ASPLOS XIX

Nineteenth International Conference on Architectural Support for Programming Languages and Operating Systems

March 1–5, 2014
Salt Lake City, Utah, USA

Sponsored by:
SIGARCH
SIGOPS
SIGPLAN

In co-operation with: SIGBED

With Support from:
NSF, Microsoft Research, ARM, AMD, Google, Hewlett-Packard, Intel, VMware, Facebook, Oracle Labs, EMC², and IBM Research
# Table of Contents

ASPLOS 2014 Organization ........................................................................................................... xv

ASPLOS 2014 Sponsors and Supporters ...................................................................................... xix

Keynote
Session Chair: Al Davis *(University of Utah)*
- Inside Windows Azure: The Challenges and Opportunities of a Cloud Operating System .......... 1
  Brad Calder *(Microsoft)*

Session 1A: Data Centers
Session Chair: Anand Sivasubramaniam *(Pennsylvania State University)*
- Scale-Out NUMA .................................................................................................................. 3
  Stanko Novaković, Alexandros Daglis, Edouard Bugnion, Babak Falsafi *(École Polytechnique Fédérale de Lausanne)*, Boris Grot *(University of Edinburgh)*
- Rhythm: Harnessing Data Parallel Hardware for Server Workloads ........................................... 19
  Sandeep R. Agrawal, Valentin Pistol, Jun Pang *(Duke University)*, John Tran, David Tarjan *(NVIDIA)*, Alvin R. Lebeck *(Duke University)*

Session 1B: Approximate Computing
Session Chair: Luis Ceze *(University of Washington)*
- Paraprox: Pattern-Based Approximation for Data Parallel Applications ....................................... 35
  Mehrzad Samadi, Davoud Anoushe Jamshidi, Janghaeng Lee, Scott Mahlke *(University of Michigan)*
- Uncertain&lt;7&gt;: A First-Order Type for Uncertain Data ............................................................... 51
  James Bornholt *(Australian National University)*, Todd Mytkowicz, Kathryn S. McKinley *(Microsoft Research)*

Session 2A: Security
Session Chair: Yuanyuan Zhou *(University of California, San Diego)*
- Using ARM TrustZone to Build a Trusted Language Runtime for Mobile Applications ................ 67
  Nuno Santos *(INESC-ID & University of Lisbon)*, Himanshu Raj, Stefan Saroiu, Alec Wolman *(Microsoft Research)*
- Virtual Ghost: Protecting Applications from Hostile Operating Systems ...................................... 81
  John Criswell, Nathan Dautenhahn, Vikram Adve *(University of Illinois at Urbana-Champaign)*
- Sapper: A Language for Hardware-Level Security Policy Enforcement ....................................... 97
  Xun Li *(Facebook)*, Vinceth Kashyap *(University of California, Santa Barbara)*, Jason K. Oberg *(University of California, San Diego)*, Mohit Tiwari *(University of Texas, Austin)*, Vasanth Ram Rajaratnam *(AMD)*, Ryan Kastner *(University of California, San Diego)*, Timothy Sherwood, Ben Hardekopf, Frederic T. Chong *(University of California, Santa Barbara)*
- Finding Trojan Message Vulnerabilities in Distributed Systems .................................................. 113
  Radu Banabic, George Canda, Rachid Guerraoui *(École Polytechnique Fédérale de Lausanne)*

Session 2B: Resource Management
Session Chair: Tim Harris *(Oracle Labs)*
- Quasar: Resource-Efficient and QoS-Aware Cluster Management ............................................. 127
  Christina Delimitrou, Christos Kozyrakis *(Stanford University)*
- REF: Resource Elasticity Fairness with Sharing Incentives for Multiprocessors .............................. 145
  Seyed Majid Zahedi, Benjamin C. Lee *(Duke University)*
Session 3A: Software Reliability and Testing I
Session Chair: Santosh Nagarakatte (Rutgers University)

- Comprehending Performance from Real-World Execution Traces: A Device-Driver Case
  Xiao Yu (North Carolina State University), Shi Han (Microsoft Research), Dongmei Zhang (Microsoft Research), Tao Xie (University of Illinois at Urbana-Champaign)

- Leveraging the Short-Term Memory of Hardware to Diagnose Production-Run Software Failures
  Joy Arulraj, Guoliang Jin, Shan Lu (University of Wisconsin-Madison)

- RelaxReplay: Record and Replay for Relaxed-Consistency Multiprocessors
  Nima Honarmand, Josep Torrellas (University of Illinois at Urbana-Champaign)

- Prototyping Symbolic Execution Engines for Interpreted Languages
  Stefan Bucur (École Polytechnique Fédérale de Lausanne), Johannes Kinder (École Polytechnique Fédérale de Lausanne & Royal Holloway, University of London), George Candea (École Polytechnique Fédérale de Lausanne)

Session 3B: Heterogeneous Computing
Session Chair: Debbie Mart (Intel Corp.)

