

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:

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

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

INTERPOLATION

Use a polynomial $P(x)$ to approximate $f(x)$.

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)

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

POLYNOMIAL QUADRATIC REGRESSION

Goal: find a quadratic polynomial $P(x) = a_0 + a_1 x + a_2 x^2$ that fits the data points.

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

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

Runge-Kutta method:

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

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

Taylor Series

$f(x) = f(x_0) + f'(x_0)(x-x_0) + \frac{f''(x_0)}{2!}(x-x_0)^2 + \dots$

CLASSIC 4th ORDER RUNGE-KUTTA

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

$k_1 = f(x_i, y_i)$
 $k_2 = f(x_i + \frac{1}{2}\Delta x, y_i + \frac{1}{2}\Delta x k_1)$
 $k_3 = f(x_i + \frac{1}{2}\Delta x, y_i - \frac{1}{2}\Delta x k_1 + \Delta x k_2)$
 $k_4 = f(x_i + \Delta x, y_i + \Delta x k_3)$

PDE'S

FINITE DIFFERENCE METHOD

Central difference: $\frac{\partial^2 u}{\partial x^2} \approx \frac{u_{i+1} - 2u_i + u_{i-1}}{\Delta x^2}$

EIGEN VALUES

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

Characteristic equation: $\det(A - \lambda I) = 0$

$$\begin{vmatrix} a-\lambda & b \\ c & d-\lambda \end{vmatrix} = (a-\lambda)(d-\lambda) - bc = 0$$

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

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

Single 2x2

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

$\det(A - \lambda I) = 0$

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

Two eigen values

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

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

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

Two eigen values

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

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

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

HEAT CONDUCTION

1D heat conduction in a rod of length L.

Boundary conditions: $u(0, t) = u(L, t) = 0$

Central difference: $\frac{\partial^2 u}{\partial x^2} \approx \frac{u_{i+1} - 2u_i + u_{i-1}}{\Delta x^2}$

Discretized heat equation: $u_t = \alpha (u_{i+1} - 2u_i + u_{i-1}) + q$

RIGHT BOUNDARY B.C.

$\frac{\partial u}{\partial x} = 0$ at $x=L$

Central difference: $\frac{u_{i+1} - u_{i-1}}{2\Delta x} = 0$

$u_{i+1} = u_{i-1}$

LEFT BOUNDARY B.C.

$\frac{\partial u}{\partial x} = 0$ at $x=0$

Central difference: $\frac{u_1 - u_{-1}}{2\Delta x} = 0$

$u_1 = u_{-1}$

TOP BOUNDARY B.C.

$u = 0$ at $t=0$

$u_{i,0} = 0$

LEFT BOUNDARY B.C.

$u = 0$ at $x=0$

$u_{i,0} = u_{i-1,0} - 2\alpha \Delta t u_{i-1,0}$

[A] MATRIX

Matrix for the heat equation:

$$A_{i,j} = \begin{cases} -1 & j=i-1 \\ 2 & j=i \\ -1 & j=i+1 \end{cases}$$

FINITE DIFFERENCE

Centered finite-difference approximation:

$$f''(x) \approx \frac{f(x+\Delta x) - 2f(x) + f(x-\Delta x))}{\Delta x^2}$$

RIGHT BOUNDARY B.C.

$\frac{\partial u}{\partial x} = 0$ at $x=L$

$u_{i+1} = u_{i-1}$

LEFT BOUNDARY B.C.

$\frac{\partial u}{\partial x} = 0$ at $x=0$

$u_1 = u_{-1}$

TOP BOUNDARY B.C.

$u = 0$ at $t=0$

$u_{i,0} = 0$

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