

An Introduction to Parallel Programming Solutions, Chapter 1

Jinyoung Choi and Peter Pacheco

February 1, 2011

1.


```

quotient = n / p;
remainder = n % p;
if (my_rank < remainder) {
    my_n_count = quotient + 1;
    my_first_i = my_rank * my_n_count;
} else {
    my_n_count = quotient;
    my_first_i = my_rank * my_n_count + remainder;
}
my_last_i = my_first_i + my_n_count;
      
```
2. We are assigning blocks of elements to cores in order (the first n/p elements to core 0, the next n/p elements to core 1, so on). So, for example, if $n = 12$ and $p = 4$, core 0 spends 12 milliseconds in the call to `Compute_next_value` ($i = 0, 1, 2$), core 1 spends 30 milliseconds ($i = 3, 4, 5$), core 2 spends 48 milliseconds ($i = 6, 7, 8$), and core 3 spends 66 milliseconds ($i = 9, 10, 11$). So clearly this assignment will do a very poor job of load balancing.

A better approach uses a *cyclic* assignment of the work to the cores:

```

/* assign[c][j] is the jth value of i assigned to core c */
/* work[c] is the total amount of work assigned to core c */
c = j = 0;
for (i = 0; i < n; i++) {
    work[c] += 2*(i+1);
    assign[c][j] = i;
    c = (c + 1) % p;
    if (c == 0) j++;
}
      
```

Introduction To Parallel Programming Pacheco Solutions

RJ Alexander



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An Introduction to Parallel Programming Peter Pacheco, Matthew Malensek, 2021-08-27 An Introduction to Parallel Programming Second Edition presents a tried and true tutorial approach that shows students how to develop effective parallel programs with MPI Pthreads and OpenMP As the first undergraduate text to directly address compiling and running parallel programs on multi core and cluster architecture this second edition carries forward its clear explanations for designing debugging and evaluating the performance of distributed and shared memory programs while adding coverage of accelerators via new content on GPU programming and heterogeneous programming New and improved user friendly exercises teach students how to compile run and modify example programs Takes a tutorial approach starting with small programming examples and building progressively to more challenging examples Explains how to develop parallel programs using MPI Pthreads and OpenMP programming models A robust package of online ancillaries for instructors and students includes lecture slides solutions manual downloadable source code and an image bank New to this edition New chapters on GPU programming and heterogeneous programming New examples and exercises related to parallel algorithms [A Tutorial on Elliptic PDE Solvers and Their Parallelization](#) Craig C. Douglas, Gundolf Haase, Ulrich Langer, 2003-01-01 A Tutorial on Elliptic PDE Solvers and Their Parallelization is a valuable aid for learning about the possible errors and bottlenecks in parallel computing One of the highlights of the tutorial is that the course material can run on a laptop not just on a parallel computer or cluster of PCs thus allowing readers to experience their first successes in parallel computing in a relatively short amount of time This tutorial is intended for advanced undergraduate and graduate students in computational sciences and engineering however it may also be helpful to professionals who use PDE based parallel computer simulations in the field [An Introduction to Parallel Programming](#) Scott L. Hamilton, 2013-12-31 An introduction to parallel programming with openmpi using C It is written so that someone with even a basic understanding of programming can begin to write mpi based parallel programs *Computational Methods Of Linear Algebra (3rd Edition)* Granville Sewell, 2014-07-07 This book presents methods for the computational solution of some important problems of linear algebra linear systems linear least squares problems eigenvalue problems and linear programming problems The book also includes a chapter on the fast Fourier transform and a very practical introduction to the solution of linear algebra problems on modern supercomputers The book contains the relevant theory for most of the methods employed It also emphasizes the practical aspects involved in implementing the methods Students using this book will actually see and write programs for solving linear algebraic problems Highly readable FORTRAN and MATLAB codes are presented which solve all of the main problems studied **Parallel Scientific Computing in C++ and MPI** George Karniadakis, Robert M. Kirby, 2003-06-16 Numerical algorithms modern programming techniques and parallel computing are often taught serially across different courses and different textbooks The need to integrate concepts and tools usually comes only in employment or in research after the

