Recent Technical Report List

March 1994–

New York University
Courant Institute of Mathematical Sciences
Computer Science Department

659 **A New Primal-Dual Interior-Dual Interior-Point Method for Semidefinite Programming**
F. Alizadeh, J.P. Haeberly, M. Overton

Semidefinite programming (SDP) is a convex optimization problem in the space of symmetric matrices. Primal-dual interior-point methods for SDP are discussed. These generate primal and dual matrices X and Z which commute only in the limit. A new method is proposed which iterates in the space of commuting matrices.

660 **Optimizing Eigenvalues of Symmetric Definite Pencils**
J.P. Haeberly, M. Overton

We consider the following quasiconvex optimization problem: minimize the largest eigenvalue of a symmetric definite matrix pencil depending on parameters. A new form of optimality conditions is given, emphasizing a complementarity condition on primal and dual matrices. Newton's method is then applied to these conditions to give a new quadratically convergent interior-point method which works well in practice. The algorithm is closely related to primal-dual interior-point methods for semidefinite programming.

661 **A Polylogarithmic Bound for an Iterative Substructuring Method for Special Elements in Three Dimensions**
L. Pavarino, O. Widlund

Iterative substructuring methods form an important family of domain decomposition algorithms for elliptic finite element problems. A p-version finite element method based on continuous, piecewise Q_p functions is considered for second order elliptic problems in three dimensions; this special method can also be viewed as a conforming spectral element method. An iterative method is designed for which the condition number of the relevant operator grows only in proportion to $(1+\log p)^2$. This bound is independent of jumps in the coefficient of the elliptic problem across the interfaces between the subregions. Numerical results are also reported which support the theory.

662 **Multilevel Schwarz Methods for Elliptic Problems with Discontinous Coefficients in Three Dimensions**
M. Dryja, M. Sarkis, O. Widlund

Multilevel Schwarz methods are developed for a conforming finite element approximation of second order elliptic problems. We focus on problems in three dimensions with possibly large jumps in the coefficients across the interface separating the subregions. We establish a condition number estimate for the iterative operator, which is independent of the coefficients, and grows at most as the square of the number of levels. We also characterize a class of distributions of the coefficients, called quasi-monotone, for which the weighted L^2-projection is stable and for which we can use the standard piecewise linear functions as a coarse space. In this case, we obtain optimal methods, i.e. bounds which are independent of the number of levels and subregions. We also design and analyze multilevel methods with new coarse spaces given by simple explicit formulas. We consider nonuniform meshes and conclude by an analysis of multilevel iterative substructuring methods.

663 **Iterative Substructuring Methods for Spectral Elements: Problems in Three Dimensions Based on Numerical Quadrature**
L. Pavarino, O. Widlund

Iterative substructuring methods form an important family of domain decomposition algorithms for elliptic finite element problems. Two preconditioners for p-version finite element methods based on continuous, piecewise Q_p functions are considered for second order elliptic problems in three dimensions; these special methods can also be viewed as spectral element methods. The first iterative method is designed for the Galerkin formulation of the problem. The second applies to linear systems for a discrete model derived by using Gauss-Lobatto-Legendre quadrature. For both methods, it is established that the condition number of the relevant operator grows only in proportion to $(1+\log p)^2$. These bounds are independent of the number of elements, into which the given region has been divided, their diameters, as well as the jumps in the coefficients

of the elliptic equation between elements. Results of numerical computations are also given, which provide upper bounds on the condition numbers as functions of p and which confirms the correctness of our theory.

664 Conceptual and Pragmatic Tools for Design and Control of Manufacturing Systems
M. Antoniotti

In this survey we explore two conceptual tools that have been used in recent (and not so recent) years to build "models of and to "control" various Manufacturing Systems (MS) and processes. Our aim is to investigate some "computational frameworks" that could be interpreted and used to (partially) perform the tasks of

- Simulation of an (arbitrary) MS; - Preventive Verification of some of its properties; - Evaluation of some of its characteristic parameters; - Control of its behavior.

These tasks require well defined computational models, that should be easily equipped with an appropriate "semantics", capable of expressing several properties of MS's. Petri Nets and RW-Systems satisfy these requirements.

665 Cursor Stereo
S. Gomory, R. Wallace

Matching pairs of stereo images by computer is a computationally expensive and not completely reliable method for recovering depth information from a scene. However, applications exist in teleoperation and stereo cartography which require accurate matching of images for a small, arbitrarily shaped portion of the entire image, where there may be few matchable features. This work is a step toward creating dense depth maps for those applications. We propose to use a robust stereo-matching algorithm to get within a few pixels of the correct match and then refine our match to a fraction of a pixel using an adaptive-window algorithm.

As a first pass we use a multi-resolution image pyramid with a Moravec interest operator to get close to the right answer. We then apply an adaptive window algorithm due to Okutomi and Kanade. We present a framework for selecting subimages which unifies the one and two dimensional adaptive window algorithms they present, and test the algorithm on real images and artificial data sets. We report our observations about the workings of the adaptive algorithm.

