25 YEARS
OF ENABLING TECHNOLOGIES
FOR SCIENTIFIC COMPUTING

ICL UT
INNOVATIVE
COMPUTING LABORATORY
THE UNIVERSITY of TENNESSEE

2014/15 REPORT

INNOVATIVE COMPUTING LABORATORY **ICL 2014/15 REPORT**

EDITED BY **Sam Crawford** DESIGNED BY **David Rogers**

ICL 2014/15 REPORT

Jack Dongarra
DIRECTOR, ICL

FROM THE DIRECTOR

This year we are celebrating the 25th anniversary of the Innovative Computing Laboratory. When I reflect on two and a half decades of leading ICL, which has gone by all too quickly, I find it has been a period full of remarkable changes on every side. Most obviously, the rapid evolution and growing impact of high performance computing technology has been truly astonishing. In the past 25 years we have seen Gigascale systems, with tens of processors, turn into Terascale systems with thousands of processors, and then into Petascale systems with hundreds of thousands, even millions of processing elements, or "cores." It is clear in less than a decade we will be at Exascale computing, with billions of threads, and incorporating a host of revolutionary new innovations.

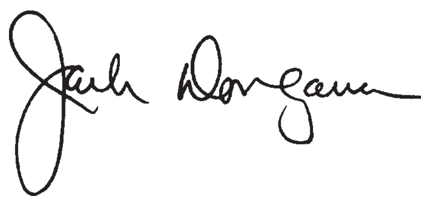
"Going to Exascale" will require utterly unprecedented increases in parallelism, fault tolerance, and energy efficiency; and these requirements will in turn demand equally radical changes to computing architecture, software, and algorithms. At the same time, we know that the recent dawn of the era of "Big Data," with explosive growth in the amount, the sources, and the types of digital data, means that computational science now confronts an operational landscape that is full of opportunity to those who can conquer its extraordinary new challenges.

If I feel confident that we are ready for these challenges, it is because I know we are cultivating fertile ground that has been well prepared by those who have come before. Over the past 25 years, we have developed robust research programs, attracted some of the best and brightest students and researchers, and created leading-edge research programs. A look at the timeline with which we begin this report, which lines up the tenure of some exceptional ICL alumni with the lifespan of major ICL projects, reminds us that we are drawing on the rich legacy left to us by the many creative and energetic people who have come through ICL over the years. The names of the projects that they have helped lead—PVM, MPI, LAPACK, ScaLAPACK, BLAS, ATLAS, Netlib, NHSE, TOP500, PAPI, NetSolve, Open-MPI, FT-MPI, the HPC Challenge, LINPACK, and the HPCG benchmark—are familiar to HPC users around the world. And the software that they have produced now provides critical research infrastructure for hundreds of thousands, if not millions, of users.

This past year saw the growth of projects that will undoubtedly add to this estimable list. Especially notable are major efforts that address either the “Big Data” dimension, or the “Going to Exascale” dimension of the current research landscape. In the case of the former, this year the National Science Foundation funded the Rapid Python Deep Learning Infrastructure (RaPyDLI) project—a collaboration between ICL, Indiana University, and Stanford University. RaPyDLI will increase the productivity and performance of Deep Learning research by the community through the combination of high level Python, C/C++, and Java environments with carefully designed libraries supporting GPU accelerators and MIC coprocessors (Intel Xeon Phi). Deep Learning (DL)—a form of machine learning that relies on training massive neural networks—has made major impacts in areas like speech recognition, drug discovery, and computer vision. ICL’s contribution will focus on efficient GPU kernel execution and optimization of scheduling strategies. By providing such support for hardware accelerators, RaPyDLI should increase available computational power by more than an order of magnitude, and thereby enable far more sophisticated and powerful neural networks. RaPyDLI now joins the SciDB project—a collaboration between MIT and the Intel Parallel Computing Laboratory begun in 2013—as the second prong in ICL’s Big Data strategy.

Our progress on the scientific communities’ journey to Exascale computing also continued with the official launch of the ARGO project. ARGO represents a major effort of DOE to develop a new Exascale Operating System and Runtime (OS/R). Designed from the ground up to run future HPC applications at extreme scales, it is clear that achieving this goal will require ARGO to leverage disruptive new computing technologies, such as 3D memory, ultra-low-power cores, and embedded network controllers, which will change the scientific computing landscape. ICL’s PaRSEC team will help lead in the development of a new, agile modular architecture that supports the balance between global optimization and local control that Exascale capable applications will require.

So the stage is set for what promises to be a very exciting and rewarding anniversary year for ICL, both in its main areas of research and in its work to grow and strengthen UTK and its broader community. During these exciting times, I am grateful to our sponsors for their continued support of our efforts. My special thanks and congratulations go to the ICL staff and students for their skill, dedication, and tireless efforts to make ICL one of the best centers in the world for scientific computing technologies.



INTRODUCTION

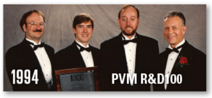
25 YEARS
OF ENABLING TECHNOLOGIES
FOR SCIENTIFIC COMPUTING

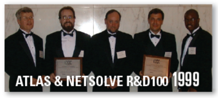
Now in its 25th year, the Innovative Computing Laboratory (ICL) is a large Computer Science research and development group situated in the heart of the University of Tennessee's Knoxville campus. ICL's mission is to establish and maintain the University of Tennessee as a world leader in advanced scientific and high performance computing through research, education, and collaboration.

KEY RESEARCH PROJECTS

- 1989: Level 3 BLAS, PVM
- 1992: BLACS, LAPACK
- 1993: TOP500
- 1994: MPI
- 1995: ScaLAPACK
- 1996: DOD PET
- 1997: ATLAS, NetSolve, RIB
- 1999: HARNESS, PAPI
- 2000: HPL


1989
ICL ESTABLISHED IN AYRES HALL






2000
MOVE TO CLAXTON BUILDING

1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001

SELECT ALUMNI

- 1994-2004 **Phil Mucci**
- 1994 **Frederic Desprez** ENS-LYON, FRANCE
- 1996-1997 **Yves Robert** ENS-LYON, FRANCE
- 1989-2001 **Susan Blackford** CSP, INC.
- 1991-1992 **Adam Beguelin** SENSR.NET
- 1994-2009 **Keith Seymour**
- 1992-2005 **Victor Eijkhout** UNIVERSITY OF TEXAS, AUSTIN
- 1992-1995 **Jaeyoung Choi** SOONGSIL UNIVERSITY, KOREA
- 1996-2001 **Dorian Arnold** UNIVERSITY OF NEW MEXICO
- 1993-2001 **Antoine Petitet** ESI GROUP, FRANCE
- 1989-1991 **Ed Anderson** EPA
- 1993-1994 **Bernard Tourancheau** UNIVERSITÉ JOSEPH FOURIER DE GRENOBLE
- 1996-2006 **Graham Fagg** MICROSOFT
- 1991-1994 **Roldan Pozo** NIST
- 1995-2001 **Erich Strohmaier** LAWRENCE BERKELEY NATIONAL LABORATORY
- 1989-1990 **Zhaojun Bai** UNIVERSITY OF CALIFORNIA, DAVIS
- 1992-1994 **Richard Barrett** SANDIA NATIONAL LABORATORIES
- 1995-1998 **Henri Casanova** UNIVERSITY OF HAWAII, MANOA
- 1999-2004 **Ken Roche** UNIVERSITY OF WASHINGTON
- 1995-1996 **Greg Henry** INTEL
- 1999-2003 **Sathish Vadhiyar** INDIAN INSTITUTE OF SCIENCE, INDIA
- 1990-1996 **Bob Manchek** STRATUS TECHNOLOGIES
- 1999-2010 **David Cronk** LOCKHEED-MARTIN
- 1990-1991 **Robert van de Geijn** UNIVERSITY OF TEXAS, AUSTIN
- 1995-1996 **Andy Cleary** AMAZON
- 1995-1996 **Sven Hammarling** NUMERICAL ALGORITHMS GROUP
- 1996-2005 **Kevin London** MICROSOFT
- 1996-1999 **Martin Swany** INDIANA UNIVERSITY
- 1991-2001 **Clint Whaley** LOUISIANA STATE UNIVERSITY
- 1990-1996 **Reed Wade** WETA DIGITAL
- 1997 **Françoise Tisseur** MANCHESTER UNIVERSITY, ENGLAND
- 1993-2012 **Shirley Moore** UNIVERSITY OF TEXAS AT EL-PASO
- 1989-2007 **Keith Moore**

ICL's founder, Dr. Jack Dongarra, established the lab in 1989 when he received a dual appointment as a Distinguished Professor at UTK and as a Distinguished Scientist at Oak Ridge National Laboratory. Since then, ICL has grown into an internationally recognized research laboratory, specializing in Numerical Linear Algebra, Distributed Computing, and Performance Evaluation and Benchmarking. The lab now employs nearly forty researchers, students, and staff, and has earned many accolades, including four R&D100 awards.

