ENHANCING DECISION MAKING OF CRITICAL INFORMATION SYSTEMS THROUGH OPTIMIZATION MODELS AND THE IMPROVED PARALLEL CONJUGATE METHOD ALGORITHM

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Abstract

Diverse classes of information systems provide time sensitive technical support in critical information systems problem domains. These classes of information systems, which include emergency notification response systems, intrusion detection systems, and fraud detection systems, incorporate linear optimization models. Since these systems require very fast response, the algorithms for solving the linear models are less efficient imposing penalties on the desired system performance. In this paper, we propose the reformulation of linear optimization models for critical information systems to take advantage of the improved parallel conjugate gradient method. This approach provides a means by which decision makers can gain access to critical information in time sensitive situations.

Keywords: Decision models, response time, information Systems, Linear Programming, optimization, improved conjugate gradient method**.**

INTRODUCTION

Diverse classes of information systems provide time sensitive operational decision support functions. These classes include emergency notification response systems, intrusion detection systems, and fraud detection systems. The need for quick response is crucial for these systems. For instance, in crisis management contexts, the timeliness of a response is determined with reference to a fixed instant of an absolute action threshold. This establishes the last possible point in time where any solution is available. Once an action threshold passes, a crisis is no longer containable; whatever adverse consequences a problem portends are thereafter inescapable (Thomas et al 2007).

Linear programming has been used as a modeling tool in these systems (Makowski, 1994). However, it has been argued that the classical standard Linear programming approach for addressing such problems is not efficient and does not provide quick response to decision makers (Osatuyi 2007, Mukkamala et al 2006). Further, an analysis of several DSS models revealed that formulation, portability, and reusability are typical problems with the design of effective DSS models (Makowski 1994).

Recently, it has been shown that an Improved Conjugate Gradient Method (ICGM) can be used to solve such linear programming problems, and that it is better in terms of parallel performance than the conventional conjugate gradient method (Osatuyi 2007). By parallel performance, we mean the scalability (proper distribution of components on a parallel machine), speed and efficiency of an algorithm in a distributed system.

We show in this paper, how linear programming models in critical information systems such as emergency response systems and intrusion detection systems can be reformulated to take advantage of the improved conjugate gradient method. The conjugate gradient algorithm is an iterative solution technique known to be effective for systems of the form:

$$min \sum_{i=0}^{k} Ax_i = b \qquad (1)$$

$$\mathrm{b} - \mathrm{r} \leq Ax \leq \mathrm{b} \qquad (1a)$$

where A is a square, symmetric, positive-definite matrix of dimension n, and x and b are column vectors of length n (Shewchuk, 1994).

The rest of the paper is presented as follows. The next section is a review of the literature on critical information systems problems with a description of a test problem suitable for the ICGM. The description of the conjugate gradient method, and discussions of results are presented in sections three and four respectively. Finally, the paper is concluded with a discussion of managerial applications.

QUICK RESPONSE IN CRITICAL IT-ENABLED SYSTEMS

Information Technology (IT) enabled systems are used to support three levels of organizational decision-making (Muralidhar *et al* 2001). Systems at the operational level are typically used by first-level managers to direct specific tasks. Mid-level systems are automated systems that support managerial activities such as the monitoring and control of operations. Executive systems consolidate organizational, historical, and projective data to support long term strategic planning (Simon 1960). The three levels of organizational decision-making have been characterized as structured, semi-structured and ill structured, respectively (Gorry and Morton 1971).

Decision support systems (DSS) are usually used for operational and midlevel decisions. Emergency response systems, fraud detection systems and intrusion detection systems are examples. Using Simon's (1955) classical four phases of the decision-making process (intelligence, design, choice, and implementation and control), a typical DSS concentrates on the design and choice phases (Fazlollahi and Vadihov 2001).

It has been observed that effective management decisions are critically dependent on the aptness and access to real-time updates of the situational factors in the affected zone. Recent challenging emergency management situations incclude: The Tsunami destruction along the pacific rim (Van de Walle and Turoff 2007), the breakdown of emergency management coordination processes in the aftermath of disasters such as the SARS outbreak in Southeast Asia and the Katrina hurricane devastations on the Gulf Coast. These challenges re-emphasize the importance of design, development and evaluation of effective and time-sensitive emergency systems (Van de Walle and Turoff 2007). Similarly, the need for time efficient solutions has been alerted in intrusion detection systems (IDS) for effectively balancing response for authorized users while preventing intruders from getting access to private data (Axelsson 2000; Daniels and Spafford 1999; Denning 1987; Frincke 2000; Stillerman et *al*. 1999). In the next section, we present a linear optimization model in Emergency Response Management System and discuss how the ICGM can be used to enhance the response of this model.

