

The Numerical Integration of Ordinary Differential Equations†

By C. W. Gear

Abstract. Multistep methods for initial value problems are expressed in a matrix form. The application of such methods to higher-order equations is studied with the result that new techniques for both first- and higher-order equations are found. The direct approach to higher-order equations is believed to offer speed and accuracy advantages; some numerical evidence is presented. The new technique applied to first-order equations is a slight extension of the conventional multistep method and avoids the Dahlquist [2] stability theorem, that is, these new k -step methods are of order $2k$ and yet convergent. The matrix formalism introduced provides an easy mechanism for examining the equivalence of methods as introduced by Descloix [3]. It is pointed out that the new first-order method on k -steps, Adams' method on $(2k - 1)$ -steps and Nordsieck's [7] method with $2k$ components are equivalent to each other. In fact, all methods discussed can be placed in equivalence classes so that theorems need only be proved for one member of each class. The choice between the members of a class can be made on the basis of round-off errors and amount of computation only. Arguments are given in favor of the extension of Nordsieck's method for general use because of its speed and applicability to higher order problems directly. The theorems ensuring convergence and giving the asymptotic form of the error are stated. The proofs can be found in a cited report.

1. Introduction. This paper is concerned with the integration of initial value problems for a system of ordinary differential equations of the form

$$(1.1) \quad y_i^{(p_i)} = f_i(x, y_1, \dots, y_1^{(p_1-1)}, y_2, \dots, y_s^{(p_s-1)}), \quad i = 1, 2, \dots, s,$$

where $y^{(k)} = d^k y / dx^k$. The motivation for the work was to try and integrate such equations directly rather than as a larger system of first-order equations. The study led to a matrix representation for multistep methods that is an extension of a similar representation due to Descloix [3]. This representation provides a unified approach to equations of all orders; it is sufficient and easier to study it in detail for first-order equations. The usual theorems of stability and convergence, etc. are stated for general higher-order systems in Section 5. The proofs can be found in Gear [5].

2. Multistep Methods. The equation $y' = f(x, y)$ is frequently integrated numerically by a predictor-corrector algorithm of the following form:

Let $x_n = x_0 + nh$ where h is the step size, and let y_n and y_n' be approximations to the values of $y(x_n)$ and $dy(x_n)/dx$ obtained in some manner. The values of y and y' at x_{n+1} are found by the sequence of steps: predictor formula

$$(2.1) \quad y_{n+1}^{(0)} = \sum_{j=1}^k (\alpha_j^* y_{n-j+1} + \beta_j^* h y'_{n-j+1}),$$

Received February 21, 1966. Revised July 22, 1966.

† This work was supported under the auspices of the United States Atomic Energy Commission at Argonne National Laboratory and under A.E.C. 1469 at the University of Illinois.

Numerical Integration Of Differential Equations

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