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# Data-Flow Algorithms for Parallel Matrix Computations

DIANNE P. O'LEARY and G.W. STEWART

**ABSTRACT:** *In this article we develop some algorithms and tools for solving matrix problems on parallel processing computers. Operations are synchronized through data-flow alone, which makes global synchronization unnecessary and enables the algorithms to be implemented on machines with very simple operating systems and communication protocols. As examples, we present algorithms that form the main modules for solving Liapunov matrix equations. We compare this approach to wave front array processors and systolic arrays, and note its advantages in handling mixed problems, in evaluating variations of algorithms or architectures, in moving algorithms from system to system, and in debugging parallel algorithms on sequential machines.*

## 1. INTRODUCTION

In this article we shall be concerned with algorithms partitioned into computational processes, called nodes, whose computations are triggered by the flow of data from neighboring nodes. Each node proceeds independently through cycles of waiting for data, computing, and sending data to other nodes. Such *data-flow algorithms* are well suited for parallel implementation on networks of processors, since they require no global control: once a data-flow algorithm is started, it continues to completion without the need for external intervention.

Our purpose is to describe how data-flow algorithms may be applied to the parallel solution of problems in numerical linear algebra. There are three reasons why such an article is timely. First, the data-flow paradigm places a large number of parallel matrix algorithms,

derived from different points of view, into a common framework. Second, these algorithms form a nontrivial test bed for general data-flow schemes. Here it is particularly important that most of the algorithms are adaptations of existing sequential algorithms with well established numerical properties, so that one can ignore rounding error analysis and concentrate on data-flow properties. Finally, a detailed consideration of how data-flow algorithms for matrix computations might be implemented suggests architectural features that would be desirable in a data-flow computer for matrix computations.

Because the term data-flow is used variously in the literature it is important that we specify at the outset what we mean by it. We shall essentially follow Treleaven, Brownbridge, and Hopkins [21] in regarding a data-flow algorithm as a collection of "instructions" in a directed graph that represents the flow of data between the instructions. Instructions execute only when the data they require have arrived. However, our "instructions" can be rather complex algorithm segments that can vary their input requirements and can direct their outputs to different instructions at different times.<sup>1</sup> To avoid confusion with the low-level instructions assumed in much of the data-flow literature, we shall call our instructions *computational nodes* (or, for short, simply *nodes*) and the graphs in which they lie *computational networks*.

Parallel matrix algorithms are by no means new. Since the time of the ILLIAC IV, it has been recognized that many algorithms in numerical linear algebra have

<sup>1</sup> Formally, our model of computation is the same as the one described by Karp and Miller [9], with the exception that an operation is allowed to change the parameters related to the input queues and the quantity of the output.

# Parallel Algorithms And Matrix Computation

**RJ Shavelson**



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