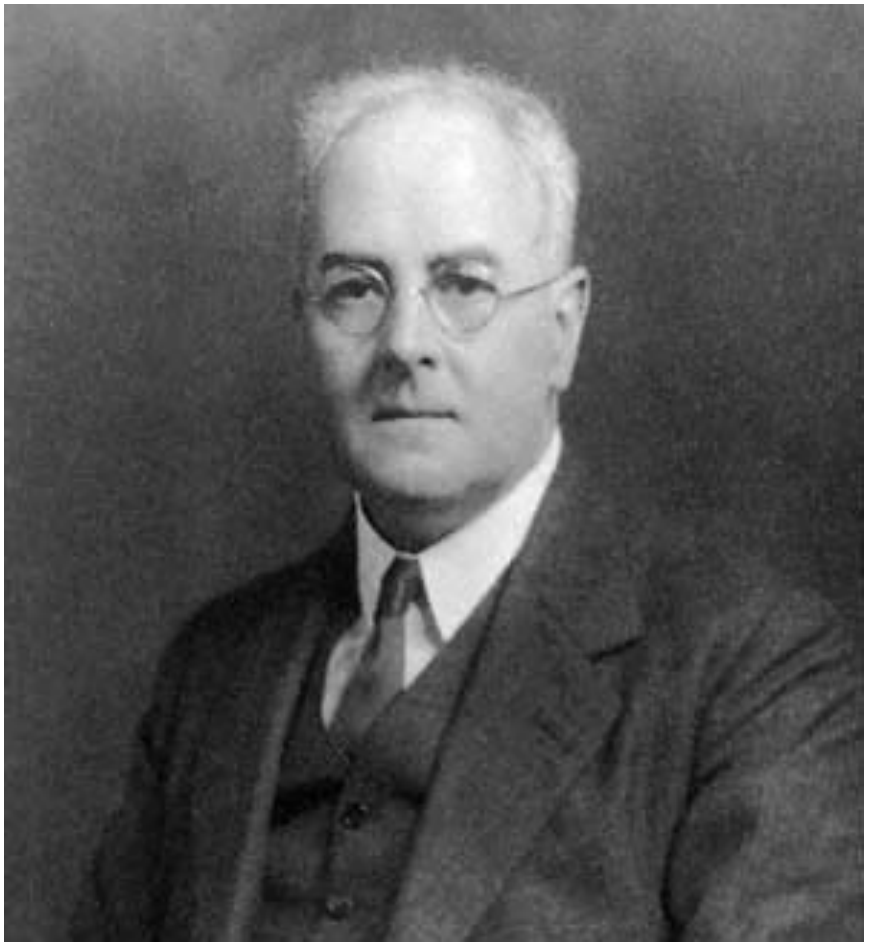
ECRC Communication Meeting

12 October 2021

جامعة الملك عبدالله للعلوم والتقنية
King Abdullah University of Science and Technology

Extreme Computing Research Center

Happy Birthday, Lewis



Lewis Frye Richardson

11 October 1881 born Newcastle Upon Tyne

1903 Natural Sciences Tripos, Cambridge
1903-09 National Physical Laboratory
1909-12 Sunbeam Lamp Company
1912-13 Manchester College
1913-16 Meteorological Office
1916-19 WW I, in France, ambulance crew
1920-29 Westminster College
1929-40 Paisley Technology School
1940 Retired "so that he could *work*" ☺
on pacifist manifestos
1953 Died in Scotland

1922 Numerical Weather Prediction book
1926 Elected to Royal Society

Gave us: Richardson extrapolation
Richardson iteration
fundamental work on fractals
first practical application of finite difference methods in PDEs

Richardson quotation

Big whorls have little whorls,
That feed on their velocity;
And little whorls have lesser whorls,
And so on to viscosity.

[verse to summarize his 1920 paper
The supply of energy from and to Atmospheric Eddies]

Richardson quotation

An advantage of a mathematical statement is that it is so definite that it might be definitely wrong; and if it is found to be wrong, there is a plenteous choice of amendments ready in the mathematicians' stock of formulae. Some verbal statements have not this merit; they are so vague that they could hardly be wrong, and are correspondingly useless.

[*Mathematics of War and Foreign Politics*]

An early visionary: L. F. Richardson

from 1922 book on

Weather Prediction by Numerical Processes

Richardson’s parallel computer

In his 1922 book *Weather Prediction by Numerical Processes*, British fluid dynamicist L. F. Richardson proposed the creation of a global weather prediction facility, which he dubbed the “forecast factory.” It would employ some 64,000 human computers sitting in tiers around the circumference of a gigantic globe to dynamically calculate a PDE model of the global weather.

“Imagine a large hall like a theatre, except that the circles and galleries go right round through the space usually occupied by the stage. The walls of this chamber are painted to form a map of the globe. The ceiling represents the north polar regions, England is in the gallery, the tropics in the upper circle, Australia on the dress circle and the Antarctic in the pit.