- Q100: The Architecture and Design of a Database Processing Unit
  Lisa Wu, Andrea Lottarini, Timothy K. Paine, Martha A. Kim, Kenneth A. Ross (Columbia University)

- DianNao: A Small-Footprint High-Throughput Accelerator for Ubiquitous Machine-Learning
  Tianshi Chen, Zidong Du, Ninghui Sun, Jia Wang, Chengyoung Wu, Yunji Chen (Institute of Computing Technology), Olivier Temam (Inria, France)

- K2: A Mobile Operating System for Heterogeneous Coherence Domains
  Felix Xiaozhu Lin, Zhen Wang, Lin Zhong (Rice University)

- Disengaged Scheduling for Fair, Protected Access to Fast Computational Accelerators
  Konstantinos Menychtas, Kai Shen, Michael L. Scott (University of Rochester)

Keynote
Session Chair: Rajeev Balasubramonian (University of Utah)

- Neuromorphic Processing: A New Frontier in Scaling Computer Architecture
  Jeff Gehlhaar (Qualcomm Technologies, Inc.)

Session 4A: Virtualization
Session Chair: Carl A. Waldspurger (independent)

- I/O Paravirtualization at the Device File Boundary
  Ardalan Amini Sani, Kevin Boos, Shaopu Qin, Lin Zhong (Rice University)

- KVM/ARM: The Design and Implementation of the Linux ARM Hypervisor
  Christoffer Dall, Jason Nieh (Columbia University)

- VSWAPPER: A Memory Swapper for Virtualized Environments
  Nadav Amit, Dan Tsafrir, Assaf Schuster (Technion – Israel Institute of Technology)

- Cider: Native Execution of iOS Apps on Android
  Jeremy Andrus, Alexander Van’t Hof, Naser AlDuaij, Christoffer Dall, Nicolas Viennot, Jason Nieh (Columbia University)
Session 4B: Transactional Memory and Consistency
Session Chair: Sandhya Dwarkadas (University of Rochester)

- SI-TM: Reducing Transactional Memory Abort Rates through Snapshot Isolation .................................................. 383
  Heiner Litz, David Cheriton (Stanford University), Amin Firoozshahian, Omid Azizi (HICAMP Systems), John P. Stevenson (Stanford University)

- Transactionalizing Legacy Code: An Experience Report Using GCC and Memcached ............................................. 399
  Wenjia Ruan, Trilok Vyas, Yujie Liu, Michael Spear (Lehigh University)

- Fence-Free Work Stealing on Bounded TSO Processors ............................................................................................... 413
  Adam Morrison (Technion – Israel Institute of Technology), Yehuda Afek (Tel Aviv University)

- Heterogeneous-race-free Memory Models .................................................................................................................. 427
  Derek R. Hower (AMD Research), Blake A. Hechtman (AMD Research & Duke University), Bradford M. Beckmann, Benedict R. Gaster (AMD Research), Mark D. Hill (University of Wisconsin-Madison & AMD Research), Steven K. Reinhardt (AMD Research), David A. Wood (University of Wisconsin-Madison & AMD Research)

Session 5A: Storage Systems
Session Chair: Martha Kim (Columbia University)

- Triple-A: A Non-SSD Based Autonomic All-Flash Array for High Performance Storage Systems 441
  Myoungsoo Jung, Wonil Choi (The University of Texas at Dallas), John Shalf (Lawrence Berkeley National Laboratory), Mahmut Taylan Kandemir (The Pennsylvania State University)

- NVM Duet: Unified Working Memory and Persistent Store Architecture ................................................................. 455
  Ren-Shuo Liu, De-Yu Shen, Chia-Lin Yang, Shun-Chih Yu (National Taiwan University), Cheng-Yuan Michael Wang (Macronix International Co., Ltd.)

- SDF: Software-Defined Flash for Web-Scale Internet Storage Systems ................................................................. 471
  Jian Ouyang, Shiding Lin (Baidu, Inc.), Song Jiang (Peking University & Wayne State University), Zhenyu Hou, Yong Wang, Yuanzheng Wang (Baidu, Inc.)

