Introduction to the Special Section on Visual Computing in the Cloud: Fundamentals and Applications

CLOUD computing involves a large number of terminals connected through a real-time high-speed network (such as the Internet). The adoption rates for private and hybrid cloud services increased to 40% in 2013, with computing shifting from on-premise infrastructure to the cloud. To keep pace with the ever-accelerating rate of innovation, companies are moving to the cloud. However, visual computing in the cloud brings great challenges, such as how to measure and then improve the quality of experience in cloud computing. This Special Section provides the image/video community a forum to present new academic research and industrial development in running visual computing services in the cloud. This Special Section aims to address fundamental and practical aspects of visual computing in the cloud, such as how to build cloud platforms that can cope with seemingly unlimited supply of content coming from traditional media sources as well as new media uploaded to the Internet (YouTube, Facebook, etc.); how to leverage cloud technology to build high-quality image/video browsing and delivery experiences for a global audience; how to ingest, encode, process, adapt, as well as protect contents and privacy of users; how to provide both on-demand and live-streaming capabilities; how to tag image/video and allow consumers to access the image/video contents with high availability; how to support image/video services in mobile devices; and how to perform real-time image/video analytics in the cloud, to mention a few among a diverse range of challenges.

We received 25 submissions for this Special Section, and after careful review by a group of experts in the field, we selected five papers for the first round. These papers were thoroughly revised by the authors and underwent a second round of review to ensure that they met the standard of IEEE TRANSACTIONS ON CIRCUITS AND SYSTEMS FOR VIDEO TECHNOLOGY. These papers cover a wide range of topics in the fundamentals and applications of visual computing in the cloud.

The first paper, "Specific Versus Diverse Computing in Media Cloud" by L. Zhou, examines the choice of specific computing (SC) and diverse computing (DC), two main visual computation manners that have been widely utilized in the media cloud. The paper analytically studies the characteristics of SC and DC by designing a so-called collapsing approximation method to precisely approximate the distribution of the service dynamics. It demonstrates that the optimal computing configuration should largely depend on SC and a little on DC.

To address the heterogeneity challenges in complex systems, the second paper, entitled "CHCF: A Cloud-Based Heterogeneous Computing Framework for Large-Scale Image Retrieval" by H. Wang *et al.*, develops a novel framework, namely, cloud-based heterogeneous computing framework (CHCF), with a set of tools and techniques for compilation, optimization, and execution of multimedia mining applications on heterogeneous systems. With the aid of the compiler and the utility library provided by CHCF, users are able to develop multimedia mining applications rapidly and efficiently.

The third paper, "Optimal Transcoding and Caching for Adaptive Streaming in Media Cloud: An Analytical Approach" by Y. Jin *et al.*, investigates the three-way trade-off between caching, transcoding, and bandwidth cost at each edge server of a media cloud, used for on-demand adaptive video streaming. An optimization model is established to pursue optimal dynamic scheduling of multiple resources for total operational cost minimization in the media cloud. A two-step approach is proposed to analytically derive the closed-form solution for optimal transcoding configuration and caching space allocation at every edge server. Extensive simulations show the effects of a set of control knobs (system parameters), such as unit resource cost and hop distance to the origin server, as well as demonstrate significant cost savings compared with methods used in existing content delivery networks.

Cloud computing grows together with social networking and mobile computing, and visual objects are among the most demanding contents in storage, transmission, and processing. The fourth paper, "Cloud-Based Distributed Image Coding" by X. Song *et al.*, investigates the problem that there is a lot of redundancy among similar images on social networks. In particular, it targets reducing the client-side image uploading bandwidths by using distributed source coding to exploit external correlations with similar images in the cloud. Up to 5-dB gains and 70% bits saving are achieved over JPEG on landmark images.

The last paper, "MoVieUp: Automatic Mobile Video Mashup" by Y. Wu *et al.*, addresses the challenges in mobile cloud computing. It presents a fully automatic mobile video mashup system that works in the cloud to combine recordings captured by multiple devices from different view angles and at different time slots into a single yet enriched and professional-looking video–audio stream. It summarizes a set of computational filming principles for multicamera settings from a formal focus study. Based on these principles, given a set of recordings of the same event, the system is able to

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synchronize these recordings with audio fingerprints, assess audio and video quality, detect video cut points, and generate video and audio mashups. Evaluations show that the system achieves performance results that are superior to state-of-the-art video mashup techniques, thus providing a better user experience.

