Application of Dependence Analysis and Runtime Data Flow Graph Scheduling to Matrix Computations by Ernie W. Chan, B.S; M.S Dissertation **SuperMatrix** ted to the Faculty of the Graduate School of rsity of Texas at Austin in Partial Fulfillment of the Requirements for the Degree of Ernie Chan, Ph.D. Doctor of Philosoph Department of Computer Science The University of Texas at Austin The University of Texas at Austin August 2010 S O F T W A R E E N G I N E E R I N G ENCY AND COMPUTATION: PRACTICE AND EXPERIENC (Company: Proct. Eque: 2007; 19:1749–1783 alian 5 July 2007 in Wiley InterScience (www.interscience.wiley Programming Matrix Algorithms-by-Blocks for Thread-Level Parallelism 14 Collective communication: theory, practice, and experience The libflame Library for Dense GREGORIO QUINTANA-ORTÍ and ENRIQUE S. QUINTANA-ORTÍ On Optimizing Collective Communi-Matrix Computations nie W. Chan, Mareel F. Heimlich, Avi Parkayastha, and Robert A. van de Geijn The University of Texus at Austin (echan, heimlich, rwóg)@cs.utexas.edu, avijit@tacc.utexas.edu <section-header><section-header><section-header><text><text><text><text><text><text><text><text> Ernie Chan^{1, s, †}, Marcel Hei and Robert van de Geiin¹ and ROBERT A. VAN DE GEIJN, FIELD G. VAN ZEE, and ERNIE CHAN The University of Texas at Austin mlich1, Avi Purkay Researchers from the Formal Linear Algebra Method Environment (Hame) project have developed new methodologies for analyzing, designing, and implementing linear algeba libraries. These solutions, which have calminated in the liblame library, seem to solve m of the programmability problems that have arisen with the advent of multicere and ma of Computer Sciences, The University of Texas at Austin, Austin, TX 78712, U.S.A. cord Computing Center, The University of Texas at Austin, Austin, TX 78712, U.S.A. I thread-level parallelism as the primary means for continued p rammability issue has reemeged as an obtacle to the use of a date volving lengery libraries for dense and handel linnar algo constraints imposed by early design decisions. We propose a jun of removes that records an a recording monitor in this works <text><text><text><text><text><text><text> und 24 January 2007; Accepted 10 March 2007 <text><text><text><text><text><text> 1. INTRODUCTION his paper makes a number of contributions to the topic of collective comm out per data transmission time.
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Cent of computations: The outs surgively to prefere an estimation of the low strainting outside to order the constrainting analytic of compatibility of the survey of these conducting an analytic of compatibility of the survey o A review of best practices: Collective communication was an active research in the 1980s and early 1990s as distributed-memory architectures with large numbers of processors were first introduced [1–7]. Since then an occasional paper has been published [8–16], but no dramatic new developments have been reported. ddresses: G. Quintana-Orti and E. S. Quintana-Orti, Departamento de Ingenieria y Computadores, Universidad Jaume 1, Campus Biu Sec, 12.071, Castellin, Spain aintan,quintana)dicc.uji.ec; R. A. van de Geljn, F. G. Van Zee, and E. Chan te d'Comcuter Sciences. The University of Tenss at Austin, Austin. TX 19712: email priority restores, in a summary and this work for percessal or data (digital or hand copies of part et al di ef this work for percessal or data line perceided that oppies are not made or distributed for perfort core oppies show the notice on the fost page or initial cores of a flag oppies. The second second second second second second second g with confit is permitted. To may etherwise, its reputibulis, its paid is to its use any composant of flab work in other works requires pri-fits. The second second second second second second second second flat to the second second second second second second second flat to the second second second second second second second flat to the second second second second second second second flat to the second se *Corresponder U.S.A. †E-mail: echa per nonzer neme. vev upannov tvo venigate are otner paraenzone. New, ave Romer A, vev na Gauye e e Ann Genomm Qerexon-Oert e Ann Genomm Qerexon-Oert nanwexinexasiani ani sponsor: National Science Foundation; contract/grant number: CCF-0540926 ght © 2007 John Wiley & Sons, Ltd. C InterScience Satisfying Your Dependencies with SuperMatrix rMatrix Out-of-Order Scheduling of Matrix Operations for SMP and Multi-Core Architectures Collective Communication on Architectures that Support Simultaneous Communication over Multiple Links Ernie Chan^{#3}, Field G. Van Zee^{#4}, Enrique S. Quintano-Orti¹¹⁴, Gregorio Quintano-Orti¹¹⁴, Robert van de Geiji [#]Department of Computer Sciences, The University of Texas at Austin Austria Change Strange William Gropp Rajeev Thakur Chan Robert van de Geijn Ernie Chan ue S. Quintana-Orti Gregorio tamento de Ingenieria y Departame Department of Computer Sciences The University of Texas at Austin (tchat, refg)#craters add ematics and Computer Science D Argonne National Laboratory (propp., takar)@mcc.arLpre cheduling of QR Factorization on SMP and Multi-Core Ar Sciences The University of Texas at Austin Austin, Texas 78712 echan@cs.utexas.edu Universidad Jaume I 12.071–Castellon, Spain gquintan@icc.uji.es Universidad Jaume I 