2002	FT-MPI GCO
2003	HPC Challenge LAPACK for Clusters
2006	FT-LA Open MPI
2008	MAGMA PLASMA
2009	Blackjack IESP MuMMI
2010	DPLASMA
2011	PULSAR
2012	PaRSEC
2013	BDEC BEAST HPCG
2014	ARGO RaPyDLI

2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014


2009 20TH ANNIVERSARY


2013 KEN KENNEDY AWARD

2003-2004 **Edgar Gabriel**
UNIVERSITY OF HOUSTON

2006-2008 **Karl Fuerlinger**
LUDWIG-MAXIMILIANS-UNIVERSITY MUNICH

2010-2012 **Mathieu Faverge**
UNIVERSITY OF BORDEAUX

2003-2007 **Thara Angskun**
SURANAREE UNIVERSITY OF TECHNOLOGY

2002-2009 **Haihang You**
CHINESE ACADEMY OF SCIENCES

2003-2006 **Julien Langou**
UNIVERSITY OF COLORADO, DENVER

2003-2006 **Felix Wolf**
JÜLICH SUPERCOMPUTING CENTRE

2009 **Emmanuel Agullo**
INRIA, FRANCE

2001-2006 **Zizhong (Jeffrey) Chen**
UNIVERSITY OF CALIFORNIA, RIVERSIDE

2008-2011 **Hatem Ltaief**
KAUST, SAUDI ARABIA

2004-2007 **Alfredo Buttari**
CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE

2001-2006 **Nathan Garner**
INTUIT

2010-2012 **Vince Weaver**
UNIVERSITY OF MAINE

2001-2014 **Dan Terpstra**
LIVING WATERS FOR THE WORLD

2014 HIGHLIGHTS

For ICL, 2014 marks the 25th year of conducting innovative research in high performance computing and cyberinfrastructure, and the lab made significant contributions to the HPC community during the past year. The sections below illustrate ICL's commitment to excellence, and set the bar for continued progress in our areas of research.

INDUSTRY EXCELLENCE

For years, ICL has been recognized by industry as a leader in information technology research. Vendors like NVIDIA and Intel regularly collaborate with the lab's research scientists, exchanging hardware and expertise, in an effort to improve both the hardware and software used in their products. These collaborations have led to very close working relationships and recognition of ICL's efforts among vendors.

INTEL PARALLEL COMPUTING CENTER

The Intel Parallel Computing Center (IPCC) program is comprised of universities, institutions, and labs that are leaders in their field, focusing on modernizing applications to increase parallelism and scalability through optimizations that leverage cores, caches, threads, and vector capabilities of microprocessors and coprocessors.

The objective of the Innovative Computing Laboratory's IPCC is the development and optimization of numerical linear algebra libraries and technologies for applications, while tackling current challenges in heterogeneous Intel® Xeon Phi™ coprocessor-based High Performance Computing. In collaboration with Intel's MKL team, the IPCC at ICL will modernize the popular LAPACK and ScaLAPACK libraries to run efficiently on current and future manycore architectures, and will disseminate the developments through the open source MAGMA MIC library.

ACCOLADES

Hard work seldom goes unnoticed, and in 2014 members of the ICL team earned several awards in recognition of the lab's research efforts and history of excellence.

DONGARRA NAMED TEXAS A&M FACULTY FELLOW

In 2014, Texas A&M University's Institute for Advanced Study (TIAS) named ICL director Jack Dongarra as a TIAS 2014-2015 Faculty Fellow. Jack will work with faculty and students in the Dwight Look College of Engineering's Department of Computer Science and Engineering at Texas A&M. Each year—since 2010—TIAS invites internationally prominent Faculty Fellows to pursue advanced study at TIAS, in collaboration with Texas A&M faculty and students, in order to provide an ideal setting for research and scholarship.

BEST PAPER AWARDS

VECPAR 2014

On June 30th, ICL's Ichitaro Yamazaki and his co-authors were presented with a best paper award for their entry in the 11th International Meeting on High Performance Computing for Computational Science (VECPAR). The paper, "Mixed-precision Orthogonalization Scheme and Adaptive Step Size for CA-GMRES on GPUs," proposes an original mixed-precision orthogonalization algorithm that uses a higher-precision only at the critical segments of the algorithm, and shows that this mixed-precision approach can improve not only the stability of the solver, but also the performance.

Yamazaki, I., S. Tomov, T. Dong, and J. Dongarra, "**Mixed-precision orthogonalization scheme and adaptive step size for CA-GMRES on GPUs**," *VECPAR 2014 (Best Paper)*, Eugene, OR, 06/2014.

PDSEC 2014

Azzam Haidar and his co-authors earned a best paper award for their entry in the 15th IEEE International Workshop on Parallel and Distributed Scientific and Engineering Computing (PDSEC). The paper, "New Algorithm for Computing Eigenvectors of the Symmetric Eigenvalue Problem," proposes an algorithm and HPC implementation for computing not only eigenvalues but also eigenvectors (full set or partial subset) of a symmetric or hermitian matrix and, as a result, achieves performance that is superior to any existing codes—academic or commercial.

Haidar, A., P. Luszczek, and J. Dongarra, "**New Algorithm for Computing Eigenvectors of the Symmetric Eigenvalue Problem**," *Workshop on Parallel and Distributed Scientific and Engineering Computing, IPDPS 2014 (Best Paper)*, Phoenix, AZ, IEEE, 05/2014.

RESEARCH

Increased efforts to keep pace with the evolution in HPC hardware and software present unique challenges that only a handful of enabling technology researchers are capable of addressing successfully. Our cutting-edge research efforts of the past have provided the foundation for addressing these challenges and serve as catalysts for success in our ever growing research portfolio. Our vision, our expertise, our determination, and our track record continue to position ICL as a leader in academic research.

What originally began 25 years ago as in-depth investigations of the numerical libraries that encode the use of linear algebra in software, has grown into an extensive research portfolio. We have evolved and expanded our research agenda to accommodate the aforementioned evolution of the HPC community, which includes a focus on algorithms and libraries for multicore and hybrid computing. As we have gained a solid understanding of the challenges presented in these domains, we have further expanded our research to include work in performance evaluation and benchmarking for high-end computers, as well as work in high performance parallel and distributed computing, with efforts focused on message passing and fault tolerance.

Demonstrating the range and diversity of our research, we will be engaged in more than 25 significant research projects during 2014-2015 across our main areas of focus. On the following pages, we provide brief summaries of some of our efforts in these research areas. For more detailed information about our reseach, visit our website – http://icl.utk.edu/.

NUMERICAL LINEAR ALGEBRA

PERFORMANCE EVALUATION AND BENCHMARKING

DISTRIBUTED COMPUTING

Numerical Linear Algebra algorithms and software form the backbone of many scientific applications in use today. With the ever-changing landscape of computer architectures, such as the massive increase in parallelism and the introduction of hybrid platforms utilizing both traditional CPUs as well as accelerators, these libraries must be revolutionized in order to achieve high performance and efficiency on these new hardware platforms. ICL has a long history of developing and standardizing these libraries in order to meet this demand, and we have multiple projects under development in this arena.

ICL TEAM

Hartwig Anzt
Chongxiao Cao
Tingxing Dong
Mark Gates
Azzam Haidar
Blake Haugen
Yulu Jia
Khairul Kabir
Jakub Kurzak
Julie Langou
Piotr Luszczek
Yves Robert
Stanimire Tomov
Ichitaro Yamazaki
Asim YarKhan

Performance Evaluation and Benchmarking are vital to developing science and engineering applications that run efficiently in an HPC environment. ICL's Performance Evaluation tools allow programmers to see the correlation between the structure of source/object code and the efficiency of the mapping of that code to the underlying architecture. These correlations are important for performance tuning, compiler optimization, debugging, and finding and correcting performance bottlenecks. ICL's benchmark software is widely used to determine the performance profile of modern HPC machines, and has come to play an essential role in the purchasing and management of major computing infrastructure by government and industry around the world.

ICL TEAM

Piotr Luszczek
Heike McCraw
Sangamesh Ragate
Asim YarKhan

Distributed Computing is an integral part of the high performance computing landscape. As the number of cores, nodes, and other components in an HPC system continue to grow explosively, applications need runtime systems that can exploit all this parallelism. Moreover, the drastically lower meantime to failure of these components must be addressed with fault tolerant software and hardware, and the escalating communication traffic that they generate must be addressed with smarter and more efficient message passing standards and practices. Distributed Computing research at ICL has been a priority for nearly two decades, and the lab has several projects in that arena under active development.

ICL TEAM

George Bosilca
Aurelien Bouteiller
Anthony Danalis
David Eberius
Thomas Herault
Reazul Hoque
Xi Luo
Thananon Patinyasakdikul
Stephen Richmond
Chunyan Tang
Wei Wu

NUMERICAL LINEAR ALGEBRA

BEAST

Bench-testing Environment for Automated Software Tuning

FIND OUT MORE AT
http://icl.utk.edu/beast/

The objective of the Bench-testing Environment for Automated Software Tuning (BEAST) project is to embrace the nature of accelerators, such as Graphics Processing Units (GPUs) from NVIDIA and AMD, and Xeon Phi coprocessors from Intel, which offer an order of magnitude more computing power and an order of magnitude more memory bandwidth than standard processors, and create an unprecedented opportunity for breakthroughs in science and technology.

Accelerators are a different kind of beast when it comes to performance tuning, and their architectural features usually pose unique programming challenges. For example, accelerators have massive numbers of simple cores, with static pipelines, and no branch prediction, and a multitude of constraints that can obliterate performance in numerous situations. BEAST allows a user to write high performance kernels in a tunable manner, sweep through a large search space, collect massive amounts of performance data, and plow through that data with machine learning techniques. These features enable a user to optimize code for extreme performance, without descending into the dark abyss of assembly programming.

DOD PETTT CREATE

High-Performance Numerical Libraries with Support for Low-Rank Matrix Computations

The main objective of the High-Performance Numerical Libraries with Support for Low-Rank Matrix Computations project is to reinforce a number of hybrid finite element/boundary integral analysis codes with high-performance numerical libraries that will enable them to efficiently use current and upcoming heterogeneous multi/many-core CPU and GPU-based architectures. The applications of interest use matrix compression techniques to reduce the complexity in both computer memory and computations. The compression techniques use adaptive cross approximation and SVD approaches that lead to low-rank matrix computations. Matrix factorizations and system solvers are similar to non-compressed methods except that the underlying matrix computations are performed in low-rank form.

ICL's work on this project focuses on the development of GPU algorithms, and their CUDA/OpenCL implementations for the required low-rank matrix computations, as well as the high level factorizations and solvers that will support matrix compression through the newly developed low-rank matrix computations. Of interest are factorizations and solvers for dense matrices, and multi-frontal methods for sparse matrices.

