# 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 Liapounov matrix equations. We
compare this approach to wave front array processors and
systolic arrays, and note its advantages in handling missized
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 indepen-
dently through cycles of waiting for data, computing,
and sending data to other nodes. Such data-flow algo-
rithms are well suited for parallel implementation on
networks of processors, since they require no global
control: once a data-flow algorithm is started, it contin-
ues to completion without the need for external inter-
vention.

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 partic-
ularly important that most of the algorithms are adapta-
tions of existing sequential algorithms with well estab-
lished 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 compu-
tations.

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 Tre-
leaven, 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 "instruc-
tions" can be rather complex algorithm segments that
can vary their input requirements and can direct their
outputs to different instructions at different times.[*] To
avoid confusion with the low-level instructions as-
sumed in much of the data-flow literature, we shall call
our instructions *computational nodes* (or, for short, sim-
ply *nodes*) and the graphs in which they lie *computa-
tional 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

[*] 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

**Seyed H Roosta**

**Parallel Algorithms And Matrix Computation:**

　　Parallel Algorithms for Matrix Computations K. Gallivan,M. Heath,E. Ng,B. Peyton,R. Plemmons,C. Romine,A. Sameh,R. Voigt,1990-01-01 Mathematics of Computing Parallelism 　　**Parallelism in Matrix Computations** Efstratios Gallopoulos,Bernard Philippe,Ahmed H. Sameh,2015-07-25 This book is primarily intended as a research monograph that could also be used in graduate courses for the design of parallel algorithms in matrix computations It assumes general but not extensive knowledge of numerical linear algebra parallel architectures and parallel programming paradigms The book consists of four parts I Basics II Dense and Special Matrix Computations III Sparse Matrix Computations and IV Matrix functions and characteristics Part I deals with parallel programming paradigms and fundamental kernels including reordering schemes for sparse matrices Part II is devoted to dense matrix computations such as parallel algorithms for solving linear systems linear least squares the symmetric algebraic eigenvalue problem and the singular value decomposition It also deals with the development of parallel algorithms for special linear systems such as banded Vandermonde Toeplitz and block Toeplitz systems Part III addresses sparse matrix computations a the development of parallel iterative linear system solvers with emphasis on scalable preconditioners b parallel schemes for obtaining a few of the extreme eigenpairs or those contained in a given interval in the spectrum of a standard or generalized symmetric eigenvalue problem and c parallel methods for computing a few of the extreme singular triplets Part IV focuses on the development of parallel algorithms for matrix functions and special characteristics such as the matrix pseudospectrum and the determinant The book also reviews the theoretical and practical background necessary when designing these algorithms and includes an extensive bibliography that will be useful to researchers and students alike The book brings together many existing algorithms for the fundamental matrix computations that have a proven track record of efficient implementation in terms of data locality and data transfer on state of the art systems as well as several algorithms that are presented for the first time focusing on the opportunities for parallelism and algorithm robustness 　　*Parallel Algorithms and Matrix Computation* Jagdish J. Modi,1988 An introduction to parallel computation and the application of parallel algorithms to numerical linear algebra based on a lecture course at the University of Cambridge The emphasis is on the design and analysis of algorithms which are of importance to industrial and academic research 　　*Parallel Scientific Computing and Optimization* Raimondas Ciegis,David Henty,Bo Kågström,Julius Žilinskas,2008-10-08 Parallel Scientific Computing and Optimization introduces new developments in the construction analysis and implementation of parallel computing algorithms This book presents 23 self contained chapters including survey chapters and surveys written by distinguished researchers in the field of parallel computing Each chapter is devoted to some aspects of the subject parallel algorithms for matrix computations parallel optimization management of parallel programming models and data with the largest focus on parallel scientific computing in industrial applications This volume is intended for scientists and graduate students specializing in computer science and applied mathematics who are engaged in parallel

