

# OpenMP

Additional resource: <https://hpc.llnl.gov/openmp-tutorial>

## Introduction

- An **API** / Language-extension (**C/C++** and **Fortran**) for **multi-threaded, shared memory parallelism**
- Three primary API components:
  - Compiler Directives
  - Runtime Library Routines
  - Environment Variables

## Syntax

- General: `#pragma omp construct [clause[clause]...]{structured block}`
- Inclusion: `#include <omp.h>`
- Parallel region: `#pragma omp parallel`
- Parallel sections: Like defining threads. Every section given to a thread to be executed once.

```
pragma omp parallel sections [parameters]
{
  #pragma omp section
  { ... block ... }
  #pragma omp section
  { ... block ... }
  ...
}
```

- Work sharing (e.g. in loops): `#pragma omp parallel for`
  - Synchronizes at implicit barrier, unless `nowait` is specified
  - Different loop schedules available with `#pragma omp for schedule(schedule_type)`, see [Available loop schedules](#)

## Compiler syntax

# Openmp Api Users Guide

**Christian Terboven, Bronis R. de  
Supinski, Pablo Reble, Barbara M.  
Chapman, Matthias S. Müller**

## **Openmp Api Users Guide:**

**Openmp Api User's Guide** Sun Microsystems Inc. (NA),2007-06-01      **OpenMP in a Heterogeneous World** Barbara Chapman,Federico Massaioli,Matthias S. Müller,Marco Rorro,2012-05-23 This book constitutes the refereed proceedings of the 8th International Workshop on OpenMP held in Rome Italy in June 2012 The 18 technical full papers presented together with 7 posters were carefully reviewed and selected from 30 submissions The papers are organized in topical sections on proposed extensions to OpenMP runtime environments optimization and accelerators task parallelism validations and benchmarks      **OpenMP: Memory, Devices, and Tasks** Naoya Maruyama,Bronis R. de Supinski,Mohamed Wahib,2016-09-28 This book constitutes the proceedings of the 12th International Workshop on OpenMP IWOMP 2016 held in Nara Japan in October 2016 The 24 full papers presented in this volume were carefully reviewed and selected from 28 submissions They were organized in topical sections named applications locality task parallelism extensions tools accelerator programming and performance evaluations and optimization      **OpenMP in a New Era of Parallelism** Rudi Eigenmann,Bronis R. Supinski,2008-04-25 OpenMP is a widely accepted standard application programming interface API for high level shared memory parallel programming in Fortran C and C Since its introduction in 1997 OpenMP has gained support from most high performance compiler and hardware vendors Under the direction of the OpenMP Architecture Review Board ARB the OpenMP specification has evolved including the recent release of Specification 3.0 Active research in OpenMP compilers runtime systems tools and environments drives its evolution including new features such as tasking The community of OpenMP researchers and developers in academia and industry is united under cOMPunity [www.compunity.org](http://www.compunity.org) This organization has held workshops on OpenMP around the world since 1999 the European Workshop on OpenMP EWOMP the North American Workshop on OpenMP Applications and Tools WOMPAT and the Asian Workshop on OpenMP Experiences and Implementation WOMPEI attracted annual audiences from academia and industry The International Workshop on OpenMP IWOMP consolidated these three workshop series into a single annual international event that rotates across the previous workshop sites The first IWOMP meeting was held in Eugene Oregon USA IWOMP 2006 took place in Reims France and IWOMP 2007 in Beijing China Each workshop drew over 60 participants from research and industry throughout the world IWOMP 2008 continued the series with technical papers panels tutorials and OpenMP status reports The first IWOMP workshop was organized under the auspices of cOMPunity      **High Performance Computing** Heike Jagode,Hartwig Anzt,Guido Juckeland,Hatem Ltaief,2020-10-19 This book constitutes the refereed post conference proceedings of 10 workshops held at the 35th International ISC High Performance 2020 Conference in Frankfurt Germany in June 2020 First Workshop on Compiler assisted Correctness Checking and Performance Optimization for HPC C3PO First International Workshop on the Application of Machine Learning Techniques to Computational Fluid Dynamics Simulations and Analysis CFDML HPC I/O in the Data Center Workshop HPC IODC First Workshop Machine Learning on HPC Systems MLHPCS First

International Workshop on Monitoring and Data Analytics MODA 15th Workshop on Virtualization in High Performance Cloud Computing VHPC The 25 full papers included in this volume were carefully reviewed and selected They cover all aspects of research development and application of large scale high performance experimental and commercial systems Topics include high performance computing HPC computer architecture and hardware programming models system software performance analysis and modeling compiler analysis and optimization techniques software sustainability scientific applications deep learning