12.071-Castellon, Spain quintana@icc.uji.es ento de Ingeniería y Ciencia de Computadorez, Univ Campuz Riu Sec, 12.071, Castellón, Spain Robert van de Geijn Department of Computer Sciences <text><text><section-header><text><text><text><text><text><text><text><text><text><text><text><text> indad Jaume I, 12.071 - Castellón intan, quintana}0ice.uj: n, Robert A. van de Geijn, Field G is Il Tevas at e designed with only one other is the IBM Blue odes simultane-any of the MPI age of this abil-relace(-to-one), dace. We show its than the pre-of parallel com-formance to the The University of Texas a Austin Austin, Texas 78712 rvdg@cs.utexas.edu imie Chan, Robert A. van de Geijn, Field G Deputment of Computer Sciences. The University of Texas at Austin, Austin, Texas 78712, {echan, rvrdq, field}@cs.utexas extens. Thus, experiments are purcely implemented by individual calls to the and an encourse notices. We are the transmission of the set of th Keywords data affinity, data-flow parallelism, den e linear al bracket, dy munic chadiding, aux-of-order scores in texas.edu community of draws: Hard a spin relation by maintain we prove the state of the spin relation <section-header><section-header><text><text><text> 1. INTRODUCTION Categories and Subject Descriptors D.m [Sof Terms Alexishens Performance Critical and the set of the se Model of Parallel Computation of Parallel Computation performance of the presented algorithms, it is useful tople model of parallel computation. The following a make in this report: entrees: The target architectures are distributed-milel architectures. dexing: The parallel architecture contains 9 computational nodes (nodes hereafter). The nodes are indexed from 1 to 9 - 1 Each node has one computational processor. Categories and Subject Descriptors ation. of new parallel architectures, new models o can be developed that dramatically decrease opically fully connected: Any node can send directly to any other node where a communication network provides automatic routing. General Terms Agent has, Performance pology: The underlying topology is an N-dimensional torus. Each node is directly connected to each of its 2N nearest neighbors where two are on opposing sides of a dimensional mmunicating between nodes: At any given time, a single node can send or receive messages from 2N other nodes. A single node can do so simultaneously only if each of the messages are The process of extracting parallelism fr used libraries must be reevaluated with the SMP architectures with many processors. Storage by blocks allows the matrices to replace realism in the back under of data and appendence on blocks as the back under of company in parks. This is shown in greatly reduce the complexity of managing data et of communication: The cost of sending a message between two nodes will be modeled by $\alpha + \alpha \beta$, in the observe of servers' conflicts. Here α and β respectively represent the message 0-7685-3089-348 \$25.00 C 2988 DEE DCE 10-1109PDP 290P ** o colificary 91 1-4244-1388-507/\$25.00 () 2007 IEEE 2007 IEEE International Con Design of Scalable Dense Linear Algebra Libraries for Multithreaded Architectures: the LU Factorization Gregorio Quinnan, Orti, Environi, Carlonia Orti, Gregorio Quinnan, Orti, Circcia de Compandores Universidad James I (2017), Carcica de Compandores Universidad James I (2017), Carcia de Gaija, Fielda C. Van Zee Deparament of Company Sciences The Charlow Company Sciences Company SuperMatrix: A Multithreaded Runtime Scheduling System for Algorithms-by-Blocks Managing the Complexity of Lookahead for LU Factorization with Pivoting sforming Linear Algebra Libraries: From Abstraction to Pa ie Chan, Robert van de Geijn, and Field G. Van Zee Department of Compater Sciences The University of Texas at Austin Austin, TX 78712 {ochan, zvidg, field}ecs.utexas.edu Jim Nagle LabVIEW Math and Signal Pro National Instruments Austin, TX 78759 jim.nsgle@ni.com Paolo Bie Repartment of Computer Science The University of Texas at Austin Austin, Texas 78712 -sepater Sciences of Texas at Austin rxas 78712 t)@r* - ' <page-header><text><text><text><text><text><text><text><list-item><list-item><list-item><list-item><text><text><text><text><text><text><text> oping a high performance LU fac privating while keeping the impl contributions of this noner include A demonstration that dense lin can attain high performance eve Categories and Subject Descriptor General Terms Keywords LU factorization with par acyclic graph, lookahead INTRODUCTION NORMANN, BILLENDS Aupp are and the comparison of the community bit strate accordington such as the community mediate appendix theratics like LAPACK will need proteining that spectra and the community of the com-tent of the comparison of the comparison of the com-tent of the comparison of the comparison of the com-tent of the comparison of the compar 2. LU FACTORIZATION WITH PARTIAL PIVOTING w to intelligently schedule allelism. Specifically, it is s earlier, particularly those oth of execution, to allow xecute in parallel. This in-individual instanction learn ter utilize the compute power o sing cores [4, 5, 6, 7, 8, 21, 23]. but this notice and the fatt crathescore to the second permission and/or a fee. SPAC 10, and the second se fement with the largest magnitude in th n T., and exchanges that element with o-978-1-4244-1694-3/08/\$25.00 C2008 IEEE