

NUMERICAL GRADIENT ALGORITHMS FOR EIGENVALUE AND SINGULAR VALUE CALCULATIONS*

J.B. MOORE[†], R.E. MAHONY[‡], AND U. HELMKE[‡]

Abstract. Recent work has shown that the algebraic question of determining the eigenvalues, or singular values, of a matrix can be answered by solving certain continuous-time gradient flows on matrix manifolds. To obtain computational methods based on this theory, it is reasonable to develop algorithms that iteratively approximate the continuous-time flows. In this paper the authors propose two algorithms, based on a double Lie-bracket equation recently studied by Brockett, that appear to be suitable for implementation in parallel processing environments. The algorithms presented achieve, respectively, the eigenvalue decomposition of a symmetric matrix and the singular value decomposition of an arbitrary matrix. The algorithms have the same equilibria as the continuous-time flows on which they are based and inherit the exponential convergence of the continuous-time solutions.

Key words. eigenvalue decomposition, singular value decomposition, numerical gradient algorithm

AMS subject classifications. 15A18, 65F10

1. Introduction. A traditional algebraic approach to determining the eigenvalue and eigenvector structure of an arbitrary matrix is the QR-algorithm. In the early 1980s it was observed that the QR-algorithm is closely related to a continuous-time differential equation that has become known through study of the Toda lattice. Symes [13] and Deift, Nanda, and Tomei [6] showed that for tridiagonal real symmetric matrices, the QR-algorithm is a discrete-time sampling of the solution to a continuous-time differential equation. This result was generalised to full complex matrices by Chu [3], and Watkins and Elsner [14] provided further insight in the late 1980s.

Brockett [2] studied dynamic matrix flows generated by the double Lie-bracket equation

$$\dot{H} = [H, [H, N]], \quad H(0) = H_0$$

for constant symmetric matrices N and H_0 , and where we use the Lie-bracket notation $[X, Y] = XY - YX$. We call this differential equation the *double-bracket equation*, and we call solutions of this equation *double-bracket flows*. Similar matrix differential equations in the area of Physics were known and studied prior to the references given above. An example, is the Landau-Lifschitz-Gilbert equation of micromagnetics

$$\frac{d\hat{m}}{dt} = \frac{\gamma}{1 + \alpha^2} (\hat{m} \times \bar{H} - \alpha \hat{m} \times (\hat{m} \times \bar{H})) \quad |\hat{m}|^2 = 1,$$

as $\alpha \rightarrow \infty$ and $\gamma/\alpha \rightarrow k$, a constant. In this equation $\hat{m}, \bar{H} \in \mathbb{R}^3$ and the cross-product is equivalent to a Lie-bracket operation. The relevance of such equations

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