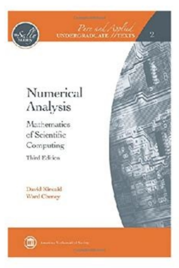
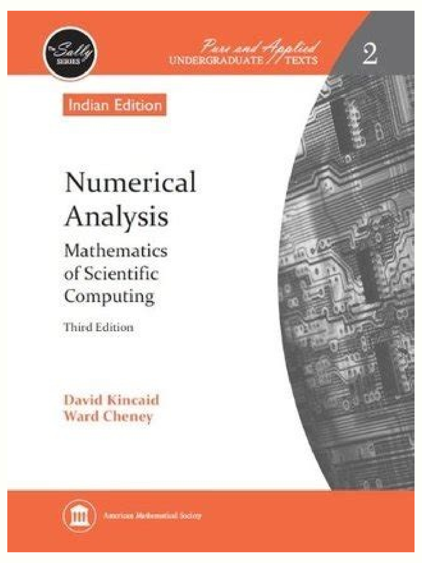
Numerical mathematical analysis pdf

Numerical Analysis: Mathematics of Scientific Computing (The Sally Series; Pure and Applied Undergraduate Texts, Vol. 2) by David Kincaid, Ward Cheney (Hardcover)





الفصل الخامس

التفاضل العددي والتكامل العددي

Numerical Differentiation and Numerical Integration

الفصل الخامس

التفاضل العددي والتكامل العددي

1-5 مقدمة

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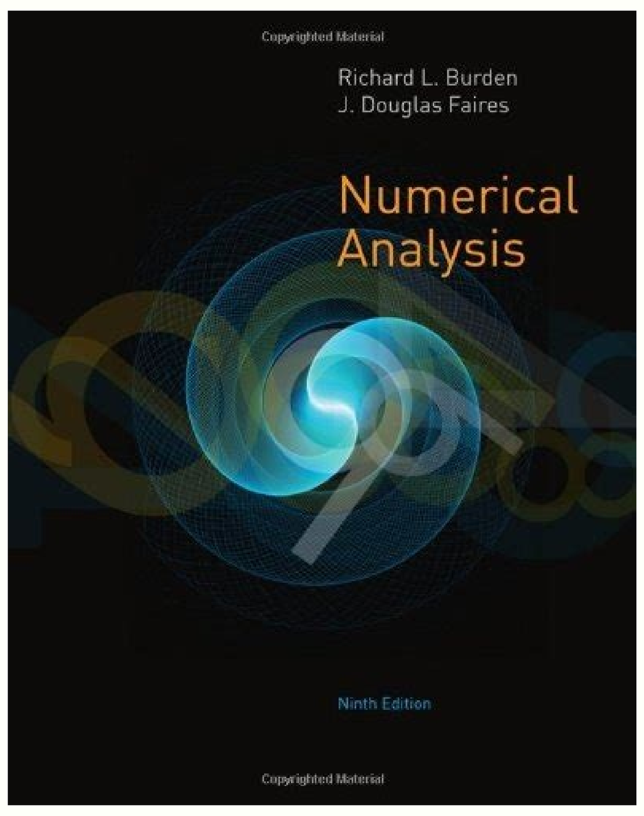