- Integrated 3D-Stacked Server Designs for Increasing Physical Density of Key-Value Stores 485
  Anthony Gutiérrez, Michael Cieslak, Bharan Giridhar, Ronald G. Dreslinski (University of Michigan). Luis Ceze (University of Washington – Seattle), Trevor Mudge (University of Michigan)

Session 5B: Parallelism I
Session Chair: Josep Torrellas (University of Illinois at Urbana-Champaign)

- Deterministic Galois: On-Demand, Portable and Parameterless .............................................................. 499
  Donald Nguyen, Andrew Lenharth, Keshav Pingali (The University of Texas at Austin)

- Energy-Efficient Work-Stealing Language Runtimes ............................................................................................. 513
  Haris Ribic, David Yu (SUNY Binghamton)

- Data-Parallel Finite-State Machines ....................................................................................................................... 529
  Todd Mytkowicz, Madanlal Musuvathi (Microsoft Research), Wolfram Schulte (Microsoft)

- Challenging the “Embarrassingly Sequential”: Parallelizing Finite State Machine-Based Computations through Principled Speculation .......................................................... 543
  Zhijia Zhao, Bo Wu, Xipeng Shen (College of William and Mary)

Session 6A: Parallelism II
Session Chair: Babak Falsafi (École Polytechnique Fédérale de Lausanne)

- The Sharing Architecture: Sub-Core Configurability for IaaS Clouds ............................................................... 559
  Yanqi Zhou, David Wentzloff (Princeton University)

- ASC: Automatically Scalable Computation ............................................................................................................. 575
  Amos Waterland, Elaine Angelino, Ryan P. Adams (Harvard University), Jonathan Appavoo (Boston University), Margo Seltzer (Harvard University)

- The Benefit of SMT in the Multi-Core Era: Flexibility towards Degrees of Thread-Level Parallelism ................. 591
  Stijn Eyerman, Lieven Eeckhout (Ghent University)
Session 6B: Compilers, Optimization, and Co-design
Session Chair: Keshav Pingali (University of Texas at Austin)

- **Finding the Limit: Examining the Potential and Complexity of Compilation Scheduling for JIT-Based Runtime Systems** ................................................................. 607  
  Yufei Ding, Mingzhou Zhou, Zhijia Zhao (The College of William and Mary), Sarah Eisenstat (Massachusetts Institute of Technology), Xipeng Shen (The College of William and Mary)

- **Speculative Hardware/Software Co-Designed Floating-Point Multiply-Add Fusion** ................................................................. 623  
  Marc Lupon, Enric Gibert, Grigorios Magklis, Sridhar Samudrala, Raúl Martínez, Kyriakos Stavrou, David R. Ditzel (Intel Barcelona Research Center)

- **Post-compiler Software Optimization for Reducing Energy** .................................................................................................................. 639  
  Eric Schulte (University of New Mexico), Jonathan Dorn (University of Virginia), Stephen Harding, Stephanie Forrest (University of New Mexico), Westley Weimer (University of Virginia)

Debate
Session Chair: David A. Wood (University of Wisconsin-Madison)

- **Resolved: Specialized Architectures, Languages, and System Software Should Largely Supplant General-purpose Alternatives within the Next Decade** ................................................................. 653  
  David A. Wood (University of Wisconsin-Madison)

Session 7A: Software Reliability and Testing II
Session Chair: Shan Lu (University of Wisconsin-Madison)

- **Guardrail: A High Fidelity Approach to Protecting Hardware Devices from Buggy Drivers** ................................................................. 655  
  Olatunji Ruwase (Microsoft Research), Michael A. Kozuch, Phillip B. Gibbons (Intel Labs Pittsburgh), Todd C. Mowry (Carnegie Mellon University)

- **Low-Level Detection of Language-Level Data Races with LARD** .......................................................................................................... 671  
  Benjamin P. Wood, Luis Ceze, Dan Grossman (University of Washington)

- **EnCore: Exploiting System Environment and Correlation Information for Misconfiguration Detection** ................................................................. 687  
  Jiaqi Zhang (University of California, San Diego), Lakshminarayanan Renganarayana, Xiaolun Zhang, Niyu Ge, Vasantha Bala (IBM T.J. Watson Research Center), Tianyin Xu, Yuanyuan Zhou (University of California, San Diego)

Session 7B: Caches and TLBs
Session Chair: Kathryn S. McKinley (Microsoft Research)

- **High-Performance Fractal Coherence** ................................................................................................................................. 701  
  Gwendolyn Voskuilen, T. N. Vijaykumar (Purdue University)

- **Locality-Oblivious Cache Organization Leveraging Single-Cycle Multi-Hop NoCs** ................................................................. 715  
  Woo-Cheol Kwon (Massachusetts Institute of Technology), Tushar Krishna (Intel Corporation), Li-Shiuan Peh (Massachusetts Institute of Technology)

- **Ubik: Efficient Cache Sharing with Strict QoS for Latency-Critical Workloads** ......................................................................................... 729  
  Harshad Kasture, Daniel Sanchez (Massachusetts Institute of Technology)

- **Architectural Support for Address Translation on GPUs: Designing Memory Management Units for CPU/GPUs with Unified Address Spaces** ................................................................. 743  
  Bharath Pichai (Rutgers University), Lisa Hsu (Qualcomm Research), Abhishhek Bhattacharjee (Rutgers University)

Author Index ............................................................................................................................................................. 758