Guest Editorial
Introduction to the Special Section on the VVC Standard

IN THIS Special Section of the IEEE TRANSACTIONS ON CIRCUITS AND SYSTEMS FOR VIDEO TECHNOLOGY, it is our honor to introduce the Versatile Video Coding (VVC) standard, the latest of the historic partnership collaborations between the International Telecommunication Union Telecommunication Standardization Sector (ITU-T), the International Organization for Standardization (ISO), and the International Electrotechnical Commission (IEC) in the field of video coding standardization.

The release of each new generation of international video coding standards has been a major event in the video community, unleashing economies of scale and driving the development of new devices and services, and this particular new standard has arrived at a crucial point in the history of technology and society.

Even before a global pandemic started in 2020 on a scale not experienced for a full century, which forced major changes to daily life in every society around the world, video usage had been on a steep upward trajectory continuously for many years and had become about 80% of Internet traffic. Strong growth in ultra-high definition (UHD), high dynamic range (HDR), security monitoring, and emerging immersive applications had commanded strong attention from the industry. Then came COVID-19, forcing people to move even more of their activities online. Video became central to learning and work, in addition to entertainment and socializing, as well as nontraditional areas including medical care, counseling, legal services, and court proceedings. The use of video for personal and business teleconferencing as well as home entertainment skyrocketed overnight, and the general growth of video traffic further accelerated, as compressed video applications were moved to the forefront of everyday life.

Despite the difficulties imposed by the sudden need to shift all face-to-face meetings of standardization groups to virtual meetings, the finalization of the VVC standard proceeded on schedule in the historic year of 2020, arriving to help meet these challenges.

Like its major predecessors, VVC has been developed jointly by the two largest international standardization organizations for video coding—the ITU-T Video Coding Experts Group (VCEG) and the ISO/IEC Moving Picture Experts Group (MPEG). The partnership is known as the Joint Video Experts Team (JVET), and the resulting VVC standard has been officially approved as ITU-T H.266 and ISO/IEC 23090-3 (MPEG-I Part 3). The core normative VVC specification is also accompanied by a new Versatile Supplemental Enhancement Information (VSEI) standard, referenced as ITU-T H.274 and ISO/IEC 23002-7, which generalizes the approach to handling supplemental data for broad and versatile applicability.

Like the three generations before it, namely, H.262/MPEG-2 Video, H.264/MPEG-4 AVC, and H.265/MPEG-H HEVC, VVC's main goal has been to address the massive yet ever-increasing bandwidth needed for video and the insatiable desire for improved quality and expanding usage. The fundamental requirement for VVC has been to improve coding efficiency—i.e., to provide a bit rate reduction over its H.265/HEVC predecessor for equivalent visual quality. Indeed, recent tests have demonstrated that VVC provides roughly a $2\times$ improvement in compression over HEVC—in other words, it reduces the necessary bit rate by about 50% for a given level of visual quality in typical consumer-application operation ranges. Considering that many applications are still using AVC, which HEVC had already surpassed by a similar amount of compression benefit, the value proposition posed by VVC in today's market is truly compelling.

Besides coding efficiency, as its name emphasizes, versatility is also a central design goal of VVC. A broad diversity of the latest application needs was considered in the development of the VVC standard. Application requirements that were strongly emphasized during its design included UHD, HDR, computer-generated and screen-captured content (e.g., for screen sharing), adaptive bit-rate streaming, 360^{o} immersive video, ultra-low-delay applications, and compressed-domain bitstream repurposing. These needs resulted in new coding tools and new high-level functionalities supported in the syntax. Furthermore, the finalized VVC standard includes profiles that support still picture coding, the coding of video in non-4:2:0 chroma formats, and multi-layer coding, e.g., for spatial, quality, and multi-view scalabilities.

This Special Section provides a comprehensive overview of the new standard and its key technical elements in a series of 11 invited articles to familiarize readers with the VVC standard.

Readers are introduced to the new VVC standard in [A1], with an overview of its target applications and key design elements, including the new coding tool features and high-level functionalities, and provides information about early implementations, conformance bitstreams, and some subjective and objective compression performance data.

Digital Object Identifier 10.1109/TCSVT.2021.3111712

1051-8215 © 2021 IEEE. Personal use is permitted, but republication/redistribution requires IEEE permission.
See https://www.ieee.org/publications/rights/index.html for more information.