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Dr. Liu was a co-recipient of the Inaugural Test of Time Paper Award from the IEEE INFOCOM in 2015, the ACM TOMCCAP Nicolas D. Georganas Best Paper Award in 2013, the ACM Multimedia Best Paper Award in 2012, the IEEE GLOBECOM Best Paper Award in 2011, and the IEEE Communications Society Best Paper Award on Multimedia Communications in 2009. He has served on the Editorial Boards of IEEE TRANSACTIONS ON BIG DATA, IEEE TRANSACTIONS ON MULTIMEDIA, IEEE COMMUNICATIONS SURVEYS AND TUTORIALS, IEEE ACCESS, IEEE INTERNET OF THINGS JOURNAL, *Computer Communications* (Elsevier), and *Wireless Communications and Mobile Computing* (Wiley).

Wenwu Zhu (M'97–SM'01–F'10) received the Ph.D. degree in electrical and computer engineering from New York University Polytechnic School of Engineering, Brooklyn, NY, USA, in 1996.

He was a Senior Researcher and Research Manager with Microsoft Research Asia, Beijing, China. He was the Chief Scientist and Director of Intel Research China, Beijing, from 2004 to 2008. He was with Bell Laboratories, Murray Hill, NJ, USA, from 1996 to 1999, as a member of the Technical Staff. He is currently a Professor and the Deputy Head of the Computer Science Department with Tsinghua University, Beijing. He has authored over 200 referred papers in multimedia computing, communications, and networking. He holds over 50 patents. His research interests include multimedia big data computing, social multimedia computing, multimedia cloud computing, and multimedia communications and networking.

Dr. Zhu is a fellow of the International Society for Optics and Photonics and an ACM Distinguished Scientist. He received six best paper awards, including the ACM Multimedia in 2012 and IEEE TRANSACTIONS ON CIRCUITS AND SYSTEMS FOR VIDEO TECHNOLOGY in 2001. He served on various editorial boards, including as a Guest Editor of PROCEEDINGS OF THE IEEE, IEEE TRANSACTIONS ON CIRCUITS AND SYSTEMS FOR VIDEO TECHNOLOGY, and IEEE JOURNAL ON SELECTED AREAS IN COMMUNICATIONS; and an Associate Editor of IEEE TRANSACTIONS ON MOBILE COMPUTING, IEEE TRANSACTIONS ON MULTIMEDIA, IEEE TRANSACTIONS ON CIRCUITS AND SYSTEMS FOR VIDEO TECHNOLOGY, and IEEE TRANSACTIONS ON BIG DATA.

Touradj Ebrahimi received the M.Sc. and Ph.D. degrees in electrical engineering from Swiss Federal Institute of Technology (EPFL), Lausanne, Switzerland, in 1989 and 1992, respectively.

He was a Research Engineer with Corporate Research Laboratories, Sony Corporation, Tokyo, Japan, in 1993. He served as a Research Consultant with AT&T Bell Laboratories, Murray Hill, NJ, USA, where he was involved in very low bit-rate video coding. He was also an Adjunct Professor with Norwegian University of Science and Technology, Trondheim, Norway, from 2008 to 2012. He has initiated more than 24 national, European, and international cooperation projects, and founded three startup companies. He is currently a Professor with EPFL, where he is heading the Multimedia Signal Processing Group. He is the Head of the Swiss Delegation to MPEG, JPEG, and SC29, and acts as the Chairman of the Advisory Group on Management in SC29. He has authored or co-authored over 200 research publications, and holds 14 patents. His research interests include still, moving, and 3-D image processing and coding, visual information security (rights protection, watermarking, authentication, data integrity, and steganography), new media, and human–computer interfaces (smart vision and brain–computer interface).

Dr. Ebrahimi is a fellow of the International Society for Optics and Photonics. He received the IEEE and Swiss National ASE Award, the SNF-PROFILE Grant for advanced researchers, four ISO-Certificates for key contributions to MPEG-4 and JPEG 2000, and the best paper award of IEEE TRANSACTIONS ON CONSUMER ELECTRONICS. He is or has been an Associate Editor of various IEEE, SPIE, and EURASIP journals, such as *IEEE Signal Processing Magazine*, IEEE TRANSACTIONS ON IMAGE PROCESSING, and IEEE TRANSACTIONS ON MULTIMEDIA. He is a member of the Scientific Advisory Board of various start-up and established companies, and served as a Scientific Expert and an Evaluator for Research Funding Agencies.