EASIR

Extreme-scale Algorithms and Solver Resilience

The mission of the Extreme-scale Algorithms and Solver Resilience (EASIR) project is to close the performance gap between the peak capabilities of HPC hardware and the performance realized by high performance computing applications. To carry out this mission, the EASIR project team develops architecture-aware algorithms and libraries, and the supporting runtime capabilities, to achieve scalable performance and resilience on heterogeneous architectures.

The project team includes personnel from ORNL, Sandia National Laboratories, University of Illinois, University of California Berkeley, and the University of Tennessee (ICL). ICL's efforts focus on providing components and services in a vertically integrated software stack, from low-level runtime process and thread scheduling to multicore aware library interfaces, multicore dense linear algebra, scalable iterative methods, and advanced parallel algorithms that break traditional parallelism bottlenecks.

FT-LA

Fault Tolerant Linear Algebra

FIND OUT MORE AT
http://icl.utk.edu/ft-la/

The Fault Tolerant Linear Algebra (FT-LA) research effort is aimed at understanding and developing Algorithm Based Fault Tolerance (ABFT) into major dense linear algebra kernels. With parallel machines currently reaching up to 3,000,000 cores, fault-tolerance has never been so paramount. The scientific community has to tackle process failures from two directions: first, efficient middleware needs to be designed to detect failures, and second, the numerical applications have to be flexible enough to permit the recovery of the lost data structures.

At ICL, we have successfully developed Fault Tolerant MPI middleware and, more recently, an FT-LA library that will efficiently handle several process failures. The project team has also integrated FT-LA in the CIFTS (Coordinated Infrastructure for Fault Tolerant Systems) environment to provide better communication and fault management between the system's software components and scientific applications. Future work in this area involves the development of scalable fault-tolerant, one-sided (Cholesky, LU, and QR) and two-sided (Hessenberg, tri-diagonalization, and bi-diagonalization) factorizations, following the ABFT principles.

LAPACK

The Linear Algebra PACKage

FIND OUT MORE AT
http://www.netlib.org/lapack/

ScaLAPACK

Scalable LAPACK

FIND OUT MORE AT
http://www.netlib.org/scalapack/

The Linear Algebra PACKage (LAPACK) and Scalable LAPACK (ScaLAPACK) are widely used libraries for efficiently solving dense linear algebra problems. ICL has been a major contributor to the development and maintenance of these two packages since their inception. LAPACK is sequential, relies on the BLAS library, and benefits from the multicore BLAS library. ScaLAPACK is parallel and distributed and relies on BLAS, LAPACK, MPI, and BLACS libraries.

LAPACK 3.5.0 was released in November 2013. LAPACK 3.5.0 includes Symmetric/Hermitian LDLT factorization routines with rook pivoting algorithms, 2-by-1 CSD to be used for tall and skinny matrices with orthonormal columns, and new stopping criteria for balancing. Since 2011, LAPACK has included LAPACKE, a native C interface for LAPACK developed in collaboration with INTEL, which provides NAN check and automatic workspace allocation. There were two new LAPACK releases in 2012 (3.4.1 and 3.4.2) for minor bug fixes. ScaLAPACK 2.0.0, which includes the MRRR algorithm and new Nonsymmetric Eigenvalue Problem routines, was released in November 2011. Two additional ScaLAPACK versions (2.0.1 and 2.0.2) were released in 2012 for minor bug fixes.

MAGMA

Matrix Algebra on GPU and Multicore Architectures

FIND OUT MORE AT
http://icl.utk.edu/magma/

Matrix Algebra on GPU and Multicore Architectures (MAGMA) is a collection of next generation linear algebra (LA) libraries for heterogeneous architectures. The MAGMA package supports interfaces for current LA packages and standards, e.g., LAPACK and BLAS, to allow computational scientists to easily port any LA-reliant software components to heterogeneous architectures. MAGMA allows applications to fully exploit the power of current heterogeneous systems of multi/many-core CPUs and multi-GPUs/coprocessors to deliver the fastest possible time to accurate solution within given energy constraints.

MAGMA 1.6 features top performance and high accuracy LAPACK compliant routines for multicore CPUs enhanced with NVIDIA GPUs and includes more than 400 routines, covering one-sided dense matrix factorizations and solvers, two-sided factorizations and eigen/singular-value problem solvers, as well as a subset of highly optimized BLAS for GPUs. In 2014, the MAGMA Sparse and MAGMA Batched packages were added with the MAGMA 1.6 release, providing support for sparse iterative and batched linear algebra on a set of small matrices in parallel, respectively. MAGMA provides multiple precision arithmetic support (S/D/C/Z, including mixed-precision). Most of the algorithms are hybrid, using both multicore CPUs and GPUs, but starting with the 1.6 release, GPU-specific algorithms were added. MAGMA also supports AMD GPUs and Intel Xeon Phi coprocessors.

PLASMA

Parallel Linear Algebra Software for Multicore Architectures

FIND OUT MORE AT
http://icl.utk.edu/plasma/

The Parallel Linear Algebra Software for Multicore Architectures (PLASMA) package is a dense linear algebra package at the forefront of multicore computing, designed to deliver the highest possible performance from a system with multiple sockets of multicore processors. PLASMA achieves this objective by combining state-of-the-art solutions in parallel algorithms, scheduling, and software engineering. Currently, PLASMA offers a collection of routines for solving linear systems of equations, least square problems, eigenvalue problems, and singular value problems.

PLASMA relies on runtime scheduling of parallel tasks, which is based on the idea of assigning work to cores based on the availability of data for processing at any given point in time. The concept, which is sometimes called data-driven scheduling, is closely related to the idea of expressing computation through a task graph, often referred to as the DAG (Directed Acyclic Graph), and the flexibility of exploring the DAG at runtime.

PULSAR

Parallel Ultra-Light Systolic Array Runtime

FIND OUT MORE AT
http://icl.utk.edu/pulsar/

The Parallel Ultra-Light Systolic Array Runtime (PULSAR), now in version 2.0, is a complete programming platform for large-scale distributed memory systems with multicore processors and hardware accelerators. PULSAR provides a simple abstraction layer over multithreading, message-passing, and multi-GPU, multi-stream programming. PULSAR offers a general-purpose programming model, suitable for a wide range of scientific and engineering applications.

This simple programming model allows the user to define the computation in the form of a Virtual Systolic Array (VSA), which is a set of Virtual Data Processors (VDPs), and is connected with data channels. This programming model is also accessible to the user through a very small and simple Application Programming Interface (API), and all the complexity of executing the workload on a large-scale system is hidden in the runtime implementation.

QUARK

QUeuing And Runtime for Kernels

FIND OUT MORE AT
http://icl.utk.edu/quark/

QUARK (QUeuing And Runtime for Kernels) provides a library that enables the dynamic, superscalar execution of tasks with data dependencies in a multi-core, multi-socket, shared-memory environment. QUARK infers data dependencies and precedence constraints between tasks based on the way the data is used, and then executes the tasks in a dynamic, asynchronous, superscalar fashion in order to achieve a high utilization of the available resources.

QUARK is designed to be easy to use, scales to large numbers of cores, and enables the efficient expression and implementation of complex algorithms. The QUARK runtime is codesigned with the PLASMA linear algebra library, and it contains optimizations inspired by the algorithms in PLASMA.

RaPyDLI

Rapid Python Deep Learning Infrastructure

The Rapid Python Deep Learning Infrastructure (RaPyDLI) project delivers productivity and performance to the Deep Learning community by combining high level Python, C/C++, and Java environments with carefully designed libraries supporting GPU accelerators and MIC coprocessors (Intel Xeon Phi). Deep Learning (DL) has made major impacts in areas like speech recognition, drug discovery and computer vision. This success relies on training large neural nets—currently, up to 10 billion connections trained on 10 million images—using either large scale commodity clusters or smaller HPC systems where accelerators perform with high efficiency. This approach is of prime importance as the hardware accelerators enable much more sophisticated neural networks by increasing the available computational power by more than an order of magnitude.

RaPyDLI is a collaboration between ICL, Indiana University, and Stanford University, with each institution contributing their long standing expertise in the field. Currently, ICL's focus for the RaPyDLI project is on efficient GPU kernel execution and optimization of scheduling strategies to reduce inefficiencies in the current code base in terms of performance and idle time.

SILAS

Sustained Innovation for Linear Algebra Software

The main goal of the NSF funded project on Sustained Innovation for Linear Algebra Software (SILAS) is to update two of the most widely used numerical libraries in the history of Computational Science and Engineering—LAPACK and ScaLAPACK—for the ongoing revolution in processor architecture and system design. Working with partners at the University of California, Berkeley and the University of Colorado, Denver, ICL is using SILAS to enhance and harden these essential libraries in order to prepare them for the kind of extreme scale systems and applications that are now coming online.

SILAS is organized around three complementary objectives: 1) Wherever possible, SILAS delivers seamless access to the most up-to-date algorithms, numerical implementations, and performance, by way of the familiar Sca/LAPACK programming interface; 2) Wherever necessary, SILAS makes advanced algorithms, numerical implementations and performance capabilities available through new interface extensions; and 3) SILAS provides a well engineered conduit through which new discoveries at the frontiers of research in these areas can be channeled as quickly as possible to all the application communities.

PERFORMANCE EVALUATION AND BENCHMARKING

CoDAASH

Co-design Approach for Advances in Software and Hardware

The Co-design Approach for Advances in Software and Hardware (CoDAASH) project focuses on understanding the relationship between algorithms and hardware platforms and how to jointly optimize the software and hardware in order to achieve efficient implementations for applications in materials science, chemistry, and physics. CoDAASH is a joint effort between the University of Tennessee, Knoxville, the University of Texas, El Paso, and the University of California, San Diego, and is funded by the United States Air Force Office of Scientific Research (AFOSR).