*High Performance Computing* Michela Taufer, Bernd Mohr, Julian M. Kunkel, 2016-10-05 This book constitutes revised selected papers from 7 workshops that were held in conjunction with the ISC High Performance 2016 conference in Frankfurt Germany in June 2016 The 45 papers presented in this volume were carefully reviewed and selected for inclusion in this book They stem from the following workshops Workshop on Exascale Multi Many Core Computing Systems E MuCoCoS Second International Workshop on Communication Architectures at Extreme Scale ExaComm HPC I/O in the Data Center Workshop HPC IODC International Workshop on OpenPOWER for HPC IWOPH Workshop on the Application Performance on Intel Xeon Phi Being Prepared for KNL and Beyond IXPUG Workshop on Performance and Scalability of Storage Systems WOPSSS and International Workshop on Performance Portable Programming Models for Accelerators P3MA

**Petascale Computing** David A. Bader, 2007-12-22 Although the highly anticipated petascale computers of the near future will perform at an order of magnitude faster than today's quickest supercomputer the scaling up of algorithms and applications for this class of computers remains a tough challenge From scalable algorithm design for massive concurrency to performance analyses and scientific vis

**OpenMP Shared Memory Parallel Programming** Rudolf Eigenmann, Michael J. Voss, 2003-05-15 This book contains the presentations given at the Workshop on OpenMP Applications and Tools WOMPAT 2001 The workshop was held on July 30 and 31 2001 at Purdue University West Lafayette Indiana USA It brought together designers users and researchers of the OpenMP application programming interface OpenMP has emerged as the standard for shared memory parallel programming For the first time it is possible to write parallel programs that are portable across the majority of shared memory parallel computers WOMPAT 2001 served as a forum for all those interested in OpenMP and allowed them to meet share ideas and experiences and discuss the latest developments of OpenMP and its applications WOMPAT 2001 was co-sponsored by the OpenMP Architecture Review Board ARB It followed a series of workshops on OpenMP including WOMPAT 2000 EWOMP 2000 and WOMPEI 2000 For WOMPAT 2001 we solicited papers formally and published them in the form of this book The authors submitted extended abstracts which were reviewed by the program committee All submitted papers were accepted The authors were asked to prepare a final paper in which they addressed the reviewers' comments The proceedings in the form of this book were created in time to be available at the workshop In this way we hope to have brought out a timely report of ongoing OpenMP related research and development efforts as well as ideas for future improvements

*Using and Improving OpenMP for Devices,*

*Tasks, and More* Luiz DeRose, Bronis R. de Supinski, Stephen L. Olivier, Barbara M. Chapman, Matthias S. Müller, 2014-09-23

This book constitutes the refereed proceedings of the 10th International Workshop on OpenMP held in Salvador Brazil in September 2014. The 16 technical full papers presented were carefully reviewed and selected from 18 submissions. The papers are organized in topical sections on tasking models and their optimization, understanding and verifying correctness of OpenMP programs, OpenMP memory extensions, extensions for tools and locks, experiences with OpenMP device constructs.

**Stochastic Equations for Complex Systems** Stefan Heinz, Hakima Bessaih, 2015-05-06. Mathematical analyses and computational predictions of the behavior of complex systems are needed to effectively deal with weather and climate predictions, for example, and the optimal design of technical processes. Given the random nature of such systems and the recognized relevance of randomness, the equations used to describe such systems usually need to involve stochastics. The basic goal of this book is to introduce the mathematics and application of stochastic equations used for the modeling of complex systems. A first focus is on the introduction to different topics in mathematical analysis. A second focus is on the application of mathematical tools to the analysis of stochastic equations. A third focus is on the development and application of stochastic methods to simulate turbulent flows as seen in reality. This book is primarily oriented towards mathematics and engineering. PhD students, young and experienced researchers and professionals working in the area of stochastic differential equations and their applications. It contributes to a growing understanding of concepts and terminology used by

mathematicians, engineers and physicists in this relatively young and quickly expanding field. From Software Engineering to Formal Methods and Tools, and Back Maurice H. ter Beek, Alessandro Fantechi, Laura Semini, 2019-10-08. This volume was published in honor of Stefania Gnesi's 65th birthday. The Festschrift volume contains 32 papers written by close collaborators and friends of Stefania and was presented to her on October 8, 2019, one day colloquium held in Porto Portugal. The Festschrift consists of eight sections, seven of which reflect the main research areas to which Stefania has contributed. Following a survey of Stefania's legacy in research and a homage by her thesis supervisor, these seven sections are ordered according to Stefania's life cycle in research: from software engineering to formal methods and tools and back. Software Engineering, Formal Methods and Tools, Requirements Engineering, Natural Language Processing, Software Product Lines, Formal Verification and Applications. Facing the Multicore-Challenge III Rainer Keller, David Kramer, Jan-Philipp Weiß, 2013-01-11. This state-of-the-art survey features topics related to the impact of multicore, manycore and coprocessor technologies in science and large scale applications in an interdisciplinary environment. The papers included in this survey cover research in mathematical modeling, design of parallel algorithms, aspects of microprocessor architecture, parallel programming languages, hardware aware computing, heterogeneous platforms, manycore technologies, performance tuning and requirements for large scale applications. The contributions presented in this volume are an outcome of an inspiring conference conceived and organized by the editors at the University of Applied Sciences HTW in Stuttgart, Germany, in