courses are concluded forcing the student to synthesise what is perceived to be three independent subfields into one This book provides a seamless approach to stimulate the student simultaneously through the eyes of multiple disciplines leading to enhanced understanding of scientific computing as a whole The book includes both basic as well as advanced topics and places equal emphasis on the discretization of partial differential equations and on solvers Some of the advanced topics include wavelets high order methods non symmetric systems and parallelization of sparse systems The material covered is suited to students from engineering computer science physics and mathematics

Introduction to Parallel Computing Zbigniew J. Czech, 2017-01-11 The constantly increasing demand for more computing power can seem impossible to keep up with However multicore processors capable of performing computations in parallel allow computers to tackle ever larger problems in a wide variety of applications This book provides a comprehensive introduction to parallel computing discussing theoretical issues such as the fundamentals of concurrent processes models of parallel and distributed computing and metrics for evaluating and comparing parallel algorithms as well as practical issues including methods of designing and implementing shared and distributed memory programs and standards for parallel program implementation in particular MPI and OpenMP interfaces Each chapter presents the basics in one place followed by advanced topics allowing novices and experienced practitioners to quickly find what they need A glossary and more than 80 exercises with selected solutions aid comprehension The book is recommended as a text for advanced undergraduate or graduate students and as a reference for practitioners

Parallel Programming Thomas Rauber, Gudula Rünger, 2023-04-04 This textbook covers the new development in processor architecture and parallel hardware It provides detailed descriptions of parallel programming techniques that are necessary for developing efficient programs for multicore processors as well as for parallel cluster systems and supercomputers The book is structured in three main parts covering all areas of parallel computing the architecture of parallel systems parallel programming models and environments and the implementation of efficient application algorithms The emphasis lies on parallel programming techniques needed for different architectures In particular this third edition includes an extended update of the chapter on computer architecture and performance analysis taking new developments such as the aspect of energy consumption into consideration The description of OpenMP has been extended and now also captures the task concept of OpenMP The chapter on message passing programming has been extended and updated to include new features of MPI such as extended reduction operations and non blocking collective communication operations The chapter on GPU programming also has been updated All other chapters also have been revised carefully The main goal of this book is to present parallel programming techniques that can be used in many situations for many application areas and to enable the reader to develop correct and efficient parallel programs Many example programs and exercises are provided to support this goal and to show how the techniques can be applied to further applications The book can be used as a textbook for students as well as a reference book for professionals The material of the book has been used

for courses in parallel programming at different universities for many years

Computational Mathematics Robert E. White, 2015-11-11 Computational Mathematics Models Methods and Analysis with MATLAB and MPI is a unique book covering the concepts and techniques at the core of computational science The author delivers a hands on introduction to nonlinear 2D and 3D models nonrectangular domains systems of partial differential equations and large algebraic problems requiring

Parallel Programming with MPI Peter Pacheco, 1997 Mathematics of Computing Parallelism

Progress in Landslide Research and Technology, Volume 1 Issue 1, 2022 Kyoji Sassa, Kazuo Konagai, Binod Tiwari, Željko Arbanas, Shinji Sassa, 2023-01-10 This open access book provides an overview of the progress in landslide research and technology and is part of a book series of the International Consortium on Landslides ICL The book provides a common platform for the publication of recent progress in landslide research and technology for practical applications and the benefit for the society contributing to the Kyoto Landslide Commitment 2020 which is expected to continue up to 2030 and even beyond to globally promote the understanding and reduction of landslide disaster risk as well as to address the 2030 Agenda Sustainable Development Goals