ICL's contribution focuses on expressing certain computational chemistry algorithms in the form of a data flow graph (DAG) and subsequently mapping the DAG representation of the kernels to the hardware platforms. This representation allows for capturing the essential properties of the algorithms (e.g., data dependencies), and enables computation at extreme scale in the era of many-core and highly heterogeneous platforms, by utilizing the hardware components (e.g., CPU or GPU) that perform best for the type of computational task under consideration. The dataflow-based form of these algorithms makes them compatible with next generation task scheduling systems, such as PaRSEC.

HPCC

The HPC Challenge Benchmark

FIND OUT MORE AT
http://www.hpcchallenge.org/

The HPC Challenge (HPCC) benchmark suite is designed to establish, through rigorous testing and measurement, the bounds of performance on many real-world applications for computational science at extreme scale. To this end, the benchmark includes a suite of tests for sustained floating point operations, memory bandwidth, rate of random memory updates, interconnect latency, and interconnect bandwidth. The main factors that differentiate the various components of the suite are the memory access patterns that, in a meaningful way, span the space of memory access characteristics, which is spanned by temporal and spatial locality. The components of the suite are brought together inside HPCC, which allows information to pass between the components and provide a comprehensive testing and measurement framework that goes beyond the sum of its parts.

Each year, the HPCC Awards competition features contestants who submit performance numbers from the world's largest supercomputer installations, as well as alternative implementations that use a vast array of parallel programming environments. The results from the competition are announced at the annual gathering of the International Conference for High Performance Computing, Networking, Storage and Analysis, and are available to the public to help track the progress of both the high-end computing arena and the commodity hardware segment.

HPCG

The High Performance Conjugate Gradients Benchmark

FIND OUT MORE AT
http://hpcg-benchmark.org/

The High Performance Conjugate Gradients (HPCG) benchmark is designed to measure performance that is representative of modern scientific applications. It does so by exercising the computational and communication patterns that are commonly found in real science and engineering codes, that are often based on sparse iterative solvers. HPCG exhibits the same irregular accesses to memory and fine-grain recursive computations that dominate large-scale scientific workloads used to simulate complex physical phenomena. Intended as a candidate for a new HPC metric, HPCG implements the preconditioned conjugate gradient algorithm with a local symmetric Gauss-Seidel as the preconditioner. Additionally, the essential components of the geometric multigrid method are present in the code as a way to represent execution patterns of modern multigrid solvers.

HPCG 1.0 was released on November 19, 2013, and coincided with the SC13 conference in Denver, Colorado. This initial release code includes both testing and verification of the run, and allows users to supply optimized kernels for computationally intensive portions of the code. The current version, 2.4, was released in June 2014 and includes the multigrid method as well as better accounting for the optimization time and the performance achieved. The community's reception of the benchmark has been overwhelmingly positive, and the constant feedback feeds the continuous improvement of the code and its scope. Future releases will include additional refinements that allow HPCG to reflect the behavior of explicit methods that involve unassembled matrices.

HPL

Fault Tolerant Linear Algebra

FIND OUT MORE AT
http://icl.utk.edu/hpl/

The High Performance LINPACK (HPL) benchmark is a software package that solves a (randomly generated) dense linear system in double precision (64-bit) arithmetic on distributed-memory computers. Written in a portable ANSI C and requiring an MPI implementation as well as either the BLAS or VSIPL library, HPL is often one of the first programs to run on large computer installations, producing a result that can be submitted to the biannual TOP500 list of the world's fastest supercomputers.

HPL 2.1, released in 2012, includes several major bug fixes and accuracy enhancements based on user feedback. The major focus of HPL 2.1 is to improve the accuracy of reported benchmark results, and ensure scalability of the code on large supercomputer installations with hundreds of thousands of computational cores. The last version also featured a detailed time-of-run accounting to help with assessing power requirements at the time of execution, a metric which has been reported with TOP500 results since 2007 and is also highlighted on the Green500 list. In 2011, the LINPACK benchmark app for iOS achieved performance of over 1 Gflop/s on an Apple iPad 2, with per-Watt performance easily beating supercomputing solutions, including the most power-efficient systems based on hardware accelerators. The App now achieves over 4 Gflop/s on the iPad Air.

PAPI

The Performance API

FIND OUT MORE AT
http://icl.utk.edu/papi/

The Performance API (PAPI) provides simultaneous access to performance counters on CPUs, GPUs, and other components of interest (e.g., network and I/O systems). Provided as a linkable library or shared object, PAPI can be called directly in a user program, or used transparently through a variety of third-party tools, making it a de facto standard for hardware counter analysis. Industry liaisons with Bull, Cray, Intel, IBM, NVIDIA, and others ensure seamless integration of PAPI with new architectures at or near their release. As the PAPI component architecture becomes more populated, performance tools that interface with PAPI automatically inherit the ability to measure these new data sources, usually with no changes at the user level. This provides a richer environment in which performance analysts can work.

Components are available for network counters, GPGPUs like those from NVIDIA, system health monitoring, and power and energy measurement. Virtual PAPI—supported since PAPI 5.0—provides performance measurement standards in virtual environments, which are common in cloud computing. Recent versions of PAPI support measuring energy consumption on Intel Sandy Bridge and its successor processors through the RAPL (Running Average Power Limit) interface, and power measurements are now possible through both a native and host-based power component for Intel Xeon Phi. Support for power monitoring on IBM BlueGene/Q via the EMON functionality is now available with PAPI 5.4. More work is underway to support other methods for power and energy measurement as they become available.

SUPER

The Institute for Sustained Performance, Energy, and Resilience

FIND OUT MORE AT
http://super-scidac.org/

The Institute for Sustained Performance, Energy, and Resilience (SUPER), led by the University of Southern California, has organized a broad-based project involving several universities and DOE laboratories with expertise in compilers, system tools, performance engineering, energy management, and resilience to ensure that DOE's computational scientists can successfully exploit the emerging generation of high performance computing (HPC) systems.

SUPER is extending performance modeling and autotuning technology to heterogeneous and petascale computing systems, investigating application-level energy efficiency techniques, exploring resilience strategies for petascale applications, and developing strategies that collectively optimize performance, energy efficiency, and resilience. UTK work focuses on performance measurement, power and energy measurements, and resilience techniques for hard and soft errors.

TOP500

Ranking the 500 fastest computers in the world

FIND OUT MORE AT
http://www.top500.org/

Since 1993, a ranking of the top 500 fastest computers in the world has been compiled biannually with published results released in June and November at major HPC gatherings in the US and Europe. Each machine on the TOP500 list is ranked based on its performance result from running the computationally intensive High Performance LINPACK (HPL) benchmark developed by ICL, which may be further optimized by the vendor, integrator, or the benchmarking engineer from the affiliated institution.

While new benchmarks, including HPCC, have been developed to measure performance of HPC systems, the TOP500 still relies on the HPL benchmark and remains the de-facto ranking used by commercial, industrial, government, and academic institutions. ICL continues to partner with NERSC/Lawrence Berkeley National Laboratory and Prometeus to produce the rankings.

In June 2013, China's Tianhe-2 supercomputer took the #1 spot on the TOP500 at an astounding 33.86 petaflop/s, and continues to maintain that position as of November 2014. The surprise appearance of Tianhe-2, two years ahead of the expected deployment, marks China's first return to the #1 position since November 2010, when Tianhe-1A was the top system. Tianhe-2 has 16,000 nodes, each with two Intel Xeon Ivy Bridge processors and three Xeon Phi coprocessors for a combined total of 3,120,000 computing cores.

DISTRIBUTED COMPUTING

ADAPT

Next-Gen Open MPI

The ADAPT project proposes to enhance, harden, and modernize the Open MPI library in the context of the ongoing revolution in processor architecture and system design. On the large systems expected before the end of this decade, the degree of parallelism (intra and inter node) will presumably increase by several orders of magnitude (based on the Exascale Roadmap predictions). To efficiently handle such systems, MPI implementations will have to adopt more asynchronous and thread-friendly behaviors to extract the best from more complex architectures.

The project team seeks to create a viable foundation for a new generation of Open MPI components, which enables a rapid exploration of new physical capabilities, provides greatly improved performance portability, and works toward full interoperability between classes of components. ADAPT explores process placement, distributed topologies, file accesses, point-to-point and collective communications, and different approaches to fault tolerance.

ARGO

A new architecture for Exascale computing

The ARGO project is developing a new Exascale Operating System and Runtime (OS/R) designed to support extreme-scale scientific computation. Disruptive new computing technologies, such as 3D memory, ultra-low-power cores, and embedded network controllers, are changing the scientific computing landscape. As it becomes clear that incremental approaches to operating systems and runtimes (OS/R) cannot grow into an Exascale solution, we propose a novel radical approach.

ARGO is designed on a new, agile modular architecture that supports both global optimization and local control. It aims to efficiently leverage new chip and interconnect technologies while addressing the new modalities, programming environments, and workflows expected at Exascale. It is designed from the ground up to run future HPC applications at extreme scales.

DPLASMA

Distributed Parallel Linear Algebra Software for Multicore Architectures

FIND OUT MORE AT
http://icl.utk.edu/parsec/

The Distributed Parallel Linear Algebra Software for Multicore Architectures (DPLASMA) package is the leading implementation of a dense linear algebra package for distributed heterogeneous systems. It is designed to deliver sustained performance for distributed systems where each node features multiple sockets of multicore processors, and if available, accelerators like GPUs or Intel Xeon Phi. DPLASMA achieves this objective by deploying the Parallel Linear Algebra Software for Multicore Architectures (PLASMA) algorithms on distributed memory systems by leveraging the state-of-the-art PaRSEC runtime.