Web Servers and Emergency Response Management Systems

Federal, state, and local governmental agencies are faced with diverse responsibilities in responding and managing various natural and unnatural emergencies. The handling of emergencies is difficult and complex because an emergency may require managing a large area of coverage, responders and decision makers in a wide geographical area. Quite recently, an enhanced emergency response system, EVResponse, was proposed (Thomas et al. 2007). This architecture uses web services ties to provide HTTP based transport interface to enable other agencies have access to reports and historic data of affected agencies in a collaborative decision making environment. Thus, web services facilitate effective communication and collaboration between human decision makers. However, the web servers can become overloaded during the emergency period as requests could arrive faster than the servers were designed to handle. Linear optimization models can be implemented to minimize the server unavailability so that communication to and from individuals within the affected zone can be received. This problem has to be solved in a continuous mode during the peak period to identify the servers that may be down so that the available servers can share the load. It is important that the algorithm for solving the optimization problem is fast so that actions can be taken as quickly as possible in this problem domain to minimize the effect of the disaster.

THE CONJUGATE GRADIENT (CG) METHOD

The conjugate gradient method is an algorithm for the iterative solution of specific systems of linear equations. This method has been used to enhance the performance of optimization models in several application domains (e.g., Navon et al (1987). In the information systems discipline, a variant of the conjugate gradient method has been used to investigate intrusion detection mechanisms (Mukkamala et al, 2006). The basic components of the conjugate gradient algorithm consist of matrix-vector products, vector updates and dot products, which make it especially appealing for parallel implementations. As with many parallel interpretations of algorithms, the most straightforward manner of implementing the procedure does not lead to the best parallel performance and we argue for the ICGM as a means of over-coming some of the limitations of the CG method. ICGM uses the parallel version of the CG method, which is discussed in a later section.

For the web server unavailability problem that was presented earlier, the use of the MPI_Allgather function can be eliminated and replaced with a more efficient swapping procedure that uses no more communication (data distribution and collection) than is necessary. Experiments reveal that the speed of prediction with the improved algorithm is much faster than the conventional CG algorithm.

Basic Parallel Algorithm

The parallel implementation of the CG algorithm was constructed based on the assumption that it is necessary to compute only the most time consuming operations in parallel (Bycul 2002). These operations include the matrix-vector product, the scalar products and the vector sums (Cichomski 2001; Jordan *et al* 2002). The most straightforward method of decomposing the problem for parallel computation employs a row-wise block decomposition of the coefficient matrix with a conformal partitioning of the remaining vectors.

Assuming request to a web sever follows Poisson model where each node receives local_n$\left(=\frac{n}{p}\right)$ rows of A where p is the number of nodes used in the parallel cluster of servers (Martinello *et al* 2005). Examining the matrix-vector product Ax, under the assumption of row major storage of A indicates that each process requires a global copy of the vector x for the computation of the matrix- vector product. Because the vector x is distributed among the p processes, the local contributions of x need to be collected over all processes. The MPI_Allgather function from the MPI standard is used to accomplish this operation. The MPI_Allgather function is a gather process in which the data contributed by each process is gathered on all processes, instead of just the root process as in MPI_Gather (Thakur et *al* 2003). Detailed illustration of the partitioning of the matrix and vectors into the CG algorithm 1 is provided in Osatuyi (2007).

This algorithm is suitable for a general coefficient matrix. However, the matrix that arises in the test problem has a special structure that should be taken into account. We are interested in estimating the arrival rate at each server node over a given period in order to make preemptive reallocation of nodes to prevent overload. This period therefore specifies a boundary for which the arrival rate is to be determined. Such boundary conditions that supply the Poisson problem model with values are referred to as Dirichlet boundary conditions given by

$$u''(x) = f(x),\ x \in [a,b],\ u(a) = u_A,\ u(b) = u_B \tag{5}$$

where $f(x)$ is the web service unavailability function expressed as the Poisson traffic model (Martinello *et al* 2005):

$$f(x) = \sum_{k=a}^{b} \pi_k \{L(k) + L(k\gamma)\} + \sum_{k=a}^{b} \pi_{Dk} L(D_k) + \pi_0 \qquad (6)$$

where *L(k)*: the request loss probability due to buffer overflow in state k

L(kγ): the request loss probability caused by a transition from state k to state Dk, due to a server failure

$L(D_k)$: the request loss probability in state Dk, during the node failure detection time.