September 2012 The 10 revised full papers selected from 21 submissions are presented together with the twelve poster abstracts and focus on combination of new aspects of microprocessor technologies parallel applications numerical simulation and software development thus they clearly show the potential of emerging technologies in the area of multicore and manycore processors that are paving the way towards personal supercomputing and very likely towards exascale computing

High Performance Computing Ponnuswamy Sadayappan,Bradford L. Chamberlain,Guido Juckeland,Hatem

Ltaief,2020-06-15 This book constitutes the refereed proceedings of the 35th International Conference on High Performance Computing ISC High Performance 2020 held in Frankfurt Main Germany in June 2020 The 27 revised full papers presented were carefully reviewed and selected from 87 submissions The papers cover a broad range of topics such as architectures networks artificial intelligence and machine learning data storage emerging technologies HPC algorithms HPC applications performance modeling programming models systems software The conference was held virtually due to the COVID 19 pandemic Chapters Scalable Hierarchical Aggregation and Reduction Protocol SHARP Streaming Aggregation Hardware Design and Evaluation Solving Acoustic Boundary Integral Equations Using High Performance Tile Low Rank LU Factorization Scaling Genomics Data Processing with Memory Driven Computing to Accelerate Computational Biology Footprint Aware Power Capping for Hybrid Memory Based Systems and Pattern Aware Staging for Hybrid Memory Systems are available open access under a Creative Commons Attribution 4 0 International License via link [springer.com](https://www.springer.com) **Using**

**OpenMP** Barbara Chapman,Gabriele Jost,Ruud Van Der Pas,2007-10-12 A comprehensive overview of OpenMP the standard application programming interface for shared memory parallel computing a reference for students and professionals I hope that readers will learn to use the full expressibility and power of OpenMP This book should provide an excellent introduction to beginners and the performance section should help those with some experience who want to push OpenMP to its limits from the foreword by David J Kuck Intel Fellow Software and Solutions Group and Director Parallel and Distributed Solutions Intel Corporation OpenMP a portable programming interface for shared memory parallel computers was adopted as an informal standard in 1997 by computer scientists who wanted a unified model on which to base programs for shared memory systems OpenMP is now used by many software developers it offers significant advantages over both hand threading and MPI Using OpenMP offers a comprehensive introduction to parallel programming concepts and a detailed overview of OpenMP Using OpenMP discusses hardware developments describes where OpenMP is applicable and compares OpenMP to other programming interfaces for shared and distributed memory parallel architectures It introduces the individual features of OpenMP provides many source code examples that demonstrate the use and functionality of the language constructs and offers tips on writing an efficient OpenMP program It describes how to use OpenMP in full scale applications to achieve high performance on large scale architectures discussing several case studies in detail and offers in depth troubleshooting advice It explains how OpenMP is translated into explicitly multithreaded code providing a valuable behind the scenes account of

OpenMP program performance Finally Using OpenMP considers trends likely to influence OpenMP development offering a glimpse of the possibilities of a future OpenMP 3.0 from the vantage point of the current OpenMP 2.5 With multicore computer use increasing the need for a comprehensive introduction and overview of the standard interface is clear Using OpenMP provides an essential reference not only for students at both undergraduate and graduate levels but also for professionals who intend to parallelize existing codes or develop new parallel programs for shared memory computer architectures

Matrix Functions and Matrix Equations Zhaojun Bai, 2015-09-04 Matrix functions and matrix equations are widely used in science engineering and social sciences due to the succinct and insightful way in which they allow problems to be formulated and solutions to be expressed This book covers materials relevant to advanced undergraduate and graduate courses in numerical linear algebra and scientific computing It is also well suited for self study The broad content makes it convenient as a general reference to the subjects