A detailed analysis of the implementation complexity of VVC and the design features it provides to enable its use in low-cost, low-power products for widespread use with a variety of implementation architectures is provided in [A2].

The versatility of the VVC standard relies on the careful design of its high-level syntax to support a diverse set of application needs. This flexible syntax that provides the framework for the use of VVC in various applications is described in [A3].

Recognizing that the emerging usage of screen content coding has posed new challenges led to the development of new coding tool features that provide particular benefits for synthetic content rather than for camera-captured content. The design elements in VVC that are specifically customized to support the efficient coding of screen content are presented in [A4].

A further series of seven articles in this Special Section presents algorithmic features in VVC that embody its substantial advances over previous standards, emphasizing particular parts of its design. Collectively, these advanced algorithmic features combine to deliver the superior compression performance of VVC. These articles are organized according to the building blocks of VVC, which follow the well-known hybrid video coding structure:

1) Block partitioning [A5]
2) Intra prediction and mode coding [A6]
3) Motion vector coding and block merging [A7]
4) Subblock-based motion derivation and inter prediction refinement [A8]
5) Transforms [A9]
6) Quantization and entropy coding [A10]
7) In-loop filters [A11]

For more background information on the history of VVC, interested readers may refer to the prior Special Section of IEEE TRANSACTIONS ON CIRCUITS AND SYSTEMS FOR VIDEO TECHNOLOGY on the Joint Call for Proposals on Video Compression With Capability Beyond HEVC, which appeared in May 2020 and described contributions to the Joint Call for Proposals that launched the VVC project.

After completing the VVC version 1 specification on schedule, and despite the disruptions brought on by the pandemic, the JVET is now working to develop a version 2 of VVC, which will expand the operation range of the VVC standard with an enhanced design for higher bit-depth higher bit-rate applications, and with the specification of additional supplemental data. New work is also underway to explore coding technologies that could provide enhanced compression capability beyond VVC, including those based on deep-learning technology as well as approaches using more conventional signal processing techniques.

VVC is a major milestone in the history of video coding and its standardization. We are proud of the accomplishment of the JVET committee and its ITU-T and ISO/IEC parents in developing this important new standard. The credit for the work is entirely due to the great contributions by the participants.

Finally, we would also like to thank the Editor-in-Chief Feng Wu and the former Editor-in-Chief Shipeng Li for their support in guiding the development of this Special Section from its initial proposal to its final publication. Moreover, we are deeply indebted to the paper reviewers for their quick and insightful responses to the manuscripts submitted during the review process.

JILL M. BOYCE
Intel
Hillsboro, OR 97124 USA
e-mail: jill.boyce@intel.com

JIANLE CHEN
Qualcomm Technologies, Inc.
San Diego, CA 92121 USA
e-mail: cjianle@qti.qualcomm.com

SHAN LIU
Tencent
Palo Alto, CA 94306 USA
e-mail: shanl@tencent.com

JENS-RAINER OHM
Institute of Communications Engineering
RWTH Aachen University
52062 Aachen, Germany
e-mail: ohm@ient.rwth-aachen.de

GARY J. SULLIVAN
Microsoft Corporation
Redmond, WA 98052 USA
e-mail: garysull@microsoft.com

THOMAS WIEGAND
Fraunhofer Heinrich Hertz Institute
10587 Berlin, Germany
Technical University of Berlin
10587 Berlin, Germany
e-mail: thomas.wiegand@hhi.fraunhofer.de

YAN YE
Alibaba Group (U.S.) Inc.
Sunnyvale, CA 94085 USA
e-mail: yan.ye@alibaba-inc.com

WENWU ZHU
Department of Computer Science and Technology
Tsinghua University
Beijing 100084, China
e-mail: wwzhu@tsinghua.edu.cn

APPENDIX
RELATED ARTICLES

[A1] B. Bross *et al.*, "Overview of the versatile video coding (VVC) standard and its applications," *IEEE Trans. Circuits Syst. Video Technol.*, vol. 31, no. 10, pp. 3736–3764, Oct. 2021.
[A2] F. Bossen, K. Suhring, A. Wieckowski, and S. Liu, "VVC complexity and software implementation analysis," *IEEE Trans. Circuits Syst. Video Technol.*, vol. 31, no. 10, pp. 3765–3778, Oct. 2021.
[A3] Y.-K. Wang *et al.*, "The high-level syntax of the versatile video coding (VVC)," *IEEE Trans. Circuits Syst. Video Technol.*, vol. 31, no. 10, pp. 3779–3800, Oct. 2021.

