Introduction to the Special Issue on HEVC Extensions and Efficient HEVC Implementations

HIGH EFFICIENCY Video Coding (HEVC) is the most recent standard in the series of major video coding standards jointly produced by the ITU-T Video Coding Experts Group (VCEG) and the ISO/IEC Moving Picture Experts Group (MPEG). HEVC was first approved in 2013 in the ITU-T as Recommendation H.265 and in ISO/IEC as International Standard 23008-2, and it offers an unprecedented degree of compression capability for a very wide variety of applications. In the three years since its initial completion, it has been extended in several important ways to further broaden its scope. This special issue on HEVC features two sections: 1) HEVC extensions and 2) efficient HEVC implementations.

The first special section features a series of invited papers to present the recent extensions to HEVC that expand its range of applications.

The paper "Overview of the Range Extensions for the HEVC Standard: Tools, Profiles and Performance" by Flynn, Marpe, Naccari, Nguyen, Rosewarne, Sharman, Sole, and Xu gives insight into the HEVC extensions to support color sampling formats other than 4:2:0, bit depths higher than 10 bits, and improved compression in the lossless and near lossless range. These range extensions (RExt) were the first additions to the core design of HEVC version 1.

The paper "Overview of SHVC: Scalable Extensions of the High Efficiency Video Coding Standard" by Boyce, Ye, Chen, and Ramasubramonian describes the new elements of SHVC that were added to support various modes of scalability and layered access, e.g., enabling decoding of lower resolution formats from parts of a bitstream.

The paper "Overview of the Multiview and 3D Extensions of High Efficiency Video Coding" by Tech, Chen, Müller, Ohm, Vetro, and Wang describes an extension for supporting stereo- and multi-view captures without changes in low-level coding tools, nicknamed MV-HEVC, and another extension called 3D-HEVC that defines new coding tools for more efficient joint compression of video and depth, as necessary for advanced 3D applications.

The HEVC additions RExt, SHVC, and MV-HEVC were finalized in 2014, and 3D-HEVC was finalized in early 2015.

New coding tools specifically designed for better compression of computer-generated content are described in "Overview of the Emerging HEVC Screen Content Coding Extension" by Xu, Joshi, and Cohen. This extension is currently under development and is expected to be finalized by early 2016.

Capabilities for compressing high dynamic range (HDR) and wide color gamut (WCG) sources are introduced in "High Dynamic Range and Wide Color Gamut Video Coding in HEVC: Status and Potential Future Enhancements" by François, Fogg, He, Li, Luthra, and Segall. HDR and WCG are expected to become especially important in future Ultra-HD services and displays. An extension for these technologies is expected for 2016 or later.

As the final contribution to the special section, the paper "Video Quality Evaluation Methodology and Verification Testing of HEVC Compression Performance" by Tan, Weerakkody, Mrak, Ramzan, Baroncini, Ohm, and Sullivan provides the results from a recent verification test about the benefits of HEVC compression in comparison with previous standards, in particular with regard to subjective quality evaluation.

The second special section features 12 papers selected from 40 submissions that aim to address the need for efficient HEVC implementations for both encoders and decoders to enable real-time processing. Topics covered range from encoder algorithm optimizations to software and hardware implementations.

The first five papers present implementation-friendly encoding algorithms that efficiently trade off coding efficiency and complexity. The paper "Subjective-Driven Complexity Control Approach for HEVC" by Deng, Xu, Jiang, Sun, and Wang proposes an approach that speeds up encoder decisions by a novel scheme for limiting the depth of the coding unit (CU) tree, based on complexity and objective/subjective distortion criteria. The paper "Fast Quantization Method with Simplified Rate-Distortion Optimized Quantization for an HEVC Encoder" by Lee, Yang, Park, and Jeon describes methods to reduce the complexity of the rate-distortion optimized quantization process in HEVC. In "Lagrangian Multiplier Adaptation for Rate-Distortion Optimization with Inter-Frame Dependency," Li, Zhu, Gao, Zhou, Dufaux, and Sun consider encoder decisions over multiple frames. The idea of the paper "Fast CU Partitioning Algorithm for HEVC Using an Online-Learning-Based Bayesian Decision Rule" by Kim and Park is to terminate the CU partitioning process early, based on a Bayesian decision rule using joint online and offline learning. The paper "DCT Coefficient Distribution Modeling and Quality Dependency Analysis-Based Frame-Level Bit Allocation for HEVC" by Wu, Wei, Hui, and Xu optimizes frame-level bit allocation for improved coding efficiency and stable buffer control. Finally, the paper "Adaptive Fast Quadtree Level Decision Algorithm for H.264/HEVC Video Transcoding" by Díaz-Honrubia, Martínez, Cuenca, Gamez, and Puerta describes a way to transcode video from the current dominant format known as Advanced Video Coding (AVC) into the newer HEVC format—doing so in a way to substantially reduce computational complexity with a minimal degradation of compression performance.