In addition to traditional ScaLAPACK data distribution, DPLASMA provides interfaces for users to expose arbitrary data distributions. The algorithms transparently operate on local data, or introduce implicit communications to resolve dependencies, removing the burden of initial data re-shuffle, and providing to the user a novel approach to address load balance.

Open MPI

Open source MPI

FIND OUT MORE AT
http://icl.cs.utk.edu/open-mpi/

The Open MPI Project is an open source Message Passing Interface (MPI) implementation that is developed and maintained by a consortium of academic, research, and industry partners. MPI primarily addresses the message-passing parallel programming model, in which data is moved from the address space of one process to that of another process through cooperative operations on each process. Open MPI integrates technologies and resources from several other projects (HARNESS/FT-MPI, LA-MPI, LAM/MPI, and PACX-MPI) in order to build the best MPI library available. A completely new MPI-3.1 compliant implementation, Open MPI offers advantages for system and software vendors, application developers, and computer science researchers.

ICL's efforts in the context of Open MPI have significantly improved its scalability, performance on many-core environments, and architecture-aware capabilities, such as adaptive shared memory behaviors and dynamic collective selection, making it ready for the next generation exascale challenges.

OpenSHMEM

Communication Library, Specification, and Tools Ecosystem

FIND OUT MORE AT
http://www.openshmem.org/

OpenSHMEM is a Partitioned Global Address Space (PGAS) library interface specification that aims to provide a standard Application Programming Interface (API) for SHMEM libraries to aid portability across multiple vendors—including SGI, Cray, IBM, HP, Mellanox, and Intel. OpenSHMEM supports one-sided communication and is a perfect fit for applications with irregular communication patterns with small/medium sized data transfers, since it is optimized for low-latency data transfers.

The OpenSHMEM Library API provides calls for data communication, group synchronization, data collection, data reduction, distributed locking of critical regions, and data and process accessibility to OpenSHMEM PEs. PEs put/get data to/from remotely accessible symmetric data objects on other PEs.

PaRSEC

Parallel Runtime Scheduling and Execution Controller

FIND OUT MORE AT
http://icl.utk.edu/parsec/

The Parallel Runtime Scheduling and Execution Controller (PaRSEC) is a generic framework for architecture-aware scheduling and management of micro-tasks on distributed many-core heterogeneous architectures. Applications we consider are expressed as a Direct Acyclic Graph (DAG) of tasks, with edges designating data dependencies. DAGs are represented in a compact problem-size independent format that can be queried to discover data dependencies in a totally distributed fashion, a drastic shift from today's programming models, which are based on sequential flow of execution.

PaRSEC assigns computation threads to the cores, overlaps communications and computations, and uses a dynamic, fully-distributed scheduler based on architectural features such as NUMA nodes and algorithmic features such as data reuse. PaRSEC includes a set of tools to generate the DAGs and integrate them in legacy codes, a runtime library to schedule the micro-tasks on heterogeneous resources, and tools to evaluate and visualize the efficiency of the scheduling. Many dense and sparse linear algebra extensions have been implemented, and computational kernels have been re-implemented using PaRSEC, enabling better performance on distributed many-core systems.

UCCS

Universal Common Communication Substrate

FIND OUT MORE AT
http://uccs.github.io/uccs/

UCCS is a new universal, portable, and performance driven communication API used to expose low level capabilities of high performance networks. It makes common network code available in order to provide critical services for implementing features needed by high level parallel programming constructs. These services include lightweight remote memory access operations, lightweight synchronizations, active messages, atomic operations, etc.

Supplemented by a robust API to access different portable runtime environments, UCCS allows for fast prototyping and reliable performance for the development of parallel programming execution environments and applications.

ULFM

User Level Failure Mitigation

FIND OUT MORE AT
http://fault-tolerance.org/

User Level Failure Mitigation (ULFM) is a set of new interfaces for MPI that enables Message Passing programs to restore MPI functionality affected by process failures. The MPI implementation is spared the expense of internally taking protective and corrective actions against failures. Instead, it reports operations whose completions were rendered impossible by failures.

Using the constructs defined by ULFM, applications and libraries drive the recovery of the MPI state. Consistency issues resulting from failures are addressed according to an application's needs and the recovery actions are limited to the necessary MPI communication objects. Therefore, the recovery scheme is more efficient than a generic, automatic recovery technique, and can achieve both goals of enabling applications to resume communication after failure and maintaining extreme communication performance outside of recovery periods.

2014 PUBLICATIONS

Evidence of our research and our contributions to the HPC community might be best exemplified by the numerous publications we produce every year. Here is a listing of our most recent papers, including journal articles, book chapters, and conference proceedings. Many of these are available for download from our website.

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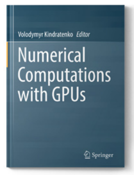

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2014 EVENTS

Every year, members of our research staff attend national and international conferences, workshops, and seminars. These meetings provide opportunities to present our research, share our knowledge, and exchange ideas with leading computational science researchers from around the world. Showing the work we have done and participating in the intellectual life of the scientific community in this way is an essential part of the research process. The following pages contain a list of events we have participated in over the past year.

FEBRUARY 4
HPCG Workshop at DOE
Washington, DC

FEBRUARY 12
ARGO Meeting
Chicago, IL

FEBRUARY 18-21
SIAM Conference on Parallel Processing for Scientific Computing
Portland, OR

FEBRUARY 26-28
Workshop on Big Data and Extreme Scale Computing
Fukuoka, Japan

MARCH 3
MPI Forum
San Jose, CA

MARCH 4
OpenSHMEM Workshop
Annapolis, MD

MARCH 23-25
IEEE International Symposium on Performance Analysis of Systems and Software (ISPASS 2014)
Monterey, CA

MARCH 24
GPU Technology Conference
San Jose, CA

MARCH 27
SUPER PI Meeting
Salt Lake City, UT

MARCH 28-30
(SICM)2 Working Group on Portable Parallel Infrastructure
New York, NY

APRIL 16
ARGO PI Meeting
Albuquerque, NM

MAY 19
28th IEEE International Parallel & Distributed Processing Symposium (IPDPS)
Phoenix, AZ

MAY 29
FutureClouds Reverse Site Visit
Indianapolis, IN

JUNE 1
International HPC Summer School
Budapest, Hungary

JUNE 2
MPI Forum
Chicago, IL

JUNE 3
ASCR Exascale Computing Systems Productivity Workshop
Gaithersburg, MD

JUNE 16
SC14 Technical Committee
Houston, TX

JUNE 22

International Supercomputing Conference (ISC14)
Leipzig, Germany

JUNE 24
Open MPI Developers Meeting
Chicago, IL

JUNE 29

International Workshop on Extreme Scale Scientific Computing
Moscow, Russia

JUNE 29-30
8th International Workshop on Parallel Matrix Algorithms and Applications (PMAA14)
Lugano, Switzerland

JUNE 30
International Meeting on High Performance Computing for Computational Science (VECPAR)
Eugene, OR

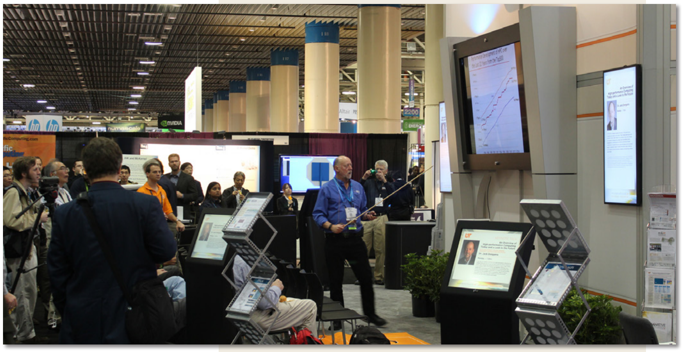
JULY 1-4
9th Scheduling for Large Scale Systems Workshop
Lyon, France

JULY 27
College Business Management Institute
Lexington, KY

JULY 28
ARGO All Hands Meeting
Chicago, IL

AUGUST 10
248th American Chemical Society National Meeting
San Francisco, CA

AUGUST 18
ISTC Research Retreat 2014
Hillsboro, OR



AUGUST 20
16th IEEE International Conference on High Performance Computing and Communications (HPCC2014)
Paris, France

SEPTEMBER 2

Clusters, Clouds, and Data for Scientific Computing (CCDSC)
Dareizé, France

SEPTEMBER 9
43rd International Conference on Parallel Processing (ICPP-2014)
Minneapolis, MN

SEPTEMBER 9-12
EuroMPI / Asia
Kyoto, Japan

SEPTEMBER 15-17
MPI Forum
Kobe, Japan

SEPTEMBER 22-26
IEEE Cluster 2014
Madrid, Spain

SEPTEMBER 23-25
IEEE 8th International Symposium on Embedded Multicore/Many-core Systems-on-Chip (MCSoC-14)
Aizu-Wakamatsu, Japan

SEPTEMBER 28
Dagstuhl Seminar 14402: Resilience in Exascale Computing
Wadern, Germany

SEPTEMBER 29
VISSOFT 2014
Victoria, British Columbia

OCTOBER 7
Open SHMEM Users Group
Eugene, OR

OCTOBER 27
IEEE International Conference on Big Data
Washington, DC

NOVEMBER 5
HPC China
Guangzhou, China

NOVEMBER 16-21
Supercomputing 2014
New Orleans, LA

DECEMBER 1-4
CHPC National Meeting 2014
Kruger National Park, South Africa

DECEMBER 2-4
JST CREST International Symposium on Post Petascale System Software
Kobe, Japan

DECEMBER 8-13
Neural Information Processing Systems Foundations
Montreal, Quebec

DECEMBER 17-21
IEEE International Conference on High Performance Computing (HiPC14)
Goa, India

SUPERCOMPUTING '14

The annual ACM/IEEE Supercomputing Conference (SC), established in 1988, is a staple of ICL's November itinerary. SC is vital to the growth and evolution of high performance computing in the United States because it is the only US event that elicits substantial participation from all segments of the HPC community, including hundreds of users, developers, vendors, research institutions, and representatives of government funding agencies.
Such a talent-rich gathering enables participants to discuss challenges, share innovations, and coordinate relationships and collaborations with some of the best minds in scientific and high performance computing.

