

# 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.



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

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

$$a_0 = \frac{\sum y_i}{n} \quad a_1 = \frac{\sum x_i y_i - \frac{(\sum x_i)(\sum y_i)}{n}}{\sum x_i^2 - \frac{(\sum x_i)^2}{n}}$$

## STANDARD ERROR:

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

## STANDARD DEVIATION:

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

## POLYNOMIAL QUADRATIC REGRESSION:



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

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

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

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

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

## EIGEN VALUES

$\lambda = \text{Eigen Value}$

Example:  $\begin{bmatrix} 2 & 1 \\ 1 & 2 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \end{bmatrix}$

$$A = \begin{bmatrix} 2 & 1 \\ 1 & 2 \end{bmatrix} \quad \det(A - \lambda I) = \det \begin{bmatrix} 2-\lambda & 1 \\ 1 & 2-\lambda \end{bmatrix} = (2-\lambda)^2 - 1 = 0$$

$$\lambda^2 - 4\lambda + 3 = 0 \Rightarrow (\lambda-1)(\lambda-3) = 0 \Rightarrow \lambda = 1, 3$$

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

$$\lambda = 3 \Rightarrow \begin{bmatrix} -1 & 1 \\ 1 & -1 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \end{bmatrix} \Rightarrow x_1 = x_2$$

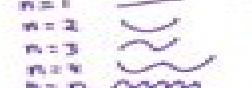
## INTERPOLATION

Use a polynomial  $P(x)$



Linear: 2 pts, 1 interval, 1 degree  
Quadratic: 3 pts, 2 intervals, 2 degree  
Cubic: 4 pts, 3 intervals, 3 degree

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



Degree 1:



Degree 2:



Degree 3:



Degree n:



$n+1$  pts,  $n+1$  nodes

## SPINES:

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

## ODE'S

### Runge-Kutta Method

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

### Heun's Method

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

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

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

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

## CLASSIC 4th ORDER Runge-Kutta

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

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

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

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

$$k_4 = f(x_i + \Delta x, y_i + \Delta x k_1)$$

Forward Euler:  $y_{i+1} = y_i + \Delta x f(x_i, y_i)$   
Backward Euler:  $y_{i+1} = y_i + \Delta x f(x_{i+1}, y_{i+1})$

## PDE'S

### FINITE DIFFERENCE METHOD



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

Forward Difference:  $\frac{\partial u}{\partial x} = \frac{u_{i+1,j} - u_{i,j}}{\Delta x}$

Backward Difference:  $\frac{\partial u}{\partial x} = \frac{u_{i,j} - u_{i-1,j}}{\Delta x}$

Central Difference:  $\frac{\partial^2 u}{\partial x^2} = \frac{u_{i+1,j} - 2u_{i,j} + u_{i-1,j}}{\Delta x^2}$

Forward Difference:  $\frac{\partial^2 u}{\partial x^2} = \frac{u_{i+2,j} - 2u_{i+1,j} + u_{i,j}}{\Delta x^2}$

Backward Difference:  $\frac{\partial^2 u}{\partial x^2} = \frac{u_{i,j} - 2u_{i-1,j} + u_{i-2,j}}{\Delta x^2}$

### HEAT CONDUCTION

1D Heat Conduction:  $\frac{\partial^2 T}{\partial x^2} = \frac{1}{\alpha^2} \frac{\partial T}{\partial t}$

Steady State:  $\frac{\partial^2 T}{\partial x^2} = 0$

Transient:  $\frac{\partial^2 T}{\partial x^2} = \frac{1}{\alpha^2} \frac{\partial T}{\partial t}$