[A4] T. Nguyen *et al.*, "Overview of the screen content support in VVC: Applications, coding tools, and performance," *IEEE Trans. Circuits Syst. Video Technol.*, vol. 31, no. 10, pp. 3801–3817, Oct. 2021.

[A5] Y.-W. Huang *et al.*, "Block partitioning structure in the VVC standard," *IEEE Trans. Circuits Syst. Video Technol.*, vol. 31, no. 10, pp. 3818–3833, Oct. 2021.

[A6] J. Pfaff *et al.*, "Intra prediction and mode coding in VVC," *IEEE Trans. Circuits Syst. Video Technol.*, vol. 31, no. 10, pp. 3834–3847, Oct. 2021.

[A7] W.-J. Chien *et al.*, "Motion vector coding and block merging in the versatile video coding standard," *IEEE Trans. Circuits Syst. Video Technol.*, vol. 31, no. 10, pp. 3848–3861, Oct. 2021.

[A8] H. Yang *et al.*, "Subblock-based motion derivation and inter prediction refinement in the versatile video coding standard," *IEEE Trans. Circuits Syst. Video Technol.*, vol. 31, no. 10, pp. 3862–3877, Oct. 2021.

[A9] X. Zhao *et al.*, "Transform coding in the VVC standard," *IEEE Trans. Circuits Syst. Video Technol.*, vol. 31, no. 10, pp. 3878–3890, Oct. 2021.

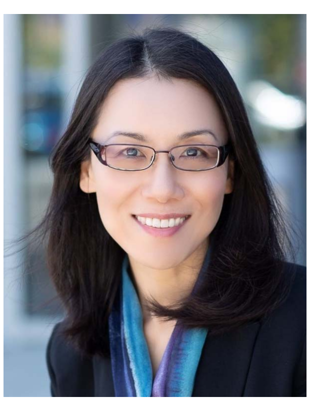
[A10] H. Schwarz *et al.*, "Quantization and entropy coding in the versatile video coding (VVC) standard," *IEEE Trans. Circuits Syst. Video Technol.*, vol. 31, no. 10, pp. 3891–3906, Oct. 2021.

[A11] M. Karczewicz *et al.*, "VVC in-loop filters," *IEEE Trans. Circuits Syst. Video Technol.*, vol. 31, no. 10, pp. 3907–3925, Oct. 2021.

Jill M. Boyce (Fellow, IEEE) received the B.S. degree in electrical engineering from the University of Kansas in 1988 and the M.S.E. degree in electrical engineering from Princeton University in 1990.

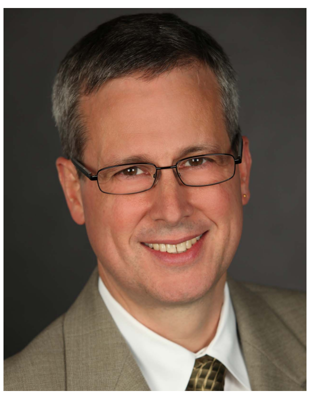
She was formerly the Director of Algorithms with Vidyo, Inc., where she led video and audio coding and processing algorithm development, formerly the VP of Research and Innovation with Princeton for Technicolor, formerly Thomson, and formerly with Lucent Technologies Bell Labs, AT&T Labs, and Hitachi America. She is currently the Intel Fellow and the Chief Media Architect with Intel, responsible for defining media hardware architectures for Intel's video hardware designs. She represents Intel at the Joint Video Exploration Team (JVET) of ITU-T SG16 and ISO/IEC MPEG. She has been an Associate Rapporteur of ITU-T VCEG since 2014. She is also an Editor of the VSEI Standard. She was an Associate Editor of IEEE TRANSACTIONS ON CIRCUITS AND SYSTEMS FOR VIDEO TECHNOLOGY from 2006 to 2010.