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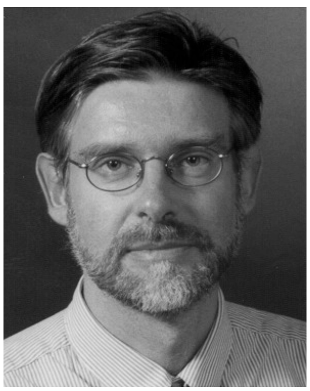
The next two papers show high-throughput software encoder and decoder implementations on multi-core processors. The paper "4K Real-Time and Parallel Software Video Decoder for Multilayer HEVC Extensions" by Hamidouche, Raulet, and Déforges describes a multi-layer HEVC decoder that is parallel friendly and supports both wavefront and frame-based parallelism techniques. The paper "A Novel Wavefront-Based High Parallel Solution for HEVC Encoding" by Chen, Sun, Duan, and Guo uses SIMD and wavefronts, across multiple frames to enable parallel encoding.

Finally, the last three papers present efficient ASIC implementation and FPGA hardware for HEVC encoders or decoders with a focus on efficient area/memory/resource utilization while delivering real-time high-resolution (Ultra-HD) processing. The paper "Merge Mode Estimation for a Hardware-Based HEVC Encoder" by Kim, Rhee, and Lee describes the implementation challenges involved in designing high-throughput motion estimation architectures for merge mode. Based on the study, it proposes a hardware engine in 65 nm that can do merge mode motion estimation for Ultra-HD 4K at 25 fps for P slices with a 366-MHz clock frequency. The paper "Algorithm and Architecture Design of the H.265/HEVC Intra Encoder" by Pastuszak and Abramowski proposes an efficient intra encoder in 65 nm that delivers Ultra-HD 4K at 30 fps while consuming 273 mW with only a 5% increase in bit rate for equal quality with the reference encoder. The paper "Lossless Frame Memory Compression Using Pixel-Grain Prediction and Dynamic Order Entropy Coding" by Lian, Liu, Zhou, and Duan describes a lossless reference frame compression implementation for an encoder that delivers 69% memory bandwidth compression and 57% reduction in DRAM power with compressor and decompressor throughputs of 1.5 and 0.8 Gpixels/s, respectively. The paper "4K Real-Time HEVC Decoder on FPGA" by Abeydeera, Karunaratne, Karunaratne, De Silva, and Pasqual demonstrates Ultra-HD 4K at 30 fps decoding implemented on a Zynq 7045 platform with a 150-MHz clock frequency.



Jens-Rainer Ohm (M'92) received the Dipl.-Ing., Dr.-Ing., and Habilitation degrees from Technical University of Berlin (TUB), Berlin, Germany, in 1985, 1990, and 1997, respectively.

He has been a Full Professor and the Chair of the Institute of Communication Engineering with RWTH Aachen University, Aachen, Germany, since 2000. He has authored German and English textbooks in multimedia signal processing, analysis, and coding, and the basics of communication engineering and signal transmission, and numerous papers in his research fields. His research interests include motion-compensated, stereoscopic, and 3D image processing, multimedia signal coding, transmission and content description, audio signal analysis, and fundamental topics of signal processing and digital communication systems.

Dr. Ohm has been participating in the work of the Moving Picture Experts Group (MPEG) since 1998. He has been the Chair and Co-Chair of various standardization activities in video coding, namely, the MPEG Video Subgroup since 2002, the Joint Video Team of MPEG and ITU-T SG 16 VCEG from 2005 to 2009, and currently, the JCT-VC as well as the JCT-3V.

Gary J. Sullivan (S'83–M'91–SM'01–F'06) received the B.S. and M.Eng. degrees in electrical engineering from University of Louisville, Louisville, KY, USA, in 1982 and 1983, respectively, and the Ph.D. and Engineering degrees in electrical engineering from University of California at Los Angeles, Los Angeles, CA, USA, in 1991.

He has been a longstanding Chairman or Co-Chairman of various video and image coding standardization activities in ITU-T VCEG and ISO/IEC MPEG and JPEG. He is best known for leading the development of the Advanced Video Coding (AVC) standard ITU-T H.264 | ISO/IEC 14496-10 and its several extensions. More recently, he led the development of the new High Efficiency Video Coding standard ITU-T H.265 | ISO/IEC 23008-2. He is a Video and Image Technology Architect with the Corporate Standardization Group, Microsoft Corporation, Redmond, WA, USA, where he has also been the Originator and Lead Designer of the DirectX Video Acceleration video decoding feature of the Microsoft Windows operating system.