A myriad computers are at work upon the weather of the part of the map where each sits, but each computer attends only to one equation or part of an equation. The work of each region is coordinated by an official of higher rank. Numerous little "night signs" display the instantaneous values so that neighbouring computers can read them. Each number is thus displayed in three adjacent zones so as to maintain communication to the North and South on the map.”

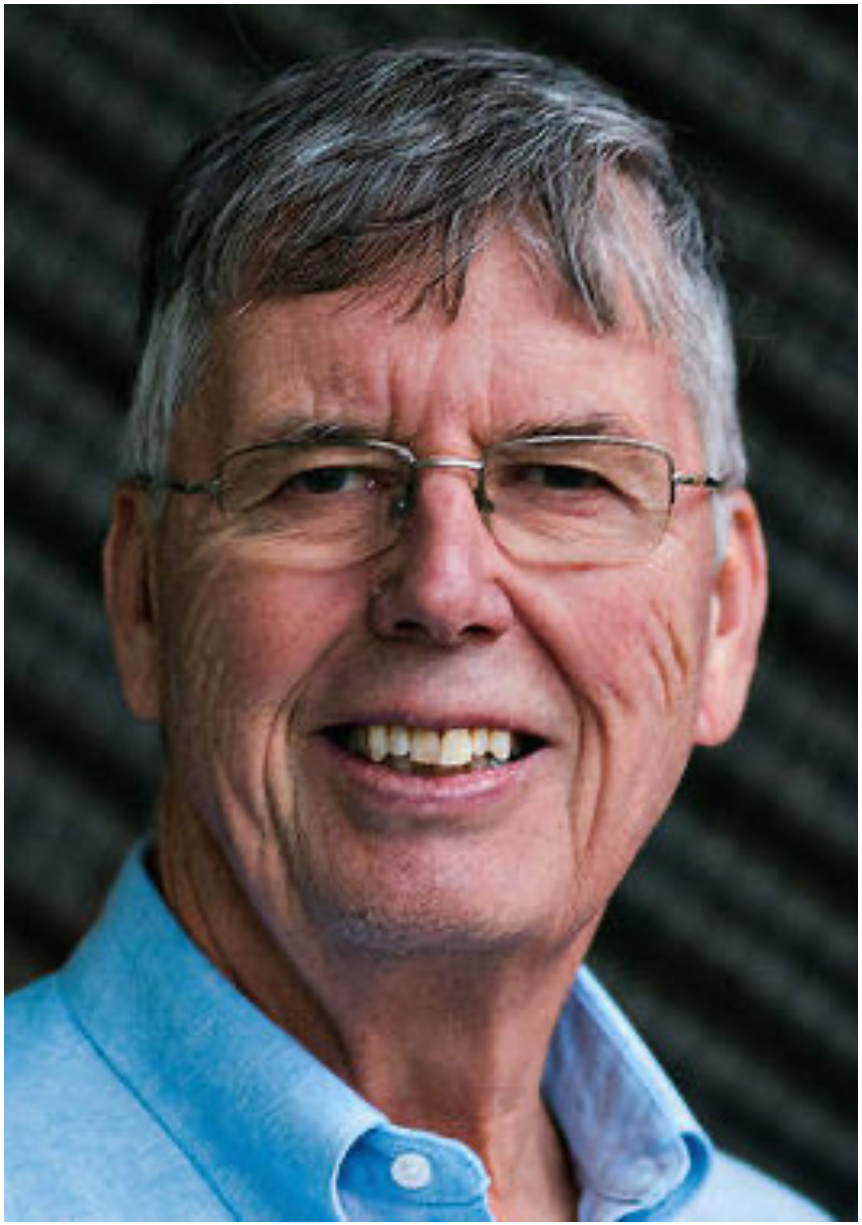
Richardson's parallel computer

"From the floor of the pit a tall pillar rises to half the height of the hall. It carries a large pulpit on its top. In this sits the man in charge of the whole theatre; he is surrounded by several assistants and messengers. One of his duties is to maintain a uniform speed of progress in all parts of the globe. In this respect he is like the conductor of an orchestra in which the instruments are slide-rules and calculating machines.

Four senior clerks in the central pulpit are collecting the future weather as fast as it is being computed, and despatching it by pneumatic carrier to a quiet room. There it will be coded and telephoned to the radio transmitting station. Messengers carry piles of used computing forms down to a storehouse in the cellar.

In a neighbouring building there is a research department, where they invent improvements. But these is much experimenting on a small scale before any change is made in the complex routine of the computing theatre. In a basement an enthusiast is observing eddies in the liquid lining of a huge spinning bowl, but so far the arithmetic proves the better way. In another building are all the usual financial, correspondence and administrative offices. Outside are playing fields, houses, mountains and lakes, for it was thought that those who compute the weather should breathe of it freely."