Parallel and High Performance Computing Robert Robey, Yuliana Zamora, 2021-06-22 Complex calculations like training deep learning models or running large scale simulations can take an extremely long time Efficient parallel programming can save hours or even days of computing time Parallel and High Performance Computing shows you how to deliver faster run times greater scalability and increased energy efficiency to your programs by mastering parallel techniques for multicore processor and GPU hardware about the technology Modern computing hardware comes equipped with multicore CPUs and GPUs that can process numerous instruction sets simultaneously Parallel computing takes advantage of this now standard computer architecture to execute multiple operations at the same time offering the potential for applications that run faster are more energy efficient and can be scaled to tackle problems that demand large computational capabilities But to get these benefits you must change the way you design and write software Taking advantage of the tools algorithms and design patterns created specifically for parallel processing is essential to creating top performing applications about the book Parallel and High Performance Computing is an irreplaceable guide for anyone who needs to maximize application performance and reduce execution time Parallel computing experts Robert Robey and Yuliana Zamora take a fundamental approach to parallel programming providing novice practitioners the skills needed to tackle any high performance computing project with modern CPU and GPU hardware Get under the hood of parallel computing architecture and learn to evaluate hardware performance scale up your resources to tackle larger problem sizes and deliver a level of energy efficiency that makes high performance possible on hand held devices When you're done you'll be able to build parallel programs that are reliable robust and require minimal code maintenance This book is unique in its breadth with discussions of parallel algorithms techniques to successfully develop parallel programs and wide coverage of the most effective languages for the CPU and GPU The programming paradigms include MPI OpenMP threading and vectorization for the CPU For the GPU the book covers OpenMP and OpenACC directive based approaches and the native based CUDA and OpenCL languages what's inside Steps for planning a new parallel project

Choosing the right data structures and algorithms Addressing underperforming kernels and loops The differences in CPU and GPU architecture about the reader For experienced programmers with proficiency in a high performance computing language such as C C or Fortran about the authors Robert Robey has been active in the field of parallel computing for over 30 years He works at Los Alamos National Laboratory and has previously worked at the University of New Mexico where he started up the Albuquerque High Performance Computing Center Yuliana Zamora has lectured on efficient programming of modern hardware at national conferences based on her work developing applications running on tens of thousands of processing cores and the latest GPU architectures

Advancing OpenMP for Future Accelerators Alexis Espinosa, Michael Klemm, Bronis R. de Supinski, Maciej Cytowski, Jannis Klinkenberg, 2024-09-18 This book constitutes the refereed proceedings of the 20th International Workshop on OpenMP Advancing OpenMP for Future Accelerators IWOMP 2024 in Perth WA Australia during September 23 25 2024 The 14 full papers presented in this book were carefully reviewed and selected from 16 submissions They are grouped into the following topics current and future openMP optimization targeting more devices best practices tools and simplifying parallelization

*OpenMP: Heterogenous Execution and Data Movements* Christian Terboven, Bronis R. de Supinski, Pablo Reble, Barbara M. Chapman, Matthias S. Müller, 2015-09-30 This book constitutes the refereed proceedings of the 11th International Workshop on OpenMP held in Aachen Germany in October 2015 The 19 technical full papers presented were carefully reviewed and selected from 22 submissions The papers are organized in topical sections on applications accelerator applications tools extensions compiler and runtime and energy

*Computational Science and Its Applications - ICCSA 2011* Beniamino Murgante, Osvaldo Gervasi, Andres Iglesias, David Taniar, Bernady O. Apduhan, 2011-06-15 The five volume set LNCS 6782 6786 constitutes the refereed proceedings of the International Conference on Computational Science and Its Applications ICCSA 2011 held in Santander Spain in June 2011 The five volumes contain papers presenting a wealth of original research results in the field of computational science from foundational issues in computer science and mathematics to advanced applications in virtually all sciences making use of computational techniques The topics of the fully refereed papers are structured according to the five major conference themes geographical analysis urban modeling spatial statistics cities technologies and planning computational geometry and applications computer aided modeling simulation and analysis and mobile communications

**Handbook of Software Solutions for ICME** Georg J. Schmitz, Ulrich Prahl, 2016-12-19 As one of the results of an ambitious project this handbook provides a well structured directory of globally available software tools in the area of Integrated Computational Materials Engineering ICME The compilation covers models software tools and numerical methods allowing describing electronic atomistic and mesoscopic phenomena which in their combination determine the microstructure and the properties of materials It reaches out to simulations of component manufacture comprising primary shaping forming joining coating heat treatment and machining processes Models and tools addressing the in service behavior like fatigue corrosion and eventually



recycling complete the compilation An introductory overview is provided for each of these different modelling areas highlighting the relevant phenomena and also discussing the current state for the different simulation approaches A must have for researchers application engineers and simulation software providers seeking a holistic overview about the current state of the art in a huge variety of modelling topics This handbook equally serves as a reference manual for academic and commercial software developers and providers for industrial users of simulation software and for decision makers seeking to optimize their production by simulations In view of its sound introductions into the different fields of materials physics materials chemistry materials engineering and materials processing it also serves as a tutorial for students in the emerging discipline of ICME which requires a broad view on things and at least a basic education in adjacent fields

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