High-Performance Computing on Complex Environments Emmanuel Jeannot, Julius Zilinskas, 2014-04-10 With recent changes in multicore and general purpose computing on graphics processing units the way parallel computers are used and programmed has drastically changed It is important to provide a comprehensive study on how to use such machines written by specialists of the domain The book provides recent research results in high performance computing on complex environments information on how to efficiently exploit heterogeneous and hierarchical architectures and distributed systems detailed studies on the impact of applying heterogeneous computing practices to real problems and applications varying from remote sensing to tomography The content spans topics such as Numerical Analysis for Heterogeneous and Multicore Systems Optimization of Communication for High Performance Heterogeneous and Hierarchical Platforms Efficient Exploitation of Heterogeneous Architectures Hybrid CPU GPU and Distributed Systems Energy Awareness in High Performance Computing and Applications of Heterogeneous High Performance Computing Covers cutting edge research in HPC on complex environments following an international collaboration of members of the ComplexHPC Explains how to efficiently exploit heterogeneous and hierarchical architectures and distributed systems Twenty three chapters and over 100 illustrations cover domains such as numerical analysis communication and storage applications GPUs and accelerators and energy efficiency

Euro-Par' 99 Parallel Processing Patrick Amestoy, Philippe Berger, Michel Dayde, Iain Duff, Valerie Frayse, Luc Giraud, Daniel Ruiz, 2003-05-21 Euro

Parisaninternationalconferencededicatedtothepromotionandadvan ment of all aspects of parallel computing The major themes can be divided into the broad categories of hardware software algorithms and applications for p allel computing The objective of Euro Par is to provide a forum within which to promote the development of parallel computing both as an industrial te nique and an academic discipline extending the frontier of both the state of the art and the state of the practice

This is particularly important at a time when parallel computing is undergoing strong and sustained development and experiencing real industrial take up. The main audience for and participants in Euro Par are seen as researchers in academic departments, government laboratories and industrial organisations. Euro Par's objective is to become the primary choice of such professionals for the presentation of new results in their specific areas. Euro Par is also interested in applications which demonstrate the effectiveness of the main Euro Par themes. There is now a permanent Web site for the series <http://brahms.fmi.uni-passau.de/ci/europar> where the history of the conference is described. Euro Par is now sponsored by the Association of Computer Machinery and the International Federation of Information Processing. Euro Par 99 follows that of the past four conferences and consists of a number of topics each individually monitored by a committee of four. There were originally 23 topics for this year's conference. The call for papers attracted 343 submissions of which 188 were accepted. Of the papers accepted 4 were judged as distinguished, 111 as regular and 73 as short papers.

Computing the Electrical Activity in the Heart Joakim Sundnes, Glenn Terje Lines, Xing Cai, Bjørn Frederik Nielsen, Kent-Andre Mardal, Aslak Tveito, 2007-06-26. The heart is a fantastic machine: during a normal lifetime it beats about 2.5 billion times and pumps 200 000 tons of blood through an enormous system of vessels extending 160 000 kilometres throughout the body. For centuries man has tried to understand how the heart works but there remain many unsolved problems: problems that have captured the attention of thousands of researchers worldwide. There is, for example, a huge amount of research being devoted to the analysis of single heart cells. Other areas of research include trying to understand how it works as a complete muscle and how blood flows through the heart. The entire process is extremely complex. The history of bioelectricity can be traced back to the late eighteenth century and the experiments of Luigi Galvani. A century later in 1887 Augustus Waller managed to measure the electrical signal generated by the heart at the surface of the body. His dog Jimmy earned a place in history by being the first to have his heart measured in this way (see Figure 1.1). In 1903 Willem Einthoven developed the first commercial device for recording electrocardiograms (ECGs) (see Figure 1.2).

Computational Mathematics, Modelling and Algorithms J. C. Misra, 2003. This comprehensive volume introduces educational units dealing with important topics in Mathematics, Modelling and Algorithms. Key Features: Illustrative examples and exercises; Comprehensive bibliography.