Jianle Chen (Senior Member, IEEE) received the B.S. and Ph.D. degrees from Zhejiang University, Hangzhou, China, in 2001 and 2006, respectively. He was formerly with Samsung Electronics Company Ltd., Qualcomm, Inc., San Diego, CA, USA, and Huawei Technologies USA Inc., focusing on the research of video technologies. Since 2006, he has been actively involved in the development of various video coding standards, including the HEVC standard, its scalable, format range and screen content coding extensions, and, most recently, the VVC standard in the Joint Video Experts Team (JVET). He has also been the main developer of the recursive partitioning structure with large block size, which is one of the key features of the HEVC standard and its potential successors. He is currently the Director of the Multimedia Research and Development Group, Qualcomm, Inc. His research interests include video coding and transmission, point cloud coding, AR/VR, and neural network compression. He was an Editor of the HEVC Specification version 2 (the scalable HEVC (SHVC) text specification) and SHVC Test Model. For VVC, he has been the Lead Editor of the Joint Exploration Test Model (JEM) and VVC Test Model (VTM). He is also an Editor of the VVC Text Specification.



Shan Liu (Senior Member, IEEE) received the B.Eng. degree in electronic engineering from Tsinghua University, and the M.S. and Ph.D. degrees in electrical engineering from the University of Southern California. She was formerly the Director of the Media Technology Division, MediaTek USA Inc. She was also formerly with MERL and Sony, etc. She is currently a Distinguished Scientist with Tencent and the General Manager of Tencent Media Laboratory. Her research interests include audio–visual, volumetric, immersive, and emerging media compression, intelligence, transport, and systems. She received its Best AE Award in 2019 and 2020. She has been a Vice Chair of the IEEE Data Compression Standards Committee since 2019. She has been an active contributor to international standards for more than a decade and has numerous technical proposals adopted into various standards, such as VVC, HEVC, OMAF, DASH, MMT, and PCC. She was an Editor of the H.265/HEVC screen content coding extension and the H.266/VVC standard. She has also been heavily involved in multimedia technology productization and made instrumental contributions to several million-user products. She has served on the Committee of Industrial Relationship for the IEEE Signal Processing Society from 2014 to 2015. She has been an Associate Editor of IEEE TRANSACTIONS ON CIRCUITS AND SYSTEMS FOR VIDEO TECHNOLOGY since 2018.

Jens-Rainer Ohm (Member, IEEE) has been holding the Chair position with the Institute of Communication Engineering, RWTH Aachen University, Aachen, Germany, since 2000. He is currently the Dean of the Faculty of Electrical Engineering and Information Technology, RWTH Aachen University. He has authored textbooks on multimedia signal processing, analysis, and coding on communication engineering and signal transmission, and numerous articles in these fields. His research interests include multimedia signal processing, analysis, compression, transmission, and content description, including 3D and VR video applications, biosignal processing and communication, application of deep-learning approaches in the given fields, and fundamental topics of signal processing and digital communication systems. Since 1998, he has been participating in the work of the Moving Picture Experts Group (MPEG). He has been chairing/co-chairing various standardization activities in video coding, namely, the MPEG Video Subgroup from 2002 to 2018, the Joint Video Team (JVT) of MPEG and ITU-T SG 16 VCEG from 2005 to 2009, the Joint Collaborative Team on Video Coding (JCT-VC) from 2010 to 2020, and the Joint Collaborative Team on 3D Video Coding Extension Development from 2012 to 2016. He is also chairing ISO/IEC JTC1/SC29/WG5, also known as the Joint Video Experts Team (JVET), in collaboration with ITU-T SG16/Q6. He has served on the editorial boards of several journals and the program committees of various conferences in the related fields.



Gary J. Sullivan (Fellow, IEEE) received the B.S. and M.Eng. degrees from the University of Louisville in 1982 and 1983, respectively, and the Ph.D. degree from the University of California at Los Angeles, Los Angeles, CA, USA, in 1991.

He is currently a Video and Image Technology Architect with Microsoft Research. He is also a fellow of SPIE. He has received the IEEE Masaru Ibuka Consumer Electronics Award, the IEEE Consumer Electronics Engineering Excellence Award, two IEEE TRANSACTIONS ON CIRCUITS AND SYSTEMS FOR VIDEO TECHNOLOGY Best Paper Awards, and the SMPTE Digital Processing Medal. The team efforts that he has led have been recognized by three Emmy Awards. He has been a longstanding Chairman/Co-Chairman of various video and image coding standardization activities in ITU-T VCEG, ISO/IEC MPEG, ISO/IEC JPEG, and in their joint collaborative teams since 1996. He has led the development of the Advanced Video Coding (AVC) standard (ITU-T H.264 | ISO/IEC 14496-10), the High Efficiency Video Coding (HEVC) standard (ITU-T H.265 | ISO/IEC 23008-2), the Versatile Video Coding (VVC) standard (ITU-T H.266 | ISO/IEC 23090-3), and various other projects. At Microsoft, he has been the originator and lead designer of the DirectX Video Acceleration (DXVA) video decoding feature of the Microsoft Windows operating system.