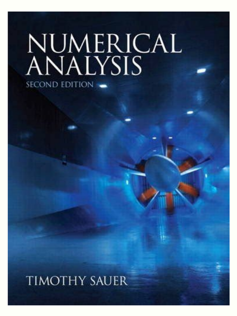

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Field of mathematics Babylonian clay tablet YBC 7289 (c. 1800–1600 BC) with annotations. The approximation of the square root of 2 is four sexagesimal figures, which is about six decimal figures. 1 + 24/60 + 51/602 + 10/603 = 1.41421296...[1] Numerical analysis is the study of algorithms that use numerical approximation (as opposed to symbolic manipulations) for the problems of mathematical analysis (as distinguished from discrete mathematics). It is the study of numerical methods that attempt at finding approximate solutions of problems rather than the exact ones. Numerical analysis finds application in all fields of engineering and the physical sciences, and in the 21st century also the life and social sciences, medicine, business and even the arts. Current growth in computing power has enabled the use of more complex numerical analysis, providing detailed and realistic mathematical models in science and engineering. Examples of numerical analysis include: ordinary differential equations as found in celestial mechanics (predicting the motions of planets, stars and galaxies), numerical linear algebra in data analysis,[2][3][4] and stochastic differential equations and Markov chains for simulating living cells in medicine and biology. Before modern computers, numerical methods often relied on hand interpolation formulas, using data from large printed tables. Since the mid 20th century, computers calculate the required functions instead, but many of the same formulas continue to be used in software algorithms.[5] The numerical point of view goes back to the earliest mathematical writings. A tablet from the Yale Babylonian Collection (YBC 7289), gives a sexagesimal numerical approximation of the square root of 2, the length of the diagonal in a unit square. Numerical analysis continues this long tradition: rather than giving exact symbolic answers translated into digits and applicable only to real-world measurements, approximate solutions within specified error bounds are used. General introduction The overall goal of the field of numerical analysis is the design and analysis of techniques to give approximate but accurate solutions to hard problems, the variety of which is suggested by the following: Advanced numerical methods are essential in making numerical weather prediction feasible. Computing the trajectory of a spacecraft requires the accurate numerical solution of a system of ordinary differential equations. Car companies can improve the crash safety of their vehicles by using computer simulations of car crashes. Such simulations essentially consist of solving partial differential equations numerically. Hedge funds (private investment funds) use tools from all fields of numerical analysis to attempt to calculate the value of stocks and derivatives more precisely than other market participants. Airlines use sophisticated optimization algorithms to decide ticket prices, airplane and crew assignments and fuel needs. Historically, such algorithms were developed within the overlapping field of operations research. Insurance companies use numerical programs for actuarial analysis. The rest of this section outlines several important themes of numerical analysis. History The field of numerical analysis predates the invention of modern computers by many centuries. Linear interpolation was already in use more than 2000 years ago. Many great mathematicians of the past were preoccupied by numerical analysis,[5] as is obvious from the names of important algorithms like Newton's method, Lagrange interpolation polynomial, Gaussian elimination, or Euler's method. To facilitate computations by hand, large books were produced with formulas and tables of data such as interpolation points and function coefficients. Using these tables, often calculated out to 16 decimal places or more for some functions, one could look up values to plug into the formulas given and achieve very good numerical estimates of some functions. The canonical work in the field is the NIST publication edited by Abramowitz and Stegun, a 1000-plus page book of a very large number of commonly used formulas and functions and their values at many points. The function values are no longer very useful when a computer is available, but the large listing of formulas can still be very handy. The mechanical calculator was also developed as a tool for hand computation. These calculators evolved into electronic computers in the 1940s, and it was then found that these computers were also useful for administrative purposes. But the invention of the computer also influenced the field of numerical analysis,[5] since now longer and more complicated calculations could be done. Direct and iterative methods Consider the problem of solving 3x3 + 4 = 28 for the unknown quantity x. Direct method 3x3 + 4 = 28. Subtract 4 3x3 = 24. Divide by 3 x3 = 8. Take cube roots x = 2. For the iterative method, apply the bisection method to f(x) = 3x3 − 24. The initial values are a = 0, b = 3, f(a) = −24, f(b) = 57. Iterative method a b mid f(mid) 0 3 1.5 −13.875 1.5 3 2.25 10.17... 