Approximating the derivatives of *u* via a second-order central difference leads to a discrete set of linear equations (Buzbee *et al* 1970). The resulting coefficient matrix is positive definite, so use of the conjugate gradient method is appropriate for this case. For this *A* matrix, the standard process would use Algorithm 1 with the matrix-vector product given in Algorithm 2 described in (Osatuyi 2007). Note that *A* does not have to be stored because of its structure.

Improved Parallel Algorithm

As seen from Algorithm 1, the MPI_Allgather function must be computed once per iteration. Examination of the structure of *A* reveals that a more efficient overlap method is possible. An exchange algorithm is used which sends and receives from a nearby process. When process *k* computes its portion of *Ad*, it does not need all of *d*. Due to the sparse structure of *A*, each process *k* needs only the last portion of *d* from process *k-1* and the first portion of *d* from process *k+1*. Hence, it is possible to develop an algorithm in which each process exchanges the necessary portions of d_{local} with neighboring process. This implementation should be faster, more efficient and less expensive when compared to the basic parallel algorithm with MPI_Allgather function since it requires only a minimum of communication and data exchanges. Hence, the modified parallel algorithm should result in a better performance when subjected to parallel benchmark testing. The exchange algorithm between processes is illustrated in (Osatuyi 2007).

DISCUSSIONS

We have shown how decision making in a typical critical information system situation can be modeled into a positive definite matrix to take advantage of the ICGM. Additional work will be done in the future compute and compare the speedup of the parallel computation when the MPI_Allgather function is used with benchmark measures. Typically, the speedup calculated should approximately be equal to the number of parallel decision making processes. With respect to the web server in the emergency response management system, we have demonstrated that the improved conjugate method can enable fast exchange of data between processes and providing efficient data flow management such that response rate is faster than that provided by the conventional CG method. This improvement will enable effective balancing the load of the web server so that majority of the requests are properly handled by the available web servers.

Managerial Applications

The proposed approach has implication for other information systems problems where quick response is very important. For instance the ICGM has practical application for intrusion detection systems. Internet security breach has negative economic impact on breached firms (e.g., Andoh-Baidoo and Osei-Bryson 2007, Cavusoglu et al. 2004). Businesses, governments, communities and individuals have great interest in internet security breach. One area of research that focuses on providing technical solution to the internet security problem is intrusion detection systems (Stillerman, Marceau, and Stillman, 1999). Intrusion detection systems provide technical solutions to prevent security incidents in networks whiles the attack is underway. These systems can inform operators about security threats or automatically shut systems when security threats are "highly" suspected. In performing these functions, the systems sometimes provide "false alarm" by indicating security threats where there is none. Hence, an effective system is one that maximizes the efficiency and minimizes false alarms. Because the intrusion detection systems have to prevent intruders from accessing computer and network resources while allowing legitimate users quick access to these resources, the decision making process for these systems need to be extremely quick. Hence, the linear programs solutions in such systems would benefit from using the fast response provided by the improved conjugate gradient algorithm.

CONCLUSIONS

Although diverse information systems are used to support critical decision-making, in some situations, the response time of the decision models is inadequate rendering the systems ineffective. In the emergency response and management area for instance, managing diverse resources and providing quick response in affected zone are very critical to minimizing the effect of both natural and man-made emergencies. It has been shown that the algorithms for solving linear programming models that are necessary in optimization decision models for critical information systems are inadequate. The improved conjugate gradient method algorithm provides efficient response in linear programming applications. We have proposed in this paper how linear programming models in critical information systems problems can be reformulated to take advantage of the improved conjugate gradient algorithm. We have presented managerial applications of the approach using the balancing of web servers in emergency response systems as a typical situation where the Poisson model of linear programming reformulation is appropriate. We believe that the use of the conjugate method can enable organizations enhance the response and provide more efficient solutions for critical information systems problems.

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