Happy Birthday, Michael



Michael Stonebraker, 1943-

- Born 11 October 1943 (Milton, NH, USA)
- 1965, B.S.E., EE, Princeton
- 1971, Ph.D., CS&E, Michigan
  - Thesis: *The Reduction of Large Scale Markov Models for Random Chains*
- 1971-2000, Berkeley
- 2001-, MIT
- Foundational in relational databases
  - Developer: Ingres and Postgres
- Started many companies:
  - Ingres, Illustra, Cohera, StreamBase, Vertica, VoltDB, Tamr, Paradigm4
- Now working on:
  - Aurora, C-Store, H-Store, Morpheus, Goby, SciDB
- CTO: Informix
- Now doing data management systems
- Recognition
  - 1969, IEEE John von Neumann Medal
  - 1994, ACM SIGMOD Innovation Award
  - 1994, Fellow, ACM
  - 1997, National Academy of Engineering
  - 2014, Turing Award

Ingres (**IN**teractive **G**raphics **RE**trieval **S**ystem)

Ingres (database)

From Wikipedia, the free encyclopedia

This article **needs additional citations for verification**. Please help improve this article by adding citations to reliable sources. Unsourced material may be challenged and removed. *(June 2011) (Learn how and when to remove this template message)*

Ingres Database (/ɪŋˈɡrɛs/ *ing-GRESS*) is a commercially supported, open-source SQL relational database management system intended to support large commercial and government applications. Ingres Database is fully open source with a global community of contributors. However, Actian Corporation controls the development of Ingres and makes certified binaries available for download, as well as providing worldwide support.

Ingres began as a research project at the University of California, Berkeley, starting in the early 1970s and ending in 1985.[2] The original code, like that from other projects at Berkeley, was available at minimal cost under a version of the BSD license. Ingres spawned a number of commercial database applications, including Sybase, Microsoft SQL Server, NonStop SQL and a number of others. Postgres (**Post** In**gres**), a project which started in the mid-1980s, later evolved into PostgreSQL. It is ACID compatible and is fully transactional (including all DDL statements) and is part of the Lisog open-source stack initiative.

Ingres

Ingres Corporation logo from 2007

Original author(s)	University of California, Berkeley
Developer(s)	Actian Corporation
Stable release	10.2 / September 30, 2014[1]
Written in	C
Operating system	Cross-platform
Type	RDBMS
License	GNU General Public License or proprietary
Website	www.actian.com/products/operational-databases/ingres/

Berkeley webpage

Michael Stonebraker

Biographical Summary:

Dr. Stonebraker is Professor of Electrical Engineering and Computer Sciences at the University of California at Berkeley, where he joined the faculty in 1971. He is widely recognized as one of the world's foremost experts in database technology and is noted for his insight in operating systems and expert systems.

He received a Bachelor of Science degree from Princeton University and Master of Science and Doctor of Philosophy degrees from the University of Michigan. Dr. Stonebraker has held visiting professorships at the Pontifico Universitade Catholique (PUC), Rio de Janeiro, Brazil; the University of California, Santa Cruz; and the University of Grenoble, France.

Dr. Stonebraker founded Ingres Corp. in 1980 and served on the company's board of directors until 1993. (Ingres Corp. was purchased by Computer Associates in 1994.) INGRES, the company's primary product, was a commercialization of Dr. Stonebraker's INGRES research project into relational database management systems (RDBMS) at Berkeley. Ingres Corp. has been widely recognized as a leader in RDBMS technology.

More recently, Dr. Stonebraker has managed another research project known as POSTGRES, one of the most advanced such projects ever undertaken on the Berkeley campus. In August 1992, Dr. Stonebraker co-founded Illustra Information Technologies, Inc. in order to commercialize his research in object-relational database technology. He is a member of the company's board of directors and serves as its Chief Technology Officer.

Dr. Stonebraker is currently focusing on DBMS support for visualization environments and on next-generation distributed DBMSs. In addition, he leads a project which is developing alternative data management strategies for NASA's Earth Observing System (EOS).

His professional activities include:

1. General Chairman of SIGMOD annual conference, 1987
2. Member of SIGMOD Advisory Committee, 1989 to present
3. Program Chairman of SIGMOD annual conference, 1992
4. Member of Technical Advisory Committee for Citicorp, DB Software, and Bull

MIT webpage

MIT COMPUTER SCIENCE AND ARTIFICIAL INTELLIGENCE LABORATORY

CSAIL

SEARCH

ABOUT CSAIL | RESEARCH | NEWS + EVENTS | RESOURCES | PEOPLE | ALUMNI & FRIENDS

PEOPLE

- Principal Investigators
- All Members
- Student Spotlights

Home » People » Michael Stonebraker

MICHAEL STONEBRAKER

[Login to edit profile]

Position: Adjunct Professor
Office: 32-G922
Phone: +1 (617) 253-3538
Email: stonebraker@csail.mit.edu
Areas of Study: Systems & Networking
Last Update: July 9, 2008
Download vCard

BIOGRAPHY

Michael Stonebraker has been a pioneer of data base research and technology for more than a quarter of a century. He was the main architect of the INGRES relational DBMS, the object-relational DBMS, POSTGRES, and the federated data system, Mariposa. All three prototypes were developed at the University of California at Berkeley where Stonebraker was a Professor of Computer Science for twenty five years. He is the founder of three successful Silicon Valley startups, whose objective was to commercialize these prototypes.