1.5 2.25 1.875 −4.22... 1.875 2.25 2.0625 2.32... From this table it can be concluded that the solution is between 1.875 and 2.0625. The algorithm might return any number in that range with an error less than 0.2. Discretization and numerical integration In a two-hour race, the speed of the car is measured at three instants and recorded in the following table. Time 0:20 1:00 1:40 km/h 140 150 180 A discretization would be to say that the speed of the car was constant from 0:00 to 0:40, then from 0:40 to 1:20 and finally from 1:20 to 2:00. For instance, the total distance traveled in the first 40 minutes is approximately (2/3 h × 140 km/h) = 93.3 km. This would allow us to estimate the total distance traveled as 93.3 km + 100 km + 120 km = 313.3 km, which is an example of numerical integration (see below) using a Riemann sum, because displacement is the integral of velocity. Ill-conditioned problem: Take the function f(x) = 1/(x − 1). Note that f(1.1) = 10 and f(1.001) = 1000: a change in x of less than 0.1 turns into a change in f(x) of nearly 1000. Evaluating f(x) near x = 1 is an ill-conditioned problem. Well-conditioned problem: By contrast, evaluating the same function f(x) = 1/(x − 1) near x = 10 is a well-conditioned problem. For instance, f(10) = 1/9 ≈ 0.111 and f(11) = 0.1: a modest change in x leads to a modest change in f(x). Direct methods compute the solution to a problem in a finite number of steps. These methods would give the precise answer if they were performed in infinite precision arithmetic. Examples include Gaussian elimination, the QR factorization method for solving systems of linear equations, and the simplex method of linear programming. In practice, finite precision is used and the result is an approximation of the true solution (assuming stability). In contrast to direct methods, iterative methods are not expected to terminate in a finite number of steps. Starting from an initial guess, iterative methods form successive approximations that converge to the exact solution only in the limit. A convergence test, often involving the residual, is specified in order to decide when a sufficiently accurate solution has (hopefully) been found. Even using infinite precision arithmetic these methods would not reach the solution within a finite number of steps (in general). Examples include Newton's method, the bisection method, and Jacobi iteration. In computational matrix algebra, iterative methods are generally needed for large problems.[6][7][8][9] Iterative methods are more common than direct methods in numerical analysis. Some methods are direct in principle but are usually used as though they were not, e.g. GMRES and the conjugate gradient method. For these methods the number of steps needed to obtain the exact solution is so large that an approximation is accepted in the same manner as for an iterative method. Discretization Furthermore, continuous problems must sometimes be replaced by a discrete problem whose solution is known to approximate that of the continuous problem; this process is called 'discretization'. For example, the solution of a differential equation is a function. This function must be represented by a finite amount of data, for instance by its value at a finite number of points at its domain, even though this domain is a continuum. Generation and propagation of errors The study of errors forms an important part of numerical analysis. There are several ways in which error can be introduced in the solution of the problem. Round-off Round-off errors arise because it is impossible to represent all real numbers exactly on a machine with finite memory (which is what all practical digital computers are). Truncation and discretization error Truncation errors are committed when an iterative method is terminated or a mathematical procedure is approximated and the approximate solution differs from the exact solution. Similarly, discretization induces a discretization error because the solution of the discrete problem does not coincide with the solution of the continuous problem. In the example above to compute the solution of 3 x 3 + 4 = 28 {\displaystyle 3x^{3}+4=28} , after ten iterations, the calculated root is roughly 1.99. Therefore, the truncation error is roughly 0.01. Once an error is generated, it propagates through the calculation. For example, the operation + on a computer