In November 2014, SC returned to New Orleans, Louisiana on November 16 – 21. As usual, ICL had a significant presence at SC, with faculty, research staff, and students giving talks, presenting papers, and leading "Birds-of-a-Feather" sessions. SC14 also marks the third consecutive year in which ICL was active in the University of Tennessee's SC booth. The booth, which was organized and led by the National Institute for Computational Sciences (NICS), was visually designed with the help of ICL/CITR staff, manned with support from ICL researchers attending SC, and featured the lab's research projects in the booth's kiosks.

COMPUTATIONAL RESOURCES

As the GPU hybrid computing paradigm continues to lead the evolution of computational hardware into Petascale computing, computing architectures are increasingly changing. However, the programming tools, applications, and algorithms that form the backbone of the ever growing need for greater performance are equally important. Such myriad hardware/software configurations present unique challenges that require testing and development of applications that are often unique to the platform on which they reside. For this reason, it is imperative that we have access to a wide range of computing resources in order to conduct our cutting-edge research.

CAMPUS RESOURCES

To meet these challenges, ICL has access to multiple state-of-the-art heterogeneous systems in house. In fact, our hardware industry partners, including AMD, Intel, and NVIDIA, provide us with bleeding edge hardware resources (often under NDA and prior to public release) which we use to upgrade and maintain the lab's infrastructure. Our research staff also has access to other campus resources, including UTK's Newton Cluster.

INTEL PARALLEL COMPUTING CENTER

ICL is now an Intel Parallel Computing Center. The Intel Parallel Computing Center (IPCC) program is comprised of universities, institutions, and labs that are leaders in their field, focusing on modernizing applications to increase parallelism and scalability through optimizations that leverage cores, caches, threads, and vector capabilities of microprocessors and coprocessors.

The objective of the Innovative Computing Laboratory's IPCC is the development and optimization of numerical linear algebra libraries and technologies for applications, while tackling current challenges in heterogeneous Intel® Xeon Phi™ coprocessor-based High Performance Computing. In collaboration with Intel's MKL team, the IPCC at ICL will modernize the popular LAPACK and ScaLAPACK libraries to run efficiently on current and future manycore architectures, and will disseminate the developments through the open source MAGMA MIC library.

REGIONAL RESOURCES

Titan, Cray XK7
OAK RIDGE NATIONAL LABORATORY

Beacon, Appro Xtreme-X
NATIONAL INSTITUTE FOR COMPUTATIONAL SCIENCES

ICL has access to many local resources in East Tennessee to help keep us at the forefront of enabling technology research, including some machines that are regularly found on the TOP500 list of the world's fastest supercomputers. The recent modernization of the DOE's National Center for Computational Sciences (NCCS), just 30 minutes away at the Oak Ridge National Laboratory (ORNL), has enabled us to leverage our ORNL collaborations to take advantage of what has become one of the world's fastest scientific computing facilities.

ORNL houses Titan, a Cray XK7 supercomputer, which currently holds the number two spot on the TOP500 at 17.59 petaflop/s. The National Institute for Computational Sciences (NICS), a joint UT/ORNL computing facility in Oak Ridge, is home to Beacon, an Appro Xtreme-X Supercomputer which topped the Green500 list in November 2012, making it one of the most energy efficient supercomputers in the world.

Keeneland System Integrated with XSEDE
GEORGIA TECH

GRID RESOURCES

With the continuing trend of high performance grid and cloud computing, it is important for ICL to have access to these types of infrastructures in order to test and implement our software packages on grid hardware and virtualized environments. In keeping with this goal, research staff members at ICL have access to grid resources all over the US, as well as in Europe, including XSEDE and Grid5000.

NVIDIA CUDA CENTER OF EXCELLENCE

The Innovative Computing Laboratory joins a very small and select group of labs given a CUDA Center of Excellence designation. ICL/UTK's CCOE focuses on the development of numerical linear algebra libraries for CUDA-based hybrid architectures. ICL's work on the Matrix Algebra on GPU and Multicore Architectures (MAGMA) project further enables and expands our CUDA-based software library efforts, especially in the area of high-performance scientific computing.

The CCOE designation also led to the establishment of a productive long-term collaboration between ICL and NVIDIA. As part of the collaboration and CCOE designation, ICL has continuously received hardware, financial support, and other resources from NVIDIA.

PARTNERSHIPS

Since 1989, ICL has fostered relationships with many other academic institutions and research centers. We have also aggressively sought to build lasting, collaborative partnerships with HPC vendors and industry research leaders, both here and abroad. Together with these partners, we have built a strong portfolio of shared resources, both material and intellectual. In this section, we recognize many of the partners and collaborators that we have worked with over the years, most of whom we are still actively involved with.

INDUSTRY

Vendors and industry research leaders are an integral part of our partnerships, contributing significantly to our efforts to be a world leader in computational science research. Many have utilized our work, including our linear algebra libraries and performance analysis tools. As a result of these exchanges, we maintain close working relationships with many industry leaders.

INTEL SCIENCE AND TECHNOLOGY CENTER FOR BIG DATA

ICL joined the SciDB project of the Intel Science and Technology Center (ISTC) for Big Data, one of a series of research collaborations that Intel is establishing with universities in the US to identify and prototype revolutionary technology opportunities, and exchange expertise in various fields of high performance computing.

In the case of ICL, the lab will help improve the efficiency of large scale data analytics by providing efficient codes for linear algebra on the Intel Xeon Phi. The lab will also provide expertise on fault tolerance to help make the compute intensive portion of data management more resilient, which is essential given the large databases used in Big Data applications. Finally, the distributed nature of large data processing calls for optimal data distribution and redistribution operations, which has long been one of ICL's core strengths.

GOVERNMENT AND ACADEMIC

Our relationships with academic and government research institutions also play a pivotal role in our success. By exchanging ideas, expertise, and personnel, ICL becomes more dynamic with each new collaboration. Our lab routinely develops relationships with researchers whose primary focus is on other scientific disciplines, such as biology, chemistry, or physics, which makes many of our collaborations truly multidisciplinary.

INTERNATIONAL

Barcelona Supercomputing Center
Barcelona, Spain

Central Institute for Applied Mathematics
Jülich, Germany

Danish Computing Center for Research and Education
Lyngby, Denmark

Doshisha University
Kyoto, Japan

École Normale Supérieure de Lyon
Lyon, France

École Polytechnique Federale de Lausanne
Lausanne, Switzerland

European Centre for Research and Advanced Training in Scientific Computing
Toulouse, France

European Exascale Software Initiative
European Union

Forschungszentrum Jülich
Jülich, Germany

High Performance Computing Center Stuttgart
Stuttgart, Germany

INRIA
France

Institut ETH Zentrum
Zurich, Switzerland

Kasetsart University
Bangkok, Thailand

King Abdullah University of Science and Technology
Saudi Arabia

Moscow State University
Moscow, Russia

National Institute of Advanced Industrial Science and Technology (AIST)
Tsukuba, Japan

Parallel and HPC Application Software Exchange
Tsukuba, Japan

Prometeus
Mannheim, Germany

RIKEN
Wako, Japan

Rutherford Appleton Laboratory
Oxford, England

Soongsil University
Seoul, South Korea

Technische Universitaet Wien
Vienna, Austria

Tokyo Institute of Technology
Tokyo, Japan

Université Claude Bernard de Lyon
Lyon, France

University of Manchester
Manchester, England

University of Umeå
Umeå, Sweden

LEADERSHIP

In addition to the development of tools and applications, ICL is regularly engaged in other activities and efforts that include our leadership at conferences and workshops, as well as our teaching and outreach. Having a leadership role in the HPC arena requires that ICL be engaged with the community, and actively share our vision for the exciting future of high performance computing. This section contains some of the activities in which we are participating or have a taken a leadership role.

FIND OUT MORE AT
http://exascale.org/

BDEC BIG DATA AND EXTREME SCALE COMPUTING

BDEC Fukuoka
FEBRUARY 2014

In the past several years, the United States, the European Union, and Japan have each moved aggressively to develop their own plans for achieving exascale computing in the next decade. Such concerted planning by the traditional leaders of HPC speaks eloquently about both the substantial rewards that await the success of such efforts, and about the unprecedented technical obstacles that apparently block the path upward to get there. But while these exascale initiatives, including the International Exascale Software Project (IESP), have understandably focused on the big challenges of exascale for hardware and software architecture, the relatively recent emergence of the phenomena of "Big Data" in a wide variety of scientific fields represents a tectonic shift that is transforming the entire research landscape on which all plans for exascale computing must play out.

The workshop on Big Data and Extreme-scale Computing (BDEC) marks a distinctly new phase for the work of the IESP community, and is premised on the idea that we must begin to systematically map out and account for the ways in which the major issues associated with Big Data intersect with, impinge upon, and potentially change the national (and international) plans that are now being laid for achieving exascale computing.

In 2014, ICL was instrumental in organizing and staging the second BDEC workshop in Fukuoka, Japan. Along with Jack Dongarra, and following through with work they began with the IESP and the first BDEC meeting in Charleston, several members of ICL's CITR staff, including Terry Moore, Tracy Rafferty, Teresa Finchum, and David Rogers, played essential roles in making the second BDEC workshop a major success. The next workshop is scheduled for Barcelona, Spain, in late January. Given the ever increasing emphasis that science, government, and industry continue to place on both big data and extreme-scale computing, this example of ICL's community leadership seems likely to become more and more prominent.