Professor Stonebraker is the author of scores of research papers on data base technology, operating systems and the architecture of system software services. He was awarded the prestigious ACM System Software Award in 1992, for his work on INGRES. Additionally, he was awarded the first annual Innovation award by the ACM SIGMOD special interest group in 1994, and has been recognized by Computer Reseller News as one of the top five software developers of the century. Moreover, Forbes magazine named him one of the 8 innovators driving the Silicon Valley wealth explosion during their 80th anniversary edition in 1998. He was elected to the National Academy of Engineering in 1998 and is presently an Adjunct Professor of Computer Science at M.I.T.

PUBLICATIONS

Stan Zdonik, Michael Stonebraker, Mitch Cherniack, Ugur Cetintemal, â€œAurora*: A Distributed Stream Processing Systemâ€, to be submitted to CIDR 2003.

Don Carney, Ugur Cetintemel, Mitch Cherniack, Christian Convey, Sangdon Lee, Michael Stonebraker, Nesime Tatbul, Stan Zdonik, â€œMonitoring Streams: A New Class of Data Management Applications,â€ VLDB 2002 (expanded version will appear in the VLDB Journal).

Michael Stonebraker, â€œToo Much Middleware,â€ SIGMOD Record, March 2001.

Chris Olston, Allison Woodruff, Alexander Aiken, Michael Chu, Vuk Ercegovac, Mark Lin, Mybrid Spalding, Michael Stonebraker, â€œDataSplash,â€ SIGMOD 1998, p550-552.

Allison Woodruff, Michael Stonebraker, â€œSupporting Fine-grained Data Lineage in a Database Visualization Environment,â€ ICDE 1997, p91-102.

Alexander Aiken, Jolly Chen, Michael Stonebraker, Allison Woodruff, â€œTioga-2: A Direct Manipulation Database Visualization Environment,â€ ICDE 1996, p208-217.

Michael Stonebraker, Paul M. Aoki, Witold Litwin, Avi Pfeffer, Adam Sah, Jeff Sidell, Carl Staelin, Andrew Yu, â€œMariposa: A Wide-Area Distributed Database System,â€ VLDB Journal 5(1), p48-63 (1996).

Michael Stonebraker, Paul M. Aoki, Robert

Turing announcement

NETWORKWORLD FROM IDG

INSIDER Sign In

Database pioneer Stonebraker rocks $1M "Nobel Prize in Computing"

Credit: Wikipedia

A.M. Turing Award recognizes Ingres RDBMS creator

MORE

By Bob Brown | Follow

Network World | Mar 25, 2015 7:29 AM PT

RELATED TOPICS

Applications

Big Data/Business

Michael Stonebraker, whose database software breakthroughs helped to tame information overload long before we referred to it as big data, is the recipient of the 2014 ACM A.M. Turing Award,

RELATED

Stanford crypto expert Dan Boneh wins $175K computer science award

Crypto dream team Diffie & Hellman wins $1M "Nobel Prize of Computing"

2011 timeline of major high tech awards: Cryptographers, Unix pioneers lead...

on IDG Answers

How can Convert OST file data into PST file formats?

Turing citation

BIRTH:

October 11, 1943 in Newburyport, Mass.

EDUCATION:

Bachelor's degree in Electrical Engineering (Princeton University, 1965); M.Sc. in Electrical Engineering (University of Michigan, Ann Arbor, 1967); Ph.D. in Computer Science & Engineering (University of Michigan, Ann Arbor, 1971).

EXPERIENCE

MICHAEL STONEBRAKER

United States – 2014

CITATION

For fundamental contributions to the concepts and practices underlying modern database systems.

SHORT ANNOTATED BIBLIOGRAPHY | ACM DL AUTHOR PROFILE | ACM TURING AWARD LECTURE VIDEO | RESEARCH SUBJECTS | ADDITIONAL MATERIALS

Michael Stonebraker's contributions to the refinement and spread of database management technology are hard to overstate. He began work in this area as a young assistant professor at the University of California—Berkeley. After reading Edgar F. Codd's seminal papers on the relational model, Stonebraker started work with a colleague, Eugene Wong, to develop an efficient and practical implementation. The result was INGRES, a name that reflected the project's original intention to produce a geographically-oriented system with graphical capabilities. This officially stood for "Interactive Graphic and Retrieval System" but echoed the name of a celebrated French painter.

A prototype of INGRES was working by 1974, but the project did not stop there. Over the next decade INGRES, and systems inspired by it, built a new commercial market of relational database systems. Today the relational database management system is one of computing's most important and widely used technologies, having replaced filing cabinets as the standard way of storing and retrieving information.

Stonebraker quotation

"Knowing what I know now, I would never have started building INGRES, because it's too hard…. So I think my advice to my younger self would be to suspend your disbelief and just do it anyway. The way you climb Mt. Everest is one step at a time…"

Stonebraker quotation

"Go spend some time in the real world and work on problems people want solved… [too many people] are more interested in working on problems that are solvable rather than problems that are important."