is inexact. A calculation of the type a + b + c + d + e {\displaystyle a+b+c+d+e} is even more inexact. A truncation error is created when a mathematical procedure is approximated. To integrate a function exactly, an infinite sum of regions must be found, but numerically only a finite sum of regions can be found, and hence the approximation of the exact solution. Similarly, to differentiate a function, the differential element approaches zero, but numerically only a nonzero value of the differential element can be chosen. Numerical stability and well-posed problems Numerical stability is a notion in numerical analysis. An algorithm is called 'numerically stable' if an error, whatever its cause, does not grow to be much larger during the calculation.[10] This happens if the problem is 'well-conditioned', meaning that the solution changes by only a small amount if the problem data are changed by a small amount.[10] To the contrary, if a problem is 'ill-conditioned', then any small error in the data will grow to be a large error.[10] Both the original problem and the algorithm used to solve that problem can be 'well-conditioned' or 'ill-conditioned', and any combination is possible. So an algorithm that solves a well-conditioned problem may be either numerically stable or numerically unstable. An art of numerical analysis is to find a stable algorithm for solving a well-posed mathematical problem. For instance, computing the square root of 2 (which is roughly 1.41421) is a well-posed problem. Many algorithms solve this problem by starting with an initial approximation x0 to 2 {\displaystyle {\sqrt {2}}} , for instance x0 = 1.4, and then computing improved guesses x1, x2, etc. One such method is the famous Babylonian method, which is given by xk+1 = xk/2 + 1/xk. Another method, called 'method X', is given by xk+1 = (xk2 − 2)2 + xk.[note 1] A few iterations of each scheme are calculated in table form below, with initial guesses x0 = 1.4 and x0 = 1.42. Babylonian Babylonian Method X Method X x0 = 1.4 x0 = 1.42 x0 = 1.4 x0 = 1.42 x1 = 1.4142857... x1 = 1.41422535... x1 = 1.4016 x1 = 1.42026896 x2 = 1.414213564... x2 = 1.41421356242... x2 = 1.4028614... x2 = 1.42056... ... ... x1000000 = 1.41421... x27 = 7280.2284... Observe that the Babylonian method converges quickly regardless of the initial guess, whereas Method X converges extremely slowly with initial guess x0 = 1.4 and diverges for initial guess x0 = 1.42. Hence, the Babylonian method is numerically stable, while Method X is numerically unstable. Numerical stability is affected by the number of the significant digits the machine keeps. If a machine is used that keeps only the four most significant decimal digits, a good example on loss of significance can be given by the two equivalent functions f (x) = x (x + 1 − x) {\displaystyle f(x)=x\left({\sqrt {x+1}}-{\sqrt {x}}\right)} and g (x) = x x + 1 + x . {\displaystyle g(x)={\frac {x}{{\sqrt {x+1}}+{\sqrt {x}}}}.} Comparing the results of f (500) = 500 (501 − 500) = 500 (22.38 − 22.36) = 500 (0.02) = 10 {\displaystyle f(500)=500\left({\sqrt {501}}-{\sqrt {500}}\right)=500\left(22.38-22.36\right)=500(0.02)=10} and g (500) = 500 501 + 500 = 500 22.38 + 22.36 = 500 44.74 = 11.17 {\displaystyle {\begin{alignedat}{3}g(500)&={\frac {500}{{\sqrt {501}}+{\sqrt {500}}}}\\&={\frac {500}{22.38+22.36}}\\&={\frac {500}{44.74}}=11.17\end{alignedat}}} by comparing the two results above, it is clear that loss of significance (caused here by catastrophic cancellation from subtracting approximations to the nearby numbers 501 {\displaystyle {\sqrt {501}}} and 500 {\displaystyle {\sqrt {500}}} , despite the subtraction being computed exactly) has a huge effect on the results, even though both functions are equivalent, as shown below f (x) = x (x + 1 − x) = x (x + 1 − x) x + 1 + x x + 1 + x = x ((x + 1) 2 − (x) 2 x + 1 + x = x x + 1 − x x + 1 + x = x 1 x + 1 + x = x x + 1 + x = g (x) {\displaystyle {\begin{alignedat}{4}f(x)&=x\left({\sqrt {x+1}}-{\sqrt {x}}\right)\\&=x\left({\sqrt {x+1}}-{\sqrt {x}}\right){\frac {{\sqrt {x+1}}+{\sqrt {x}}}{{\sqrt {x+1}}+{\sqrt {x}}}}\\&=x{\frac {({\sqrt {x+1}})^{2}-({\sqrt {x}})^{2}}{{\sqrt {x+1}}+{\sqrt {x}}}}\\&=x{\frac {x+1-x}{{\sqrt {x+1}}+{\sqrt {x}}}}\\&=x{\frac {1}{{\sqrt {x+1}}+{\sqrt {x}}}}\\&={\frac {x}{{\sqrt {x+1}}+{\sqrt {x}}}}\\&=g(x)\end{alignedat}}} The desired value, computed using infinite precision, is 11.174755... The example is a modification of one taken from Mathew; Numerical methods using MATLAB, 3rd ed. Areas of study The field of numerical analysis includes many sub-disciplines. Some of the major ones are: Computing values of functions Interpolation: Observing that the temperature varies from 20 degrees Celsius at 1:00 to 14 degrees at 3:00, a linear interpolation