A Practical Approach to High-Performance Computing Sergei Kurgalin, Sergei Borzunov, 2019-11-10. The book discusses the fundamentals of high performance computing. The authors combine visualization, comprehensibility and strictness in their material presentation and thus influence the reader towards practical application and learning how to solve real computing problems. They address both key approaches to programming modern computing systems: multithreading based parallelizing in shared memory systems and applying message passing technologies in distributed systems. The book is suitable for undergraduate and graduate students and for researchers and practitioners engaged with high performance computing systems. Each chapter begins with a theoretical part where the relevant

terminology is introduced along with the basic theoretical results and methods of parallel programming and concludes with a list of test questions and problems of varying difficulty The authors include many solutions and hints and often sample code

Parallel Scientific Computing Roman Trobec, Gregor Kosec, 2015-03-27 This book is concentrated on the synergy between computer science and numerical analysis It is written to provide a firm understanding of the described approaches to computer scientists engineers or other experts who have to solve real problems The meshless solution approach is described in more detail with a description of the required algorithms and the methods that are needed for the design of an efficient computer program Most of the details are demonstrated on solutions of practical problems from basic to more complicated ones This book will be a useful tool for any reader interested in solving complex problems in real computational domains

Computational Methods for Geodynamics Alik Ismail-Zadeh, Paul Tackley, 2010-07-22 Written as both a textbook and a handy reference this text deliberately avoids complex mathematics assuming only basic familiarity with geodynamic theory and calculus Here the authors have brought together the key numerical techniques for geodynamic modeling demonstrations of how to solve problems including lithospheric deformation mantle convection and the geodynamo Building from a discussion of the fundamental principles of mathematical and numerical modeling the text moves into critical examinations of each of the different techniques before concluding with a detailed analysis of specific geodynamic applications Key differences between methods and their respective limitations are also discussed showing readers when and how to apply a particular method in order to produce the most accurate results This is an essential text for advanced courses on numerical and computational modeling in geodynamics and geophysics and an invaluable resource for researchers looking to master cutting edge techniques Links to supplementary computer codes are available online

Advanced Intelligent Systems for Sustainable Development (AI2SD'2020) Janusz Kacprzyk, Valentina E. Balas, Mostafa Ezziyyani, 2022-02-10 This book publishes the best papers accepted and presented at the 3rd edition of the International Conference on Advanced Intelligent Systems for Sustainable Development Applied to Agriculture Energy Health Environment Industry Education Economy and Security AI2SD 2020 This conference is one of the biggest amalgamations of eminent researchers students and delegates from both academia and industry where the collaborators have an interactive access to emerging technology and approaches globally In this book readers find the latest ideas addressing technological issues relevant to all areas of the social and human sciences for sustainable development Due to the nature of the conference with its focus on innovative ideas and developments the book provides the ideal scientific and brings together very high quality chapters written by eminent researchers from different disciplines to discover the most recent developments in scientific research

Proceedings of Ninth International Congress on Information and Communication Technology Xin-She Yang, Simon Sherratt, Nilanjan Dey, Amit Joshi, 2024-08-09 This book gathers selected high quality research papers presented at the Ninth International Congress on Information and Communication Technology held in London on February 19 22 2024 It discusses emerging

topics pertaining to information and communication technology ICT for managerial applications e governance e agriculture e education and computing technologies the Internet of Things IoT and e mining Written by respected experts and researchers working on ICT the book offers an asset for young researchers involved in advanced studies The work is presented in ten volumes **Internet of Everything** Teresa Pereira,Natalie Kiesler,John Impagliazzo,Henrique Santos,2025-03-19 This book constitutes the refereed post conference proceedings of the Third International Conference on Internet of Everything IoECon 2024 which took place in Guimar es Portugal in September 26 27 2024 The 10 full papers were carefully reviewed and selected from 28 submissions The papers cover the following topics Machine to Machine M2M People to Machine P2M or Machine to People M2P

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