Thomas Wiegand (Fellow, IEEE) received the Dipl.-Ing. degree in electrical engineering from the Technical University of Hamburg, Harburg, Germany, in 1995, and the Dr. Ing. degree from the University of Erlangen–Nuremberg, Germany, in 2000. He is currently a Professor with the Department of Electrical Engineering and Computer Science, Technical University of Berlin. He is jointly heading Fraunhofer Heinrich Hertz Institute, Berlin, Germany.

Since 1995, he has been an active participant in the standardization of multimedia in ITU-T and ISO/IEC. In 2000, he was appointed as the Associated Rapporteur of ITU-T VCEG, and from 2005 to 2009, he was the Co-Chair of ISO/IEC MPEG Video. Since 2018, he has been the Chair of the ITU/WHO Focus Group on Artificial Intelligence for Health. The projects that he co-chaired for the development of the H.264/MPEG-4 AVC standard have been recognized by the ATAS Primetime Emmy Engineering Award and a pair of NATAS Technology and Engineering Emmy Awards. For his research, he has received various awards, including multiple best paper awards. Thomson Reuters named him in their yearly list of The World's Most Influential Scientific Minds as one of the most-cited researchers in his field. He has been elected to the German National Academy of Engineering (Acatech) and the National Academy of Science (Leopoldina).

Yan Ye (Senior Member, IEEE) received the B.S. and M.S. degrees in electrical engineering from the University of Science and Technology of China in 1994 and 1997, respectively, and the Ph.D. degree in electrical engineering from the University of California at San Diego, San Diego, CA, USA, in 2002. She is currently the Head of video standards and implementations with Alibaba Cloud Intelligence, Alibaba Group, Sunnyvale, CA, USA, where she oversees multimedia standards development, hardware and software video codec implementations, and AI-based video research. Prior to Alibaba, she was with the Research and Development Laboratories, InterDigital Communications, Image Technology Research, Dolby Laboratories, and Multimedia Research and Development and Standards, Qualcomm. She has been involved in the development of various video coding and streaming standards, including H.266/VVC, H.265/HEVC, scalable extension of H.264/MPEG-4 AVC, MPEG DASH, and MPEG OMAF. She is an inventor of more than 100 granted U.S. patents. She has published more than 50 articles in peer-reviewed journals and conferences. Her research interests include advanced video coding, processing, and streaming algorithms, real-time and immersive video communications, AR/VR, and deep-learning-based video coding, processing, and quality assessment. She is also an Editor of the VVC Test Model and the 360Lib algorithm description and was previously the Co-Editor of the scalable extension and the screen content coding extension of the HEVC standard.

Wenwu Zhu (Fellow, IEEE) received the Ph.D. degree from New York University, New York, NY, USA, in 1996. He is currently a Professor and the Vice Chair of the Department of Computer Science and Technology, Tsinghua University, Beijing, China, the Vice Dean of National Research Center for Information Science and Technology, and the Vice Director of Tsinghua Center for Big Data. Prior to his current post, he was a Senior Researcher and a Research Manager with Microsoft Research Asia. He was the Chief Scientist and the Director with Intel Research China from 2004 to 2008. He worked with Bell Labs, Murray Hill, NJ, USA, as a Member of Technical Staff from 1996 to 1999. He has authored or coauthored more than 350 referred articles. He is an inventor or co-inventor of more than 50 patents. His current research interests include data-driven multimedia networking and cross-media big data computing. He is also a fellow of AAAS and SPIE. He is also a member of The Academy of Europe (Academia Europaea). He received eight Best Paper Awards, including the ACM Multimedia 2012 and IEEE TRANSACTIONS ON CIRCUITS AND SYSTEMS FOR VIDEO TECHNOLOGY in 2001 and 2019. He has served as a General Co-Chair for ACM Multimedia 2018 and ACM CIKM 2019. He has also served as the Editor-in-Chief for the IEEE TRANSACTIONS ON MULTIMEDIA. He has also served in the Steering Committee for IEEE TRANSACTIONS ON MULTIMEDIA from 2015 to 2016 and IEEE TRANSACTIONS ON MOBILE COMPUTING from 2007 to 2010.