of this data would conclude that it was 17 degrees at 2:00 and 18.5 degrees at 1:30pm. Extrapolation: If the gross domestic product of a country has been growing an average of 5% per year and was 100 billion last year, it might extrapolated that it will be 105 billion this year. Regression: In linear regression, given n points, a line is computed that passes as close as possible to those n points. Optimization: Suppose lemonade is sold at a lemonade stand, at $1.00 per glass, that 197 glasses of lemonade can be sold per day, and that for each increase of $0.01, one less glass of lemonade will be sold per day. If $1.485 could be charged, profit would be maximized, but due to the constraint of having to charge a whole-cent amount, charging $1.48 or $1.49 per glass will both yield the maximum income of $220.52 per day. Differential equation: If 100 fans are set up to blow air from one end of the room to the other and then a feather is dropped into the wind, what happens? The feather will follow the air currents, which may be very complex. One approximation is to measure the speed at which the air is blowing near the feather every second, and advance the simulated feather as if it were moving in a straight line at that same speed for one second, before measuring the wind speed again. This is called the Euler method for solving an ordinary differential equation. One of the simplest problems is the evaluation of a function at a given point. The most straightforward approach, of just plugging in the number in the formula is sometimes not very efficient. For polynomials, a better approach is using the Horner scheme, since it reduces the necessary number of multiplications and additions. Generally, it is important to estimate and control round-off errors arising from the use of floating-point arithmetic. Interpolation, extrapolation, and regression Interpolation solves the following problem: given the value of some unknown function at a number of points, what value does that function have at some other point between the given points? Extrapolation is very similar to interpolation, except that now the value of the unknown function at a point which is outside the given points must be found.[11] Regression is also similar, but it takes into account that the data is imprecise. Given some points, and a measurement of the value of some function at these points (with an error), the unknown function can be found. The least squares-method is one way to achieve this. Solving equations and systems of equations Another fundamental problem is computing the solution of some given equation. Two cases are commonly distinguished, depending on whether the equation is linear or not. For instance, the equation 2 x + 5 = 3 {\displaystyle 2x+5=3} is linear while 2 x 2 + 5 = 3 {\displaystyle 2x^{2}+5=3} is not. Much effort has been put in the development of methods for solving systems of linear equations. Standard direct methods, i.e., methods that use some matrix decomposition are Gaussian elimination, LU decomposition, Cholesky decomposition for symmetric (or hermitian) and positive-definite matrix, and QR decomposition for non-square matrices. Iterative methods such as the Jacobi method, Gauss–Seidel method, successive over-relaxation and conjugate gradient method[12] are usually preferred for large systems. General iterative methods can be developed using a matrix splitting. Root-finding algorithms are used to solve nonlinear equations (they are so named since a root of a function is an argument for which the function yields zero). If the function is differentiable and the derivative is known, then Newton's method is a popular choice.[13][14] Linearization is another technique for solving nonlinear equations. Solving eigenvalue or singular value problems Several important problems can be phrased in terms of eigenvalue decompositions or singular value decompositions. For instance, the spectral image compression algorithm[15] is based on the singular value decomposition. The corresponding tool in statistics is called principal component analysis. Optimization Main article: Mathematical optimization Optimization problems ask for the point at which a given function is maximized (or minimized). Often, the point also has to satisfy some constraints. The field of optimization is further split in several subfields, depending on the form of the objective function and the constraint. For instance, linear programming deals with the case that both the objective function and the constraints are linear. A famous method in linear programming is the simplex method. The method of Lagrange multipliers can be used to reduce optimization problems with constraints to unconstrained optimization problems. Evaluating integrals Main article: Numerical integration Numerical integration, in some instances also known as numerical quadrature, asks for the value of a definite integral.