Plan of today's meeting

- People
  - new members, visitors, interns, departing ?
- Announcements
- Tech Transfer Office presentation
- ECRC Culture conversation
- Roundtable

Other introductions?

By self?

By sponsor?

TTO Presentation

Dr. Salahud Din
PhD, 2012 Imperial College London, Materials Science & Nanotechnology
At KAUST since 2017

- Business Development, University-Industry Collaborations, Research Collaborations, Faculty Consultancy, Technology Piloting, Creation of Startup Companies, Expansion of the KAUST Research & Technology Park (KRTP) and facilitation of IP licensing deals.

- Identifying suitable partners (industry and others) to drive the deployment of innovative products from the intellectual assets of KAUST researchers. Externally focused role and responsible for deploying KAUST technologies to partners culminating in options, licenses and/or assignments of KAUST IP rights. Working closely with other members of the Technology Transfer Office (TTO) to achieve the objectives of the Office of Innovation and Economic Development for the benefit of KAUST and the Kingdom of Saudi Arabia.

ECRC-originated and curated software

- HiCMA [github.com/ecrc/hicma] *Hierarchical Computations on Manycore Architectures*, a dense linear algebra library exploiting data sparsity of the matrix operator
- ExaGeoStat [github.com/ecrc/exageostat] *Exascale Geospatial Statistics*, a parallel high performance framework for large-scale computational geostatistics on many-core and distributed systems
- ExaGeoStatR [github.com/ecrc/exageostatR] an R-wrapped version of ExaGeoStat, to offer the interactive features of the consortium-driven statistical toolbox R (see r-project.org)
- H2Opus [github.com/ecrc/h2opus] linear algebra based on H2 hierarchical matrices, for CPUs, GPUs, and distributed systems
- KBLAS-CPU [github.com/ecrc/kblas-cpu] *KAUST's Basic Linear Algebra Subroutines*, a high performance library implementing a subset of the standard BLAS as well as LAPACK routines on CPUs
- KBLAS-GPU [github.com/ecrc/kblas-gpu] *KAUST's Basic Linear Algebra Subroutines*, a CUDA version of KBLAS-CPU for NVIDIA GPUs

ECRC-originated and curated software

- KSVD [github.com/ecrc/ksvd] *KAUST's Singular Value Decomposition* solver, a high performance software framework for computing a dense SVD on manycore shared and distributed memory systems
- Al4SAN [github.com/ecrc/al4san] *Abstraction Layer library For Standardizing APIs of task-based eNgines*, a lightweight software library that provides APIs to unify the expression of tasks and their data dependencies from (so far) four of the major dynamic runtime engines: QUARK, PaRSEC, StarPU, and OpenMP-LLVM
- STARS-H [github.com/ecrc/al4san] *Software for Testing Accuracy, Reliability and Scalability of Hierarchical* computations, a generation and analysis library for H-matrices
- HCORE [github.com/ecrc/al4san] BLAS operations for matrices maintained in tile low-rank format
- GIRIH [github.com/girih] multicore wavefront diamond-tiling methods with an autotuning harness for fast stencil computations in manycore shared and distributed memory systems

ECRC-originated and curated software

- mpi4py-fft [pypi.org/project/mpi4py-fft/] a Python package for computing Fast Fourier Transforms (FFTs) exploiting transpose-in-the-network functionality of MPI
- GRACE [github.com/sands-lab/grace] GRAdient ComprEssion, a framework for implementing and evaluating gradient compression techniques for distributed deep learning
- SSDC [github.com/ecrc/ssdc] *Entropy Stable Discontinuous Collocation*, an *hp*-adaptive high performance CFD toolkit based on a general spectral element solver for unstructured grids
- MLBS [github.com/ecrc/mlbs] *Multi-Layer Buffer System*, a generalization of two-level cache protocols to N-level memory, which has been adopted for Aramco seismic image processing
- ExaWave [a deliverable to Aramco] is a home-grown Reverse Time Migration (RTM) seismic inversion code that is used to prototype performance improvements for Aramco's GeoDrive

ECRC-originated and curated software

- DAIET *Data Aggregation In nETwork*, leveraging the programmable data plane to reduce data traffic as it is being forwarded towards the destination by offloading the aggregation task to the network [github.com/AmedeoSapio/DAIET]
- SwitchML: Scaling Distributed Machine Learning with In-Network Aggregation [github.com/p4lang/p4app-switchML]
- OmniReduce: Efficient Sparse Collective Communication and its application to Accelerate Distributed Deep Learning [github.com/sands-lab/omnireduce]

