

Numerical integration for solving differential equations

After integration, it is natural to consider how to find numerical solutions to differential equations on the computer. Simple equations of motion lead to 2nd order differential equations. In the case of constant acceleration, we see that:

$$v = at + v_0, \quad (1)$$

so,

$$x = \frac{1}{2}at^2 + v_0t + x_0. \quad (2)$$

However, if the force and hence acceleration is related to the position or the velocity in any way, then we cannot just do simple integration in closed form (or at least not simple integration of the form that one typically learns in a first calculus class).¹

There are still plenty of such problems that can be solved in closed form. Let's consider two problems that come up a lot in a first classical mechanics course – the ideal spring which follows Hooke's Law, and the simple pendulum. In an introductory classical mechanics course, we will usually use the small angle approximation, and say that $\sin\theta = \theta$, which then reduces the math for a pendulum's angular motion to being basically the same as the math for a spring's linear motions. It's a pretty good approximation, but it's not quite right, and the differences are something that you could measure in a lab fairly easily.

So, the equations of motion of a pendulum are:

$$\alpha = \frac{-g}{l} \sin\theta = \frac{d\omega}{dt}, \quad (3)$$

and

$$\frac{d\theta}{dt} = \omega. \quad (4)$$

For if we make the small angle approximation that $\sin\theta = \theta$, then we get:

$$\frac{d^2\theta}{dt^2} = \frac{-g}{l} \theta, \quad (5)$$

which we can solve by inspection to give a sine wave with frequency $\sqrt{g/l}$.

If we don't make the small angle approximation, there is no closed form solution to the differential equation.

¹Historically, these problems were solved by perturbation analyses – one would solve a problem that was almost the problem that one wanted to solve, and then figure out how to make small changes to the solution based on the small deviations from the solvable problem. This kind of approach is still often useful for two purposes – (1) it can sometimes guide an efficient approach to finding the numerical solution to the problem and (2) it can sometimes produce simple formula which are approximately correct, and which can guide understanding of what really happens in a way that the outputs of a thousand computer simulations often cannot.

Numerical Integration Of Differential Equations

Harvard Lomax



Numerical Integration Of Differential Equations:

Geometric Numerical Integration Ernst Hairer, Christian Lubich, Gerhard Wanner, 2006-05-18 This book covers numerical methods that preserve properties of Hamiltonian systems reversible systems differential equations on manifolds and problems with highly oscillatory solutions It presents a theory of symplectic and symmetric methods which include various specially designed integrators as well as discusses their construction and practical merits The long time behavior of the numerical solutions is studied using a backward error analysis combined with KAM theory

Numerical Integration of Differential Equations Albert A. Bennett, William E. Milne, Harry Bateman, 1956

An Operational Unification of Finite Difference Methods for the Numerical Integration of Ordinary Differential Equations Harvard Lomax, 1967 One purpose of this report is to present a mathematical procedure which can be used to study and compare various numerical methods for integrating ordinary differential equations This procedure is relatively simple mathematically rigorous and of such a nature that matters of interest in digital computations such as machine memory and running time can be weighed against the accuracy and stability provided by the method under consideration Briefly the procedure is as follows 1 Find a single differential equation that is sufficiently representative this is fully defined in the report of an arbitrary number of nonhomogeneous linear ordinary differential equations with constant coefficients 2 Solve this differential equation exactly 3 Choose any given numerical method use it in its entirety to reduce the differential equation to difference equations and by means of operational techniques solve the latter exactly 4 Study and compare the results of 2 and 3 Conceptually there is nothing new in this procedure but the particular development presented in this report does not appear to have been carried out before Another purpose is to use the procedure just described to analyze a variety of numerical methods ranging from classical predictor corrector systems to Runge Kutta techniques and including various combinations of the two

Numerical Integration of Differential Equations and Large Linear Systems J. Hinze, 2006-11-15

Numerical Integration of Differential Equations and Large Linear Systems, 1980

Numerical Methods for Initial Value Problems in Ordinary Differential Equations Simeon Ola Fatunla, 2014-05-10 Numerical Method for Initial Value Problems in Ordinary Differential Equations deals with numerical treatment of special differential equations stiff stiff oscillatory singular and discontinuous initial value problems characterized by large Lipschitz constants The book reviews the difference operators the theory of interpolation first integral mean value theorem and numerical integration algorithms The text explains the theory of one step methods the Euler scheme the inverse Euler scheme and also Richardson s extrapolation The book discusses the general theory of Runge Kutta processes including the error estimation and stepsize selection of the R K process The text evaluates the different linear multistep methods such as the explicit linear multistep methods Adams Bashforth 1883 the implicit linear multistep methods Adams Moulton scheme 1926 and the general theory of linear multistep methods The book also reviews the existing stiff

codes based on the implicit semi implicit singly diagonally implicit Runge Kutta schemes the backward differentiation formulas the second derivative formulas as well as the related extrapolation processes The text is intended for undergraduates in mathematics computer science or engineering courses and for postgraduate students or researchers in related disciplines *Numerical Integration of Differential Equations and Large Linear Systems* J. Hinze, 2014-01-15

Numerical integration of differential equations Albert Arnold Bennett, National Research Council (U.S.). Committee on Numerical Integration, 1996 *Applying Integrals of Motion to the Numerical Solution of Differential Equations* Donald J. Jezewski, 1980

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