Boundary Conditions:  $T(0,t) = T(L,t) = 0$

Initial Condition:  $T(x,0) = T_0(x)$

Discretization:  $\Delta x, \Delta t$

Matrix Form:  $A \mathbf{T} = \mathbf{b}$

Right Boundary B.C.:  $\frac{\partial T}{\partial x} = 0$  at  $x=L$

Bottom Boundary B.C.:  $\frac{\partial T}{\partial y} = 0$  at  $y=0$

Top Boundary B.C.:  $\frac{\partial T}{\partial y} = 0$  at  $y=L$

Left Boundary B.C.:  $\frac{\partial T}{\partial x} = 0$  at  $x=0$

### HEAT CONDUCTION

1D Heat Conduction:  $\frac{\partial^2 T}{\partial x^2} = \frac{1}{\alpha^2} \frac{\partial T}{\partial t}$

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Left Boundary B.C.:  $\frac{\partial T}{\partial x} = 0$  at  $x=0$

### 5th ROW OF A MATRIX

Local truncation error:  $\tau_i = \frac{1}{5!} y^{(5)}(x_i) \Delta x^5$

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

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## [A] MATRIX:

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

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

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

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

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

## TRUNCATION ERROR

Local truncation error:  $\tau_i = \frac{1}{5!} y^{(5)}(x_i) \Delta x^5$

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

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# Numerical Methods Lecture Notes 01 Vsb

**JG Myers**



## **Numerical Methods Lecture Notes 01 Vsb:**

**Domain Decomposition Methods in Science and Engineering XIX** Yunqing Huang, Ralf Kornhuber, Olof Widlund, Jinchao Xu, 2010-10-27 These are the proceedings of the 19th international conference on domain decomposition methods in science and engineering Domain decomposition methods are iterative methods for solving the often very large linear or nonlinear systems of algebraic equations that arise in various problems in mathematics computational science engineering and industry They are designed for massively parallel computers and take the memory hierarchy of such systems into account This is essential for approaching peak floating point performance There is an increasingly well developed theory which is having a direct impact on the development and improvement of these algorithms Advanced Multimedia and Ubiquitous Engineering James J. (Jong Hyuk) Park, Han-Chieh Chao, Hamid Arabnia, Neil Y. Yen, 2015-05-26 This volume brings together contributions representing the state of the art in new multimedia and future technology information research currently a major topic in computer science and electronic engineering Researchers aim to interoperate multimedia frameworks transforming the way people work and interact with multimedia data This book covers future information technology topics including digital and multimedia convergence ubiquitous and pervasive computing intelligent computing and applications embedded systems mobile and wireless communications bio inspired computing grid and cloud computing semantic web human centric computing and social networks adaptive and context aware computing security and trust computing and related areas Representing the combined proceedings of the 9th International Conference on Multimedia and Ubiquitous Engineering MUE 15 and the 10th International Conference on Future Information Technology Future Tech 2015 this book aims to provide a complete coverage of the areas outlined and to bring together researchers from academic and industry and other practitioners to share their research ideas challenges and solutions **Parallel Processing and Applied Mathematics** Roman Wyrzykowski, Jack Dongarra, Marcin Paprzycki, Jerzy Wasniewski, 2003-08-01 This book constitutes the thoroughly refereed post proceedings of the 4th International Conference on Parallel Processing and Applied Mathematics PPAM 2002 held in Naleczow Poland in September 2001 The 101 papers presented were carefully reviewed and improved during two rounds of reviewing and revision The book offers topical sections on distributed and grid architectures scheduling and load balancing performance analysis and prediction parallel non numerical algorithms parallel programming tools and environments parallel numerical algorithms applications and evolutionary computing and neural networks *Domain Decomposition Methods in Science and Engineering XX* Randolph Bank, Michael Holst, Olof Widlund, Jinchao Xu, 2013-07-03 These are the proceedings of the 20th international conference on domain decomposition methods in science and engineering Domain decomposition methods are iterative methods for solving the often very large linear or nonlinear systems of algebraic equations that arise when various problems in continuum mechanics are discretized using finite elements They are designed for massively parallel computers and take the memory hierarchy of such systems in mind This is