FIND OUT MORE AT
http://citr.cs.utk.edu/

CITR
CENTER FOR INFORMATION TECHNOLOGY RESEARCH

The Center for Information Technology Research (CITR) was established in 2001 to drive the growth and development of leading edge information technology research at the University of Tennessee. CITR's first objective is to build up a thriving, well-funded community in basic and applied information technology research at UT in order to help the university capitalize on the rich supply of research opportunities that now exist in this area. As part of this goal, CITR staff members currently provide primary administrative and technical support for ICL, helping maintain the lab's status as a world leader in high performance and scientific computing research. CITR has also provided secondary support for other UT research centers.

CITR's second objective is to grow an interdisciplinary Computational Science program as part of the university curriculum. To this end, CITR helped establish the Interdisciplinary Graduate Minor in Computational Science (IGMCS) to offer UT graduate students an opportunity to acquire the balanced package of knowledge and skills required for today's computationally intensive research methods. CITR is also the sole provider of administrative support for the IGMCS.

IGMCS
INTERDISCIPLINARY GRADUATE MINOR IN COMPUTATIONAL SCIENCE

Addressing the need for a new educational strategy in Computational Science, the Center for Information Technology Research (CITR) worked with faculty and administrators from several departments and colleges in 2007 to help establish a new university-wide program that supports advanced degree concentrations in this critical new field across the curricula. Under the Interdisciplinary Graduate Minor in Computational Science (IGMCS), students pursuing advanced degrees in a variety of fields of science and engineering are able to extend their education with special courses of study that teach them both the fundamentals and the latest ideas and techniques from this new era of information intensive research.

Computational Science integrates elements that are normally studied in different parts of the traditional curriculum, but which are not fully covered or combined by any one of them. As computational power continues to increase and data storage costs decrease, the potential for new discoveries using Computational Science is greater than ever. And as more academic disciplines begin to realize and exploit the incredible benefits Computational Science provides, the IGMCS program is expected to grow by adding new disciplines, new courses, and new faculty. As of late 2014, there are 18 departments from four UT colleges contributing more than 130 courses to the program.

FIND OUT MORE AT
http://igmcs.utk.edu/

PEOPLE

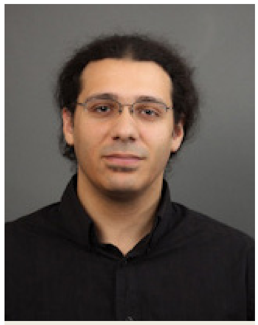
As the landscape in high performance computing continues to rapidly evolve, remaining at the forefront of discovery requires great vision and skill. To address this evolution and to remain a leader in innovation, we have assembled a staff of top researchers from all around the world who apply a variety of novel and unique approaches to the challenges and problems inherent in world-class scientific computing.

As part of an engineering college at a top 50 public research university, we have a responsibility to combine exemplary teaching with cutting-edge research. As such, we regularly employ bright and motivated graduate and undergraduate students. We have been, and will continue to be, very proactive in securing internships and assistantships for students who are hardworking and willing to learn.

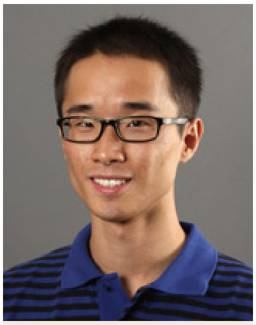
STAFF AND STUDENTS

Hartwig Anzt
POST DOCTORAL RESEARCH ASSOCIATE

George Bosilca
RESEARCH DIRECTOR



Aurelien Bouteiller
RESEARCH SCIENTIST II



Chongxiao Cao
GRADUATE RESEARCH ASSISTANT

Sam Crawford
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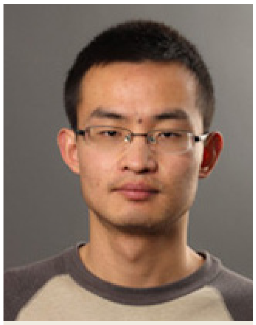
Anthony Danalis
RESEARCH SCIENTIST II



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UNIVERSITY DISTINGUISHED PROFESSOR

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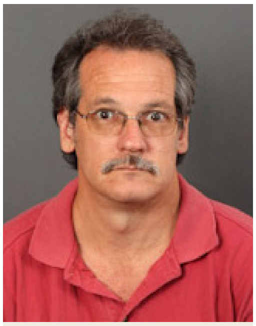

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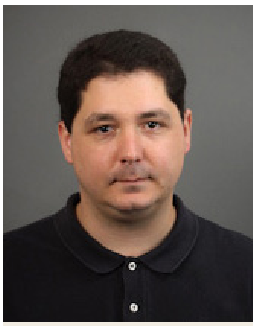
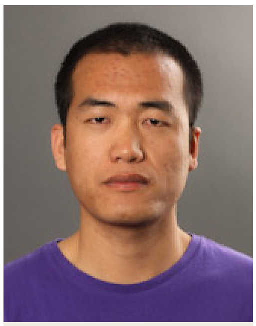


Thomas Herault
RESEARCH SCIENTIST II

Reazul Hoque
GRADUATE RESEARCH ASSISTANT



Yulu Jia
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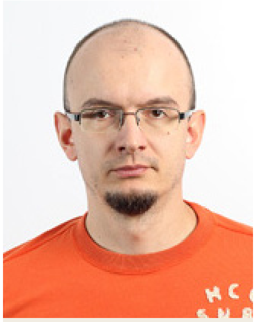
STAFF AND STUDENTS

Cindy Knisley
FINANCIAL SPECIALIST



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GRADUATE RESEARCH ASSISTANT

Piotr Luszczek
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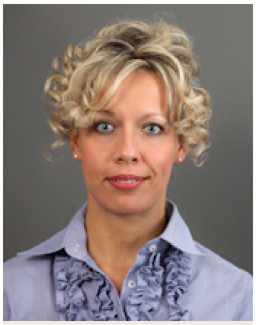
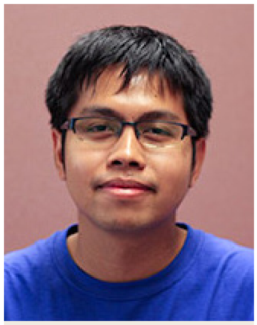


Heike McCraw
RESEARCH DIRECTOR

Terry Moore
ASSOCIATE DIRECTOR



Thananon Patinyasakdikul
GRADUATE RESEARCH ASSISTANT

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PROGRAM MANAGER

Sangamesh Ragate
GRADUATE RESEARCH ASSISTANT

Stephen Richmond
UNDERGRADUATE STUDENT ASSISTANT

Yves Robert
VISITING SCHOLAR

David Rogers
IT SPECIALIST III

Leighanne Sisk
ADMINISTRATIVE SPECIALIST I

Chunyan Tang
GRADUATE RESEARCH ASSISTANT

Stanimire Tomov
RESEARCH DIRECTOR

Wei Wu
GRADUATE RESEARCH ASSISTANT

Ichitaro Yamazaki
RESEARCH SCIENTIST I

Asim YarKhan
RESEARCH SCIENTIST II

2014 VISITORS

Since ICL was founded, we have routinely hosted many visitors, some who stay briefly to give seminars or presentations, and others who remain with us for as long as a year collaborating, teaching, and learning. By collaborating with researchers from around the globe, we are able to leverage an immense array of intellectual resources. For this reason, our list of research collaborators and partners continues to grow. These relationships present enormous opportunities to host and work with top minds within the global HPC community.

Emmanuel Agullo
INRIA
FRANCE

Dorian Arnold
UNIVERSITY OF NEW MEXICO

Marc Baboulin
INRIA
FRANCE

Alfredo Buttari
ENSEEIHT
FRANCE

Kirk Cameron
VIRGINIA TECH

Mathieu Faverge
UNIVERSITY OF BORDEAUX
FRANCE

Grigori Fursin
INRIA
FRANCE

Kris Garrett
ORNL

Ryan Glasby
JICS

Julien Herrmann
ENS-LYON
FRANCE

Atsushi Hori
RIKEN
JAPAN

Florent Lopez
ENSEEIHT
FRANCE

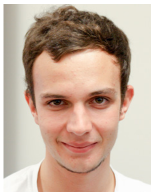
Theo Mary
CERFACS
FRANCE

Tim Mattson
INTEL

George Ostrouchov
ORNL

Gregoire Pichon
INRIA
FRANCE

Adrien Remy
LRI
FRANCE



Samuel Thibault
INRIA
FRANCE

ALUMNI

Since its inception, ICL has attracted many students, post-doctoral researchers, and professors from a variety of backgrounds and academic disciplines. Many of these experts came to UT specifically to work with Dr. Dongarra, beginning a long list of top research talent to pass through ICL and move on to make exciting contributions at other institutions and organizations.