ECRC-curated software

- PETSc [www.mcs.anl.gov/petsc/] *Portable, Extensible Toolkit for Scientific Computing*, an R&D100 Award winning toolkit of distributed data structures and solvers, supported out of Argonne National Laboratory, a workhorse code of the US DOE
- UG4 [github.com/ug4] a simulation framework for modeling differential equations on unstructured finite element grids
- SPECFEM3D [github.com/geodynamics/specfem3d] *Spectral Finite Element Method in 3D*, a modeling tool for acoustic, elastic, coupled acoustic/elastic, poroelastic, or seismic wave propagation in any type of conforming mesh of hexahedra, structure or unstructured
- CLAWPACK [clawpack.org] *Conservation Laws Package*, a toolkit for linear and nonlinear hyperbolic systems of conservation laws, implementing high-resolution Godunov type methods using limiters
- PyCLAW [clawpack.org/pyclaw/] a Python-based interface to the algorithms of Clawpack and SharpClaw, and

ECRC-curated software

- PETSc [www.mcs.anl.gov/petsc/] *Portable, Extensible Toolkit for Scientific Computing*, an R&D100 Award winning toolkit of distributed data structures and solvers, supported out of Argonne National Laboratory, a workhorse code of the US DOE
- UG4 [github.com/ug4] a simulation framework for modeling differential equations on unstructured finite element grids
- SPECFEM3D [github.com/geodynamics/specfem3d] *Spectral Finite Element Method in 3D*, a modeling tool for acoustic, elastic, coupled acoustic/elastic, poroelastic, or seismic wave propagation in any type of conforming mesh of hexahedra, structure or unstructured
- CLAWPACK [clawpack.org] *Conservation Laws Package*, a toolkit for linear and nonlinear hyperbolic systems of conservation laws, implementing high-resolution Godunov type methods using limiters
- PyCLAW [clawpack.org/pyclaw/] a Python-based interface to the algorithms of Clawpack and SharpClaw, and the PetClaw package, which adds parallelism through PETSc

ECRC-curated software

- petsc4py [pypi.org/project/petsc4py/] Python bindings for PETSc
- slepc4py [pypi.org/project/slepc4py/] Python bindings for the eigensolver package SLEPc, based on PETSc solvers
- mpi4py [pypi.org/project/mpi4py/] Python bindings for the Message Passing Interface standard
- MFEM [mfem.org] a lightweight, scalable C++ library for Finite Element Methods, supported out of Lawrence Livermore National Laboratory, a workhorse code of the US DOE, which uses PETSc solvers
- OpenFOAM [openfoam.com] Open Source Computational Fluid Dynamics Toolbox, modeling software for complex fluid flows involving chemical reactions, turbulence and heat transfer, acoustics, solid mechanics and electromagnetics, which uses PETSc solvers

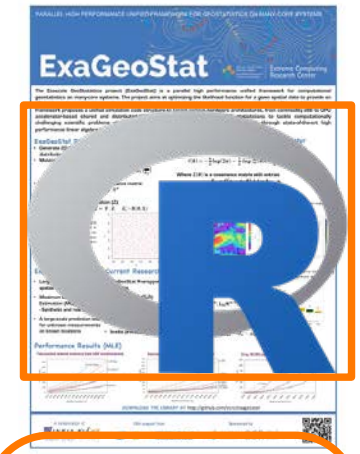
ECRC software not under curation

- KFUN3D [github.com/ecrc/kfun3d] an adaption of the NASA code FUN3D for unstructured CFD to manycore architectures, exploiting AVX-512 instructions, which uses PETSc solvers
- BEMFMM [github.com/ecrc/bemfmm] an FMM-accelerated boundary integral equation solver for wave scattering
- MOAO [github.com/ecrc/moao] *Multi-Objective Adaptive Optics*, a simulation framework for controlling adaptive optics in earth-based telescopes for manycore architectures and GPUs
- ACR [github.org/ecrc/acr] *Accelerated Cyclic Reduction*, a cyclic reduction solver for structured linear systems that exploits low rank compression of Schur complements
- RDF-EXP [github.com/ecrc/rdf-exp] a test harness for distributed SPARQL engines for Resource Descriptor Framework (RDF) database processing

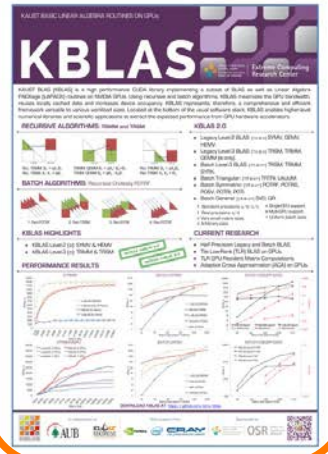
ECRC software not under curation

- iCentral [github.com/fjamour/icentral] software for detecting and updating “betweenness centrality” in evolving large graphs
- GraMi [github.com/ehab-abdelhamid/GraMi] a framework for frequent subgraph mining in large graphs
- ScaleMine [https://github.com/ehab-abdelhamid/ScaleMine] a scalable parallel version of frequent subgraph mining
- AdPart [github.com/ibrahimabdelaziz/AdPart] *Adaptive Partitioning,* a framework for accelerating SPARQL queries by exploiting hash-based locality