John Apostolopoulos (S'91-–M'97-–SM'06—F'08) received the B.S., M.S., and Ph.D. degrees from the Massachusetts Institute of Technology (MIT), Cambridge, MA, USA.

He is the VP/CTO of Cisco's Enterprise Segment, where he drives the technology and architectural direction for Cisco's efforts in the enterprise space. He also leads Innovation Labs, whose mission is to drive technology innovations aligned with Cisco's strategic directions. This covers the broad Cisco portfolio including the Internet of Things (IoT), enterprise mobility/BYOD, software defined networking (SDN), and SDN-empowered applications, such as collaboration and security, video over wired/wireless networks, and network analytics. In addition, he co-leads Cisco's next-generation Enterprise Architecture effort. Prior to joining Cisco, he was the Lab Director for the Mobile and Immersive Experience Lab, HP Labs. His work spanned novel mobile devices and sensing, client/cloud multimedia computing, multimedia networking, signal processing, immersive video conferencing, secure streaming and secure transcoding, SDN, and mobile streaming media content delivery networks for all-IP wireless networks. He was a Consulting Associate Professor of EE at Stanford (2000–2009) and is a frequent visiting lecturer at MIT.

Dr. Apostolopoulos received a number of honors and awards, including the IEEE SPS Distinguished Lecturer, was named one of the world's top 100 young (under 35) innovators in science and technology (TR100) by MIT Technology Review, received the Certificate of Honor for contributing to the U.S. Digital TV Standard (Engineering Emmy Award 1997), and received ISO/IEC recognition for contributions on mid-network transcoding while preserving end-to-end security (secure transcoding) to the JPSEC standard. He has published over 100 papers, including receiving five best paper awards, and has about 65 granted U.S. patents.

Xian-Sheng Hua received the B.S. and Ph.D. degrees in applied mathematics from Peking University, Beijing, China, in 1996 and 2001, respectively.

He became a Researcher and the Senior Director of Alibaba Group, Hangzhou, China, in 2015, leading the multimedia technology team with the Search Division. He joined Microsoft Research Asia, Beijing, in 2001, as a Researcher. He has been a Senior Researcher with Microsoft Research Redmond, Redmond, WA, USA, since 2013. He has been a Principal Research and Development Leader with Multimedia Search for the Microsoft search engine, Bing, since 2011. He has authored or co-authored over 250 research papers in his research areas and holds over 90 patents. His research interests include multimedia search, advertising, understanding, and mining, and pattern recognition and machine learning.

Dr. Hua was honored as one of the recipients of the 2008 MIT Technology Review TR35 Young Innovator Award. He received the Best Paper and Best Demonstration Awards at ACM Multimedia in 2007, the Best Poster Award at the IEEE International Workshop on Multimedia Signal Processing in 2008, the best paper award of IEEE TRANSACTIONS ON CIRCUITS AND SYSTEMS FOR VIDEO TECHNOLOGY in 2014, and a number of other best paper/demo awards. He was named one of Global Entrepreneur's "Business Elites of People Under 40 to Watch" in 2009. He served or serves as an Associate Editor of IEEE TRANSACTIONS ON MULTIMEDIA and an Associate Editor of *ACM Transactions on Intelligent Systems and Technology*. He served as the Program Co-Chair of the IEEE International Conference on Multimedia and Expo (ICME) in 2013, the ACM Multimedia in 2012, and the IEEE ICME in 2012, and on the Technical Directions Board of the IEEE Signal Processing Society.

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Dr. Wu is a member of the Association for Computing Machinery, and served as the Chair of the Interest Group on Multimedia Services and Applications over Emerging Networks of the IEEE Multimedia Communication Technical Committee from 2012 to 2014. She was a co-recipient of the best paper award from HotPOST in 2012. She has served as a TPC Member and Reviewer for international conferences and journals, including the IEEE International Conference on Computer Communications, the IEEE International Conference on Distributed Computing Systems, the ACM Multimedia, IEEE TRANSACTIONS ON PARALLEL AND DISTRIBUTED SYSTEMS, IEEE TRANSACTIONS ON NETWORKING, and IEEE TRANSACTIONS ON MULTIMEDIA.