[16] Popular methods use one of the Newton–Cotes formulas (like the midpoint rule or Simpson's rule) or Gaussian quadrature.[17] These methods rely on a "divide and conquer" strategy, whereby an integral on a relatively large set is broken down into integrals on smaller sets. In higher dimensions, where these methods become prohibitively expensive in terms of computational effort, one may use Monte Carlo or quasi-Monte Carlo methods (see Monte Carlo integration[18]), or, in modestly large dimensions, the method of sparse grids. Differential equations Main articles: Numerical ordinary differential equations and Numerical partial differential equations Numerical analysis is also concerned with computing (in an approximate way) the solution of differential equations, both ordinary differential equations and partial differential equations.[19] Partial differential equations are solved by first discretizing the equation, bringing it into a finite-dimensional subspace.[20] This can be done by a finite element method,[21][22][23] a finite difference method,[24] or (particularly in engineering) a finite volume method.[25] The theoretical justification of these methods often involves theorems from functional analysis. This reduces the problem to the solution of an algebraic equation. Software Main articles: List of numerical-analysis software and Comparison of numerical-analysis software Since the late twentieth century, most algorithms are implemented in a variety of programming languages. The Netlib repository contains various collections of software routines for numerical problems, mostly in Fortran and C. Commercial products implementing many different numerical algorithms include the IMSL and NAG libraries; a free-software alternative is the GNU Scientific Library. Over the years the Royal Statistical Society published numerous algorithms in its Applied Statistics (code for these "AS" functions is here); ACM similarly, in its Transactions on Mathematical Software ("TOMS" code is here). The Naval Surface Warfare Center several times published its Library of Mathematics Subroutines (code here). There are several popular numerical computing applications such as MATLAB,[26][27][28] TK Solver, S-PLUS, and IDL[29] as well as free and open source alternatives such as FreeMat, Scilab,[30][31] GNU Octave (similar to Matlab), and IT++ (a C++ library). There are also programming languages such as R[32] (similar to S-PLUS), Julia,[33] and Python with libraries such as NumPy, SciPy[34][35][36] and SymPy. Performance varies widely: while vector and matrix operations are usually fast, scalar loops may vary in speed by more than an order of magnitude.[37][38] Many computer algebra systems such as Mathematica also benefit from the availability of arbitrary-precision arithmetic which can provide more accurate results.[39][40][41][42] Also, any spreadsheet software can be used to solve simple problems relating to numerical analysis. Excel, for example, has hundreds of available functions, including for matrices, which may be used in conjunction with its built in "solver". See also Analysis of algorithms Computational science Computational physics Interval arithmetic List of numerical analysis topics Local linearization method Numerical differentiation Numerical Recipes Probabilistic numerics Symbolic-numeric computation Validated numerics Notes ^ This is a fixed point iteration for the equation x = (x 2 − 2) 2 + x = f (x) {\displaystyle x=(x^{2}-2)^{2}+x=f(x)} , whose solutions include 2 {\displaystyle {\sqrt {2}}} . The iterates always move to the right since f (x) ≥ x {\displaystyle f(x)\geq x} . Hence x 1 = 1.4 < 2 {\displaystyle x_{1}=1.4 2 {\displaystyle x_{1}=1.42>{\sqrt {2}}} diverges. References Citations

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The aim of the PhD Course in Mathematical Analysis, Modelling, and Applications is to educate graduate students in the fields of mathematical analysis and mathematical modelling, and in the applications of mathematical and numerical analysis to science and technology. The goal is to enable PhDs to work as high level researchers in these fields ... Numerical mathematical analysis [1962] Select. Numerical mathematical analysis. QA297 .S35 1966. SAL3 (off-campus storage) Computational Electronics Numerical Analysis. This note covers the following topics: Numerical Solution of Algebraic Equations, Gauss Elimination Method, LU Decomposition Method, Iterative Methods, Successive Over-Relaxation (SOR) Method. Author (s): Dragica Vasileska, Associate Professor, Arizona State University. 15 Pages.

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