scientific computing    *Parallel Scientific Computing and Optimization* Raimondas Ciegis,David Henty,Bo Kågström,Julius Žilinskas,2008-11-21 Parallel Scientific Computing and Optimization introduces new developments in the construction analysis and implementation of parallel computing algorithms This book presents 23 self contained chapters including survey chapters and surveys written by distinguished researchers in the field of parallel computing Each chapter is devoted to some aspects of the subject parallel algorithms for matrix computations parallel optimization management of parallel programming models and data with the largest focus on parallel scientific computing in industrial applications This volume is intended for scientists and graduate students specializing in computer science and applied mathematics who are engaged in parallel scientific computing    **Parallel Processing and Parallel Algorithms** Seyed H Roosta,2012-12-06 Motivation It is now possible to build powerful single processor and multiprocessor systems and use them efficiently for data processing which has seen an explosive ex pansion in many areas of computer science and engineering One approach to meeting the performance requirements of the applications has been to utilize the most powerful single processor system that is available When such a system does not provide the performance requirements pipelined and parallel process ing structures can be employed The concept of parallel processing is a depar ture from sequential processing In sequential computation one processor is in volved and performs one operation at a time On the other hand in parallel computation several processors cooperate to solve a problem which reduces computing time because several operations can be carried out simultaneously Using several processors that work together on a given computation illustrates a new paradigm in computer problem solving which is completely different from sequential processing From the practical point of view this provides sufficient justification to investigate the concept of parallel processing and related issues such as parallel algorithms Parallel processing involves utilizing several factors such as parallel architectures parallel algorithms parallel programming lan guages and performance analysis which are strongly interrelated In general four steps are involved in performing a computational problem in parallel The first step is to understand the nature of computations in the specific application domain    **Parallel Algorithms in Computational Science and Engineering** Ananth Grama,Ahmed H. Sameh,2020-07-06 This contributed volume highlights two areas of fundamental interest in high performance computing core algorithms for important kernels and computationally demanding applications The first few chapters explore algorithms numerical techniques and their parallel formulations for a variety of kernels that arise in applications The rest of the volume focuses on state of the art applications from diverse domains By structuring the volume around these two areas it presents a comprehensive view of the application landscape for high performance computing while also enabling readers to develop new applications using the kernels Readers will learn how to choose the most suitable parallel algorithms for any given application ensuring that theory and practicality are clearly connected Applications using these techniques are illustrated in detail including Computational materials science and engineering Computational cardiovascular analysis Multiscale analysis of wind turbines and turbomachinery Weather

forecasting Machine learning techniques Parallel Algorithms in Computational Science and Engineering will be an ideal reference for applied mathematicians engineers computer scientists and other researchers who utilize high performance computing in their work **Parallel Algorithms for Linear Models** Erricos Kontoghiorghes,2000-01-31 Parallel Algorithms for Linear Models provides a complete and detailed account of the design analysis and implementation of parallel algorithms for solving large scale linear models It investigates and presents efficient numerically stable algorithms for computing the least squares estimators and other quantities of interest on massively parallel systems The monograph is in two parts The first part consists of four chapters and deals with the computational aspects for solving linear models that have applicability in diverse areas The remaining two chapters form the second part which concentrates on numerical and computational methods for solving various problems associated with seemingly unrelated regression equations SURE and simultaneous equations models The practical issues of the parallel algorithms and the theoretical aspects of the numerical methods will be of interest to a broad range of researchers working in the areas of numerical and computational methods in statistics and econometrics parallel numerical algorithms parallel computing and numerical linear algebra The aim of this monograph is to promote research in the interface of econometrics computational statistics numerical linear algebra and parallelism Introduction to Parallel Computing Vipin Kumar,1994 Mathematics of Computing Parallelism **Parallel Algorithms** Henri Casanova,Arnaud Legrand,Yves Robert,2008-07-17 Focusing on algorithms for distributed memory parallel architectures Parallel Algorithms presents a rigorous yet accessible treatment of theoretical models of parallel computation parallel algorithm design for homogeneous and heterogeneous platforms complexity and performance analysis and essential notions of scheduling The book extract **Parallel Processing and Parallel Algorithms** Seyed H Roosta,1999-12-10 Motivation It is now possible to build powerful single processor and multiprocessor systems and use them efficiently for data processing which has seen an explosive ex pansion in many areas of computer science and engineering One approach to meeting the performance requirements of the applications has been to utilize the most powerful single processor system that is available When such a system does not provide the performance requirements pipelined and parallel process ing structures can be employed The concept of parallel processing is a depar ture from sequential processing In sequential computation one processor is in volved and performs one operation at a time On the other hand in parallel computation several processors cooperate to solve a problem which reduces computing time because several operations can be carried out simultaneously Using several processors that work together on a given computation illustrates a new paradigm in computer problem solving which is completely different from sequential processing From the practical point of view this provides sufficient justification to investigate the concept of parallel processing and related issues such as parallel algorithms Parallel processing involves utilizing several factors such as parallel architectures parallel algorithms parallel programming lan guages and performance analysis which are strongly interrelated In general four steps are involved in

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*Parallel Algorithms* Pranay Chaudhuri,1992 Mathematics of Computing Parallelism     **Parallel Matrix Computations** G. W. Stewart,Dianne P. O'Leary,MARYLAND UNIV COLLEGE PARK DEPT OF COMPUTER SCIENCE.,MARYLAND UNIV COLLEGE PARK.,1985 This project concerns the design and analysis of algorithms to be run in a processor rich environment It focuses primarily on algorithms that require no global control and that can be run on systems with only local connections among processors The properties of these algorithms both theoretically and experimentally are investigated The experimental work is done on the ZMOB a working parallel computer operated by the Laboratory for Parallel Computation of the Computer Science Department at the University of Maryland The emphasis is on two areas 1 Dense problems from numerical linear algebra and 2 The iterative and direct solution of sparse linear systems Additional keywords parallel algorithms and software development     PARALLEL ALGORITHMS FOR SOLVING AGGREGATED SHORTEST PATH PROBLEMS H. Edwin Romeijin,1993

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