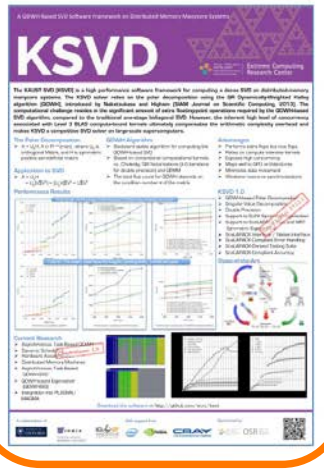
ECRC software featured at SC’21



in NVIDIA cuBLAS

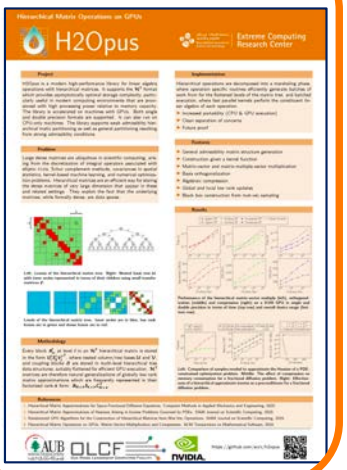


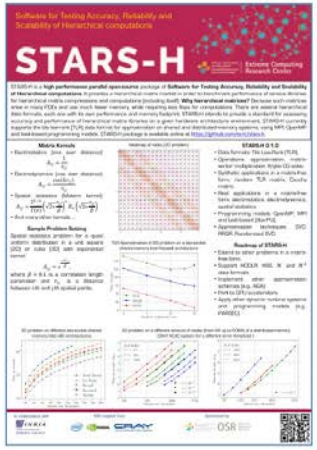
in Cray LibSci

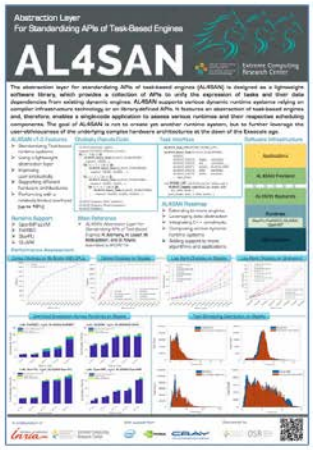


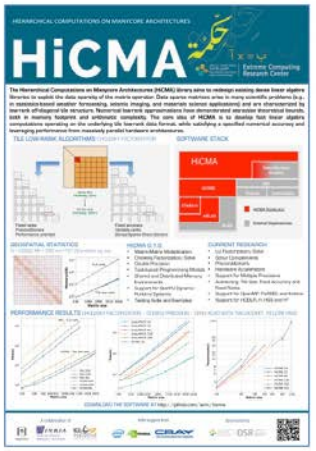
in ExaWave

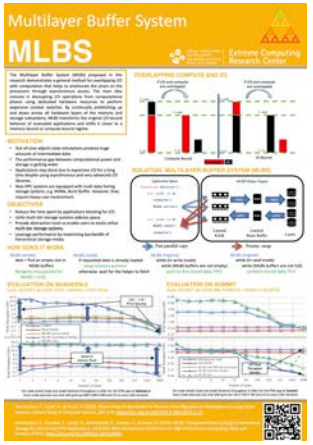
in PETSc











available at https://github.com/ecrc/

ECRC short course in progress

Theory and Application of Neural Networks

Professor Jinchao Xu (PennState) will give a self-contained introduction to the theory of the neural network function class and its application to image classification and numerical solution of partial differential equations (tentatively scheduled for the second week of October).

* Definition of the neural network function class as a generalization of classical finite element functions
* Deep ReLU neural networks versus the classic piecewise linear finite element functions
* Classical approximation theory of neural network functions
* New optimal approximate theory of stable neural network functions
* Classic machine learning methods: logistic regression and support vector machine
* Deep learning: convolutional neural networks (CNN) for image classification
* MgNet: a special CNN obtained from a minor modification of the classical multigrid method
* Application and error analysis of neural network for numerical solutions of partial differential equations (PDEs)
* Numerical quadrature and Rademacher complexity analysis
* Old and new training algorithms for machine learning and numerical PDEs

ECRC short course in progress

Theory and Application of Neural Networks

Thumbnail summary:

- The space of functions that map high-dimensional vector inputs to outputs through neural networks via ReLU activation functions is contained in piecewise linear finite elements.
- It can also be enlarged to contain piecewise linear finite elements of the same dimension by growing the neural network sufficiently deep.
- The approximation properties of ReLU are very rich. This is due, in part, to their nonlinearity.
- Though the spaces can be made identical, traditional finite elements and ReLU-based neural networks have very different structure.
- The concepts of a mesh and of a nodal basis that are so fundamental to the efficiency of solution of finite elements are not present, as such, for neural networks.
- Jinchao is pursuing the applicability of optimal solvers, such as multilevel methods, for finite element problems in neural network training.
- So far, no bottom-line breakthroughs in practical training.

