

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.



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

Residual Error = $y_i - \hat{y}_i$

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

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

STANDARD ERROR:

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

STANDARD DEVIATION:

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

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

POLYNOMIAL QUADRATIC REGRESSION:



$$S_r = \sum_{i=1}^n (y_i - a_0 - a_1 x_i - a_2 x_i^2)^2$$

Take derivative of S_r to find minimum.

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

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

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

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

Matrix inversion method

INTERPOLATION

Use a polynomial fit:



ODE'S

Euler's Method

$$\frac{dy}{dx} = f(x,y) \quad y_{n+1} = y_n + f(x_n, y_n) \Delta x$$

Runge-Kutta Method

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

$$k_1 = f(x_n, y_n)$$

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

$$k_3 = f(x_n + \Delta x, y_n + \Delta x k_2)$$

$$y_{n+1} = y_n + \Delta x \left(\frac{1}{6} k_1 + \frac{4}{6} k_2 + \frac{1}{6} k_3 \right)$$

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

$$y_{n+1} = y_n + \Delta x \left(\frac{1}{4} k_1 + 3 \frac{k_2}{4} + \frac{3}{4} k_3 + k_4 \right)$$

$$k_1 = f(x_n, y_n)$$

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

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

$$k_4 = f(x_n + \Delta x, y_n + \Delta x k_3)$$

PDE'S

Finite Difference Method



EIGEN VALUES

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

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

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

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

Single 2x2:

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

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

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

Two eigen values with same eigenvector:

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

$$(a-\lambda)x_1 + bx_2 = 0$$

$$cx_1 + (d-\lambda)x_2 = 0$$

Two eigen values with different eigenvectors:

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

$$-bx_1 + (a-\lambda)x_2 = 0$$

$$(c-\lambda)x_1 - dx_2 = 0$$

1D Heat Conduction

BC: (Boundary Conditions)

- Temp. constant at boundary
- Insulated heat flow: $u_x = 0$ at $x=0, L$
- Dirichlet BC: $u = 0$ at $x=0, L$
- Neumann BC: $u_x = 0$ at $x=0, L$

Central Difference:

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

2D Heat Conduction

BC: (Boundary Conditions)

- Temp. constant at boundary
- Insulated heat flow: $u_x = 0$ at $x=0, L$
- Dirichlet BC: $u = 0$ at $x=0, L$
- Neumann BC: $u_x = 0$ at $x=0, L$

Central Difference:

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

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

RIGHT NEUMANN B.C.

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

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

TOP NEUMANN B.C.

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

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

5th Row of A Matrix

Local stencil with adjacent to boundary:

$$\begin{bmatrix} 0 & -1 & 0 & -1 & 4 & -1 & 0 & -1 & 0 \end{bmatrix} u = 0$$

[A] MATRIX:

Interior nodes:

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

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

Boundary nodes:

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

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

5th Row of A Matrix

Centered finite-diff stencil:

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

$$f(x) = \frac{f(x+\Delta x) + 3f(x) - 3f(x-\Delta x) + f(x-\Delta x)}{4\Delta x}$$

Numerical Computing With Matlab Solutions

**Alfio Quarteroni, Fausto Saleri, Paola
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