Carolyn Aebischer 1990-1993
Bivek Agrawal 2004-2006
Sudesh Agrawal 2004-2006
Emmanuel Agullo 2009
Ahmad Abdelfattah Ahmad 2012
Jennifer Allgeyer 1993
Wes Alvaro 2007-2011
Ed Anderson 1989-1991
Daniel Andrzejewski 2007
Thara Angskun 2003-2007
Papa Arkhurst 2003
Dorian Arnold 1996-2001
Cedric Augonnet 2010
Marc Baboulin 2008
Zhaojun Bai 1990-1992
Ashwin Balakrishnan 2001-2002
Richard Barrett 1992-1994
Alex Bassi 2000-2001
David Battle 1990-1992
Micah Beck 2000-2001
Daniel Becker 2007
Dulceneia Becker 2010-2012
Adam Beguelin 1991
Annamaria Benzoni 1991
Tom Berry 1991
Vincent Berthoux 2010
Scott Betts 1997-1998
Nikhil Bhatia 2003-2005
Noel Black 2002-2003
Laura Black 1996
Susan Blackford 1989-2001
Wesley Bland 2008-2013
Kartheek Bodanki 2009
David Bolt 1991
Fernando Bond 1999-2000
Carolyn Bowers 1992
Barry Britt 2007-2009
Randy Brown 1997-1999
Cynthia Browne 2005
Murray Browne 1998-1999
Bonnie Browne 2011-2012
Antonin Bukovsky 1998-2003
Greg Bunch 1995
Alfredo Buttari 2004-2007
Giuseppe Bruno 2001
Anthony Canino 2012
Domingo Gimenez Canovas 2001
Henri Casanova 1995-1998
Cedric Castagnede 2012
Ramkrishna Chakrabarty 2005
Sharon Chambers 1998-2000
Zizhong Chen 2001-2006
Jaeyoung Choi 1994-1995
Wahid Chrabakh 1999
Eric Clarkson 1998
Andy Cleary 1995-1997
Michelle Clinard 1989-1991
Vincent Cohen-Addad 2012
Matthias Colin 2004
Charles Collins 2012
Stephanie Cooper 2011-2013
Tom Cortese 2002-2009
Camille Coti 2007
Jason Cox 1993-1997
David Cronk 1999 - 2010
Javier Cuenca 2003
Manoel Cunha 2006
Yuanshun Dai 2007-2013
Cricket Deane 1998-1999
Remi Delmas 2006
Frederic Desprez 1994-1995
Jin Ding 2003
Jun Ding 2001-2003
Ying Ding 2000-2001
Martin Do 1993-1994
Simplice Donfack 2014
Leon Dong 2000-2001
Nick Dongarra 2000
David Doolin 1997
Andrew Downey 1998-2003
Mary Drake 1989-1992
Julio Driggs 2002-2004
Brian Drum 2001-2004
Peng Du 2005-2012
Eduardo Echavarria 2005
Victor Eijkhout 1992-2005
Brett Ellis 1995-2005
Shawn Ericson 2004
Zachary Eyler-Walker 1997-1998
Lisa Ezzell 2003-2004
Christoph Fabianek 2003
Graham Fagg 1996-2006
Mathieu Faverge 2010-2012
Shengzhog Feng 2005-2006
Salvatore Filippone 2004
Anna Finchum 2010
Mike Finger 1997
Markus Fischer 1997-1998
Len Freeman 2009
Xiaoquan Fu 2003-2004
Erika Fuentes 2003-2007
Karl Fuerlinger 2006-2008
Megan Fuller 2006
Edgar Gabriel 2003-2004
Tracy Gangwer 1992-1993
Lynn Gangwer 2000-2001
Nathan Garner 2001-2006
Kelley Garner 1998
Tina Garrison 1991
Adriana Garties 2011
Peter Gaultney 2011-2014
Christoph Geile 2008
Jean Patrick Gelas 2001
Boris Gelfend 1993
Jonathan Gettler 1996
Eric Greaser 1993
Stan Green 1992-1996
Alice Gregory 2004-2006
Jason Gurley 1997-1998
Bilel Hadri 2008-2009
Hunter Hagewood 2000-2001
Christian Halloy 1996-1997
Sven Hammarling 1996-1997
J. Mike Hammond 1994-1995
Satomi Hasegawa 1995-1996
Hidehiko Hasegawa 1995-1996
Chris Hastings 1996
David Henderson 1999-2001
Greg Henry 1996
Julien Herrmann 2011-2012
Holly Hicks 1993-1994
Alexandra Hicks-Hardiman 2009
Sid Hill 1996-1998
Tomoyuki Hiroyasu 2002-2003
George Ho 1998-2000
Josh Hoffman 2008-2010
Jeff Horner 1995-1999
Mitch Horton 2010-2012
Yan Huang 2000-2001
Aurelie Hurault 2009
Chris Hurt 2002
Paul Jacobs 1992-1995
Emmanuel Jeannot 2001-2006
Weizhong Ji 1999-2000
Weicheng Jiang 1992-1995
Song Jin 1997-1998
Patrick Johansson 2001
Aral Johnson 2009
Matt Johnson 2011-2013
Sean Jolly 1997-1998
Jan Jones 1992-2008
Kim Jones 1996-1997
Vijay Joshi 2011-2013
Venkata Kakani 2007
Ajay Kalhan 1995
Balajee Kannan 2001
Madhuri Kasam 2007-2008
Kiran Kasichayanula 2010-2012
Ajay Katta 2010
David Katz 2002
Joshua Kelly 2000-2001
Supriya Kilambi 2008
Myung Ho Kim 2005-2006
Youngbae Kim 1992-1996

Jenya Kirshtein 2008
Michael Kolatis 1993-1996
Chandra Krintz 1999-2001
Tilman Kuestner 2010
Krerkchai Kusolchu 2010
Coire Kyle 2005
Amanda Laake 2003-2004
Xavier Lacoste 2012
Julien Langou 2003-2006
Jeff Larkin 2003-2005
Brian LaRose 1990-1992
Frank Lauer 2010
DongWoo Lee 2000-2002
Tracy Lee 1996-2012
Klaudia Leja 2008
Pierre Lemarinier 2008-2010
Todd Letsche 1993-1994
Sharon Lewis 1992-1995
Xiang Li 2001
Yinan Li 2006-2008
Weiran Li 2002
Chaoyang Liu 2000
Kevin London 1996-2005
Matt Longley 1999
Florent Lopez 2014
Hatem Ltaief 2008-2011
Daniel Lucio 2008
Richard Luczak 2000-2001
Teng Ma 2006-2012
Robert Manchek 1990-1996
Gabriel Marin 2013-2014
Tushti Marwah 2004
Theo Mary 2014
Donald McCasland 1994
Paul McMahan 1994-2000
Eric Meek 2003-2006
James Meyering 1991-1992
Jeremy Millar 1998-2002
Michelle Miller 1999-2003
Cindy Mitchell 2001-2002
Stuart Monty 1993

Eric Moore 2000
Keith Moore 1987-2007
Shirley Moore 1993-2012
Robert Morgan 1990-1991
Kishan Motheramgari 1997
Steven Moulton 1991-1993
Phil Mucci 1994-2004
Daichi Mukunoki 2012
Matthew Nabity 2008
Shankar Narasimhaswami 2004-2005
Rajib Nath 2008-2010
Fernando Navarro 2009
Donnie Newell 2010
John Nelson 2011-2013
Peter Newton 1994-1995
Jonas Nilsson 2001
Jakob Oestergaard 2000
Caroline Papadopoulos 1997-1998
Leelinda Parker 2002
Thibault Parpaite 2014
Dilip Patlolla 2007-2008
Andy Pearson 1989-1991
Paul Peltz 2003-2013
Theresa Pepin 1994
Antoine Petitet 1993-2001
Peter Pham 2012
Gregoire Pichon 2014
Vlado Pjesivac 2008
Jelena Pjesivac-Grbovic 2003-2007
James S. Plank 1991-1992
Ciara Proctor 2008
Tim Poore 2009
Roldan Pozo 1992-1994
Farzona Pulatova 2005-2006
Martin Quinson 2001
Tammy Race 1999-2001
James Ralph 2006-2014
Ganapathy Raman 1998-2000
Kamesh Ramani 2003
Mei Ran 1999-2004
Arun Rattan 1997

Sheri Reagan 1995-1996
Mike Reynolds 1994
George Rhinehart 2012
Jon Richardson 1990-1991
Ken Roche 1999-2004
Andrew Rogers 1997-1999
Tom Rothrock 1997-1998
Tom Rowan 1993-1997
Narapat (Ohm) Saengpatsa 2011
Kiran Sagi 2001-2005
Evelyn Sams 1998-1999
Ken Schwartz 1992-1993
Keith Seymour 1994-2009
Farial Shahnaz 2001
Brian Sheely 2009-2010
Zhiao Shi 2001-2007
Sergei Shinkarev 2005-2007
Majed Sidani 1991-1992
Shilpa Singhal 1996-1998
Matt Skinner 2008
Jonte Smith 2008
Peter Soendergaard 2000
Raffaele Solca 2012
Gwang Son 2007-2009
Fengguang Song 2003-2012
Thomas Spencer 1999-2001
Erich Strohmaier 1995-2001
Xiaobai Sun 1995
Martin Swany 1996-1999
Daisuke Takahashi 2002
Judi Talley 1993-1999
Ronald Tam 2009
Yuan Tang 2005-2006
Yusuke Tanimura 2003
Keita Teranishi 1998
Dan Terpstra 2001-2014
Joe Thomas 2002-2009
John Thurman 1998-1999
Francoise Tisseur 1997
Jude Toth 1993-1994
Bernard Tourancheau 1993-1994

Malcolm Truss 2008
Lauren Vaca 2004
Sathish Vadhiyar 1999-2003
Robert van de Geijn 1990-1991
Chad Vawter 1995
Eugene Vecharynski 2008
Scott Venckus 1993-1995
Antoine Vernois 2004
Reed Wade 1990-1996
Michael Walters 2001-2005
Mike Waltz 1999
Robert Waltz 1990-1991
Jerzy Wasniewski 2000
Vince Weaver 2010-2012
Scott Wells 1997-2010
David West 1990-1992
R. Clint Whaley 1991-2001
Jody Whisnant 1997-1998
James White 1999
Scotti Whitmire 1995-1996
Susan Wo 2000-2001
Felix Wolf 2003-2005
Jiayi Wu 2004-2007
Qiu Xia 2004-2005
Tinghua Xu 1998-2000
Tao Yang 1999
Erlin Yao 2012-2013
Jin Yi 2009-2010
Haihang You 2002-2009
Lamia Youseff 2007
Brian Zachary 2009-2010
Omar Zenati 2012
Yuanlei Zhang 2001-2005
Junlong Zhao 2002
Yong Zheng 2001
Luke Zhou 2000-2001
Min Zhou 2002-2004

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