Research Statement (Overview)

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Many important academic and industrial problems reduce to the solution of large linear algebraic systems of equations. The efficient solution requires a type of computer appropriately called a *supercomputer*. Supercomputers rely on a vast network of processors to do the work, using a method known as *parallel computing.* This means the groups of processors in the network are organized so as to operate independently, in parallel, on their own part of the total problem solving effort. This way of gaining efficiency is called *parallel computing* and depends vitally on *parallel (solution) methods*, a special class of which is the class of *Domain Decomposition* Methods.

Domain Decomposition methods comprise an important class of parallel algorithms that are naturally parallel and flexible in their application to a sweeping range of scientific and engineering problems. Their basis in mathematical theory has been one of the subjects of my research.

A brief sketch of my overall work in Domain Decomposition methods follows below.

1. **Theoretical Studies: Optimized Schwarz Methods.**

   There are two issues in my theoretical work. How can we subdivide the original problem into subproblems that can be solved in parallel? How efficiently can we gather subproblem (local) data to recover problem (global) data?

   After subdividing the original problem, we impose interface conditions on the resulting artificial boundaries to solve local problems and these interface conditions provide a communication mechanism between neighboring processors. Therefore, optimal interface conditions form a natural topic in the context of the two challenging of subdividing the original problem and the efficient recovery of global data. I found that the classical approach does not clearly explain the numerical behavior when we use general boundary conditions. To gain a better understanding, I created a new approach to analyze the relation between the original boundary conditions and the interface conditions. *From the results of this research, I realized that the interface condition is one of the most important factors affecting the performance of Domain Decomposition methods.*

2. **Efficient Parallel Algorithms.**

   Parallel iterative methods are essential in solving large linear algebraic system. The most widely used iterative methods are Krylov subspace methods such as the Conjugate Gradient (CG) method. To improve accuracy of the numerical results, the size of the problem rises to meet demand. As we increase the size of the problem, we need more processors to manage the size of the local problem in each processor. However, the large number of processors requires a complicate communication mechanism among processors. The convergence rate of Krylov methods deteriorates when the number of subdomains (processors) becomes large. Therefore, efficient parallel methods should be scalable, that is, their performance should not be sensitive to the number of processors (subdomains). The key to scalability of Krylov methods is a global communication mechanism through preconditioners. Two-level domain decomposition preconditioners introduce a coarse global problem set over the whole domain in order to provide the global communication mechanism. I have worked on developing efficient two-level domain decomposition methods which is easy to implement and flexible for practical applications. My research has been concentrated on developing efficient algorithms for two main subjects; Elliptic partial differential equations and unstructured meshes.

   - **Elliptic partial differential equations** I have studied the theoretical and numerical properties of novel two-level methods, called Overlapping Balancing Domain Decomposition (OBDD) methods. These new methods work well for Elliptic PDEs. The coarse problem of OBDD is based on the Partition of Unity (PU) functions. Therefore, the coarse matrix is sparse and the dimension of coarse problem is a multiple of the number of subdomains (processors). We have, in addition, developed effective methods for Helmholtz equations by combining OBDD and other domain decomposition ideas including a new approach, *restricted coarse space*.
   - **Unstructured meshes** Unstructured meshes are more flexible than structured meshes in adapting to complicated geometry. However, the flexibility of unstructured discretization makes the computational methods more complicated. I have developed an efficient parallel implementation of OBDD meth-

ods for unstructured meshes. The key to our approach is the efficient parallel construction of PU functions on unstructured meshes. The PU functions are essential to the construction of coarse space and the communication between coarse and fine levels. Our parallel procedures are easy to implement and scalable because they are based on subdomains (processors). The numerical results show that our methods improve the performance in comparison to other preconditioner options in PETSc.

I have learned many theoretical and numerical solutions to extend domain decomposition methods for more general cases. I also have used several parallel numerical tools including MPI, Cubit, Exodus, ParMetis and PETSc. I have acquired valuable experiences which help me immeasurably to balance the theoretical approaches and their practical implementations.

3. **Interdisciplinary Research.**

   I have actively worked at applying my knowledge of parallel algorithms towards the solution of problems originating in science and engineering. I have spent a good portion of my research involved in joint projects with engineers and scientists from other disciplines. I have applied numerical methods including domain decomposition methods to improve parallel computing performance for the solution of applied problems. A thorough knowledge of these techniques is vital to the successful completion of many research projects. Some examples of my contributions include :

   - **Cactus Computational Fluid Dynamics Toolkit**
   - **Time Parallel Solver for Linear and Nonlinear Wave Equations**
   - **Fluid Model for Wireless Sensor and Actuator Networks**
   - **Numerical Methods for SABR models (In Progress)**
   - **Pool fire Simulation**

   I am currently working with research groups in the Department of Computer Science, the Department of Physics, and the Center for Computation and Technology at Louisiana State University. I have strengthened and extended interdisciplinary research ties with several research groups in other departments.

From these several researches, I have good understanding what my colleagues need and how I can work with them efficiently. I have realized that mutual respect and positive attitude to understand different backgrounds are important to achieve success in interdisciplinary research. I have also found many funding opportunities from projects with other research groups.