essential for approaching peak floating point performance There is an increasingly well developed theory which is having a direct impact on the development and improvements of these algorithms Domain Decomposition Methods in Science and Engineering XXII Thomas Dickopf, Martin J. Gander, Laurence Halpern, Rolf Krause, Luca F. Pavarino, 2016-03-11 These are the proceedings of the 22nd International Conference on Domain Decomposition Methods which was held in Lugano Switzerland With 172 participants from over 24 countries this conference continued a long standing tradition of internationally oriented meetings on Domain Decomposition Methods The book features a well balanced mix of established and new topics such as the manifold theory of Schwarz Methods Isogeometric Analysis Discontinuous Galerkin Methods exploitation of modern HPC architectures and industrial applications As the conference program reflects the growing capabilities in terms of theory and available hardware allow increasingly complex non linear and multi physics simulations confirming the tremendous potential and flexibility of the domain decomposition concept **Optimization with PDE Constraints** Ronald Hoppe, 2014-09-11 This book on PDE Constrained Optimization contains contributions on the mathematical analysis and numerical solution of constrained optimal control and optimization problems where a partial differential equation PDE or a system of PDEs appears as an essential part of the constraints The appropriate treatment of such problems requires a fundamental understanding of the subtle interplay between optimization in function spaces and numerical discretization techniques and relies on advanced methodologies from the theory of PDEs and numerical analysis as well as scientific computing The contributions reflect the work of the European Science Foundation Networking Programme Optimization with PDEs OPTPDE *Computational Intelligence in Emerging Technologies for Engineering Applications* Orestes Llanes Santiago, Carlos Cruz Corona, Antônio José Silva Neto, José Luis Verdegay, 2020-02-14 This book explores applications of computational intelligence in key and emerging fields of engineering especially with regard to condition monitoring and fault diagnosis inverse problems decision support systems and optimization These applications can be beneficial in a broad range of contexts including water distribution networks manufacturing systems production and storage of electrical energy heat transfer acoustic levitation uncertainty and robustness of infinite dimensional objects fatigue failure prediction autonomous navigation nanotechnology and the analysis of technological development indexes All applications mathematical and computational tools and original results are presented using rigorous mathematical procedures Further the book gathers contributions by respected experts from 22 different research centers and eight countries Brazil Cuba France Hungary India Japan Romania and Spain The book is intended for use in graduate courses on applied computation applied mathematics and engineering where tools like computational intelligence and numerical methods are applied to the solution of real world problems in emerging areas of engineering The Mechanical World, 1912 **German books in print**, 2000 Bell Laboratories Talks and Papers Bell Telephone Laboratories. Libraries and Information Systems Center, 1974 Agindex, 1990 Physics Briefs, 1981 **The IEEE Standard Dictionary of Electrical and**

**Electronics Terms** Institute of Electrical and Electronics Engineers, Jane Radatz, Institute of Electrical and Electronics Engineers. Standards Coordinating Committee 10, Terms and Definitions, 1997  
Fr her u d T Institute of Electrical and Electronics Engineers The new IEEE standard dictionary of electrical and electronics terms  
Monthly Index of Russian Accessions, 1958  
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Verzeichnis lieferbarer Bücher, 1988

*Lecture Notes on Numerical Methods in Engineering and Sciences*, 2009

### **Introduction To Numerical**

**Computation, An (Second Edition)** Wen Shen, 2019-08-28 This book serves as a set of lecture notes for a senior undergraduate level course on the introduction to numerical computation which was developed through 4 semesters of teaching the course over 10 years The book requires minimum background knowledge from the students including only a three semester of calculus and a bit on matrices The book covers many of the introductory topics for a first course in numerical computation which fits in the short time frame of a semester course Topics range from polynomial approximations and interpolation to numerical methods for ODEs and PDEs Emphasis was made more on algorithm development basic mathematical ideas behind the algorithms and the implementation in Matlab The book is supplemented by two sets of videos available through the author's YouTube channel Homework problem sets are provided for each chapter and complete answer sets are available for instructors upon request The second edition contains a set of selected advanced topics written in a self contained manner suitable for self learning or as additional material for an honored version of the course Videos are also available for these added topics  
*Lecture Notes* Michael Hanke, Kungliga Tekniska högskolan. Institutionen för numerisk analys och datalogi, 2006

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