Dr. Sullivan has received several awards from the IEEE and other organizations, including the 2012 IEEE Masaru Ibuka Consumer Electronics Award. He has been a Guest Editor of several special issues of IEEE TRANSACTIONS ON CIRCUITS AND SYSTEMS FOR VIDEO TECHNOLOGY He was a Co-Editor of the book *High Efficiency Video Coding (HEVC): Algorithms and Architectures* (Springer, 2014).

Vivienne Sze (M'10) received the B.A.Sc. (Hons.) degree from University of Toronto, Toronto, ON, Canada, in 2004, and the M.S. and Ph.D. degrees from Massachusetts Institute of Technology (MIT), Cambridge, MA, USA, in 2006 and 2010, respectively, all in electrical engineering.

She was a member of the Technical Staff with the Research and Development Center, Texas Instruments (TI), Dallas, TX, USA, where she designed low-power algorithms and architectures for video coding. She also represented TI at the international JCT-VC standardization body developing High Efficiency Video Coding (HEVC). Within the committee, she was the Primary Coordinator of the core experiment on coefficient scanning and coding, and was Chair/Vice-Chair of several *ad hoc* groups on entropy coding. She has been an Assistant Professor with the Electrical Engineering and Computer Science Department, MIT, since 2013. Her research interests include energy-aware signal processing algorithms, and low-power circuit and system design for portable multimedia applications.

Prof. Sze was a recipient of the 2014 DARPA Young Faculty Award and the 2007 DAC/ISSCC Student Design Contest Award, and a co-recipient of the 2008 A-SSCC Outstanding Design Award. She received the Jin-Au Kong Outstanding Doctoral Thesis Prize in Electrical Engineering at MIT in 2011. She was a Co-Editor of the book *High Efficiency Video Coding (HEVC): Algorithms and Architectures* (Springer, 2014).

Thomas Wiegand (M'05-SM'08-F'11) received the Dipl.-Ing. degree in electrical engineering from Technical University of Hamburg, Hamburg, Germany, in 1995 and the Dr.Ing. degree from University of Erlangen–Nuremberg, Erlangen, Germany, in 2000.

As a student, he was a Visiting Researcher with Kobe University, Kobe, Japan; University of California at Santa Barbara, Santa Barbara, CA, USA; and Stanford University, Stanford, CA, USA, where he also returned as a Visiting Professor. He was a Consultant to Skyfire, Inc., Mountain View, CA, USA. Since 2000, he has been an Associated Rapporteur of ITU-T VCEG and from 2005 to 2009, he was a Co-Chair of ISO/IEC MPEG Video. He is currently a Professor with the Department of Electrical Engineering and Computer Science, Technical University of Berlin, Berlin, Germany, and is jointly heading the Fraunhofer Heinrich Hertz Institute, Berlin. He is also a Consultant to Vidyo, Inc., Hackensack, NJ, USA.

Dr. Wiegand received various awards for his research in video coding and transmission, including the Vodafone Innovations Award, the Eduard Rhein Technology Award, the Karl Heinz Beckurts Award, and the IEEE Masaru Ibuka Technical Field Award. He has received several best paper awards for his publications. Thomson Reuters named him in their list of *The World's Most Influential Scientific Minds 2014* as one of the most cited researchers in his field. He was an Associate Editor for the IEEE TRANSACTIONS ON CIRCUITS AND SYSTEMS FOR VIDEO TECHNOLOGY from 2006 to 2010, and was a Guest Editor for three of its special issues (including the Special Issues on H.264/AVC and HEVC) and a prior special section.

Madhukar Budagavi (M'98–SM'06) received the B.E. degree in electronics engineering from National Institute of Technology, Trichy, India, in 1991; the M.S. degree in electrical engineering from Indian Institute of Science, Bangalore, India, in 1994; and the Ph.D. degree in electrical engineering from Texas A&M University, College Station, TX, USA, in 1998.

He was with the Embedded Processing Research and Development Center, Texas Instruments, Dallas, TX, USA from 1998 to 2014. He has been an active participant in the standardization of the High Efficiency Video Coding (HEVC) (ITU-T H.265 | ISO/IEC 23008-2) next-generation video coding standard by the JCT-VC committee of ITU-T and ISO/IEC. Within the JCT-VC committee, he has chaired and co-chaired technical subgroup activities on coding tools for HEVC, scalable HEVC, and the screen content coding HEVC. He is currently a Director and the Multimedia Standards Group Leader with the Standards Research Laboratory, Samsung Research America, Dallas, and represents Samsung in multimedia standards activities in ITU-T, ISO/IEC, UHD Alliance, and the Society of Motion Picture and Television Engineers. His experience includes research and development of compression algorithms, image and video processing, video codec system-on-chip architecture, embedded vision, 3D graphics, speech coding, and embedded software implementation and prototyping. He has authored several book chapters, and journal and conference papers. He was a Co-Editor of the book *High Efficiency Video Coding (HEVC): Algorithms and Architectures* (Springer, 2014).