{\sum x_i}{n} \Rightarrow a_0 = 5 - 0.8$$

STANDARD ERROR:

$$S_{y_1} = \sqrt{\frac{\sum y_i^2}{n-2}} \quad S_{y_2} = \sqrt{\frac{\sum (y_i - \bar{y})^2}{n-2}}$$

STANDARD DEVIATION:

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

$$a_0 = 5 - 0.8x$$

INTERPOLATION

Use a polynomial fit:



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



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

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 errors.

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

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

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

$$\begin{bmatrix} \sum 1 & \sum x_i & \sum x_i^2 \\ \sum x_i & \sum x_i^2 & \sum x_i^3 \\ \sum x_i^2 & \sum x_i^3 & \sum x_i^4 \end{bmatrix} \begin{bmatrix} a_0 \\ a_1 \\ a_2 \end{bmatrix} = \begin{bmatrix} \sum y_i \\ \sum y_i x_i \\ \sum y_i x_i^2 \end{bmatrix} \rightarrow [A][X] = [B]$$

$S_r = \sqrt{\frac{\sum (y_i - \hat{y}_i)^2}{n-3}}$
Coefficient of determination: $r^2 = \frac{S_r^2}{S_y^2}$

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

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

$$y' = \frac{y^2 + 2x - f(x,y)}{2}$$

$$y' = \frac{y^2 + 2x - f(x,y) + f(2x, y)}{2}$$

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

Classic 4th order Runge-Kutta

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

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

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

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

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

Forward Time, Backward Space
 $y_{i+1} = y_i + \Delta x \sum_{j=1}^n B_j k_j$ (Lump Model)
 $y_{i+1} = y_i + \Delta x \sum_{j=1}^n b_j k_j$ (Distributed Model)

PDE'S

Finite Difference Method



EIGEN VALUES

$\lambda = \text{Eigen Value}$

Example:

$$\begin{bmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ x_3 \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ 0 \end{bmatrix}$$

Tridiagonal:

$$\begin{bmatrix} a_{11} & a_{12} & 0 \\ a_{21} & a_{22} & a_{23} \\ 0 & a_{32} & a_{33} \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ x_3 \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ 0 \end{bmatrix}$$

Single 2x2:

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

$$[A] = \frac{1}{\det(A)} \begin{bmatrix} d & -b \\ -c & a \end{bmatrix} [B]$$

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

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

Two Eigen Values with same λ :

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

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

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

Eigen Value: $\lambda = 1$

$x_1 = [-1]$

$[A]^{-1} [A] = [I]$

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

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

Eigen Value: $\lambda = 1$

Two Eigenvectors: $[A] = [I]$

1D Conduction

BC: (Left boundary is fixed)

- Temp. known at boundary

Discretized Heat Eq:

$$u_i = \alpha(u_{i-1} + u_{i+1} + u_{i+2}) + q$$

at $q=0$ and $k=1$

$$u_{i+1} + u_{i+2} = 0$$

Central Difference:

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

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

2D Conduction

BC: (Left boundary is fixed)

- Temp. known at boundary

Central Difference:

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

Right Boundary B.C.:

$$\frac{\partial u}{\partial x} = 0 = \frac{u_{i+1,j} - u_{i-1,j}}{2\Delta x}$$

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

Bottom Boundary B.C.:

$$\frac{\partial u}{\partial y} = 0 = \frac{u_{i,j+1} - u_{i,j-1}}{2\Delta y}$$

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

Top Boundary B.C.:

$$\frac{\partial u}{\partial y} = 0 = \frac{u_{i,j+1} - u_{i,j-1}}{2\Delta y}$$

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

Left Boundary B.C.:

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

5th Row of A Matrix

Local's finite diff adjacent to boundary

$$\begin{bmatrix} 0 & -1 & 0 & -1 & 0 & -1 & 0 & -1 & 0 \end{bmatrix} [u] = 0$$

[A] Matrix:

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

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

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

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

TOP:

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

5th Row:

Centered finite diff adjacent to boundary

$$f(x) = \frac{f(x_2) - f(x_0)}{2\Delta x}$$

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

Numerical Analysis Using R

Wenbin Ji



Numerical Analysis Using R:

The Enigmatic Realm of **Numerical Analysis Using R**: Unleashing the Language is Inner Magic

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