666 Branching Continuous Time and the Semantics of Continuous Action
E. Davis

It is often useful to model the behavior of an autonomous intelligent creature in terms of continuous control and choice. For example, a robot who moves through space can be idealized as able to execute any continuous motion, subject to constraints on velocity and accelleration; in such a model, the robot can "choose" at any instant to change his accelleration. We show how such models can be described using a continuous branching time structure. We discuss mathematical foundations of continuous branching structures, theories of continuous action in physical worlds, embedding of discrete theories of action in a continuous structure, and physical and epistemic feasibility of plans with continuous action.

667 Representing Control in Parallel Applicative Programming
C. Yao

This research is an attempt to reason about the control of parallel computation in the world of applicative programming languages.

Applicative languages, in which computation is performed through function application and in which functions are treated as first-class objects, have the benefits of elegance, expressiveness and having clean semantics. Parallel computation and real-world concurrent activities are much harder to reason about than the sequential counterparts. Many parallel applicative languages have thus hidden most control details with their declarative programming styles, but they are not expressive enough to characterize many real world concurrent activities that can be easily explained with concepts such as message passing, pipelining and so on.

Ease of programming should not come at the expense of expressiveness. Therefore, we design a parallel applicative language Pscheme such that programmers can express explicitly the control of parallel computation while maintaining the clean semantics and the ease of programming of applicative languages. In Pscheme, we propose the concept of ports to model the general control in parallel computation. Through program examples, we show how Pscheme and ports support various parallel programming paradigms. We have also built libraries for higher level control facilities with ports so that programming in Pscheme becomes easier.

We provide an operational semantics for Pscheme, and develop a compiler and a run time system on NYU's Ultracomputer. Our experiments with parallel programs have shown satisfactory speedup. We claim that ports are the natural parallel extensions of continuations in sequential computation, and thus conclude that representing general control in parallel applicative

programming is feasible.

668 **A Direct–Drive Hand: Design, Modeling and Control**
M. Ebner, R. Wallace

An artificial 15 degrees of mobility direct drive hand, slightly bigger than a human hand, is presented. The underlying technology are the miniature direct drive actuators recently developed. The motivation for our design and the construction plan for the hand is given. The dynamics of the hand are analyzed theoretically and a model for control of the hand is presented. Finally we describe our experiences made while experimenting with the hand. A direct drive hand graphics interface has been developed to simulate the dynamics of the hand and to test out control algorithms for the hand.

669 **Scaling Direct Drive Robots**
R. Wallace, J. Selig

Recent experimental and analytical evidence indicates that direct drive robots become very practical and economical at miniature and microscopic scales, so it is interesting to understand quantitatively the properties of direct drive robots under scaling transformations. This leads to a study of how screws and their dual co-screws behave under the group of similarity transforms. This group is the group of isometries together with dilations. Several different representations are found on the space of screws and complementary representations are found on the dual space of co-screws. From the electromagnetic theory of the force and torque on a magnet in a magnetic field, we derive the scaling properties of the electromagnetic wrench. Hence, these results can be directly applied to the scaling of direct drive motors [1]. We conclude by proposing a scale-invariant measure for direct drive actuator performance.

670 **Approximate Euclidean Shortest Path in 3–Space**
J. Choi, J. Sellen, C.K. Yap

Papadimitriou's approximation approach to the Euclidean shortest path (ESP) in 3-space is revisited. As this problem is NP-hard, his approach represents an important step towards practical algorithms. However, there are several gaps in the original description. Besides giving a complete treatment in the framework of bit complexity, we also improve on his subdivision method. Among the tools needed are root-separation bounds and non-trivial applications of Brent's complexity bounds on evaluation of elementary functions using floating point numbers.

671 **Schwarz Preconditioners for Elliptic Problems with Discontinuous Coefficients Using Conforming and Non–Conforming Elements**
M.S. Martins

Additive multilevel Schwarz methods are developed for conforming finite element approximations of second order elliptic problems. We focus on problems in three dimensions with possibly large jumps in the coefficients across the interface separating the subregions. We establish condition number estimates for the iterative operators, which are independent of the coefficients, and grow at most as the square of the number of levels ℓ. For the multiplicative versions, such as the V-cycle multigrid methods using Gauss Seidel and damped Jacobi smoothers, we obtain a rate of convergence bounded from above by $1 - C\,\ell^{-2}$. We also characterize a class of distributions of values of the coefficients, called quasi-monotone, for which the error of the weighted L^2-projection is stable and for which we can use the standard piecewise linear functions as a coarse space and obtain condition number estimates independent of the number of levels, subregions, and the coefficients. We also design and analyze multilevel methods with new coarse spaces given by simple explicit formulas. We also consider nonuniform meshes, multilevel iterative substructuring methods, and two-level additive methods with inexact solvers for the local problems.

In a second part, two-level domain decomposition methods are developed for a simple nonconforming approximation of second order elliptic problems. A bound is established for the condition number of these iterative methods that grows only logarithmically with the number of degrees of freedom in each subregion. This bound holds for two and three dimensions and is independent of jumps in the value of the coefficients. For these finite elements methods, a preconditioner is constructed from the restriction of the given elliptic problem to overlapping subregions into which the given region has been decomposed. In addition, in order to enhance the convergence rate, our preconditioners include a nonstandard coarse mesh component of relatively modest dimension. We also consider multilevel Schwarz preconditioners and show that all results for the conforming case also hold for the nonconforming case.