Why the ReLU function

Traditionally, some prevalent non-linear activation functions, like sigmoid functions (or logistic) and hyperbolic tangent, are used in neural networks to get activation values corresponding to each neuron. Recently, the ReLu function has been used instead to calculate the activation values in traditional neural network or deep neural network paradigms. The reasons of replacing sigmoid and hyperbolic tangent with ReLu consist of:

Computation saving - the ReLu function is able to accelerate the training speed of deep neural networks compared to traditional activation functions since the derivative of ReLu is 1 for a positive input. Due to a constant, deep neural networks do not need to take additional time for computing error terms during training phase.

- the ReLu function does not trigger the vanishing gradient problem when the number of layers grows. This is because this function does not have an asymptotic upper and lower bound. Thus, the earliest layer (the first hidden layer) is able to receive the errors coming from the last layers to adjust all weights between layers. By contrast, a traditional activation function like sigmoid is restricted between 0 and 1, so the errors become small for the first hidden layer. This scenario will lead to a poorly trained neural network.

https://deepai.org/machine-learning-glossary-and-terms/relu

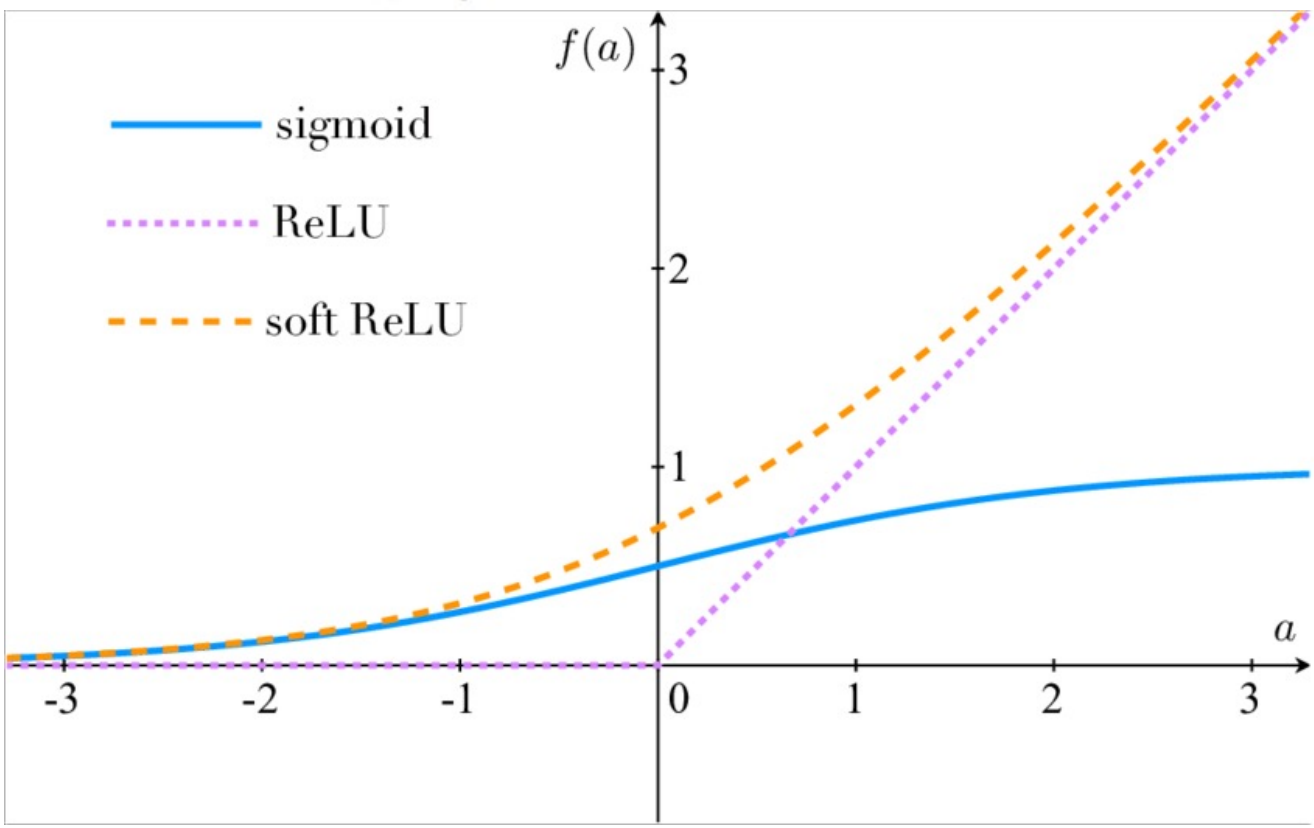
ReLU (rectified linear unit) function

ReLu is a non-linear activation function that is used in multi-layer neural networks or deep neural networks. This function can be represented as:

$$f(x) = \max(0, x) \qquad (1)$$

where x = an input value

$$f(x) = \begin{cases} 0, if\ x < 0 \\ x, if\ x \geq 0 \end{cases} \qquad (2)$$



ECRC short course in progress

Theory and Application of Neural Networks

Not too late to join for the last lecture tomorrow at 9:00am in Lecture Hall 1, Building 9, Room 2322

Topics:
A departure from the theorem-proof style of the first two lectures to look at image classification and PDEs examples.

Slides will be available.

The lectures have been recorded.

Majlis