

Multimedia Signal Processing: A history of the Multimedia Signal Processing Technical Committee

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Technological developments in the 1980's laid the foundation for the modern multimedia industry. The first compact disc (CD) appeared on the market in 1982 [1]. Personal computers gradually became more affordable throughout the decade and made their way to many homes. Video games, whose first prototypes appeared a few decades earlier, reached the level of popularity that made the gaming industry a notable segment of the tech sector. The first digital video coding standards H.120 [2] and H.261 [3], and the first media platform World Wide Web (WWW, or simply the Web) [4] were developed in the 1980's, setting the stage for subsequent technological breakthroughs. To help the reader navigate the article, Table 1 gives a list of acronyms and their definitions, while Table 2 summarizes the multimedia standards mentioned in the text.

Table 1: Acronyms and their definitions in alphabetical order	
Acronym	Definition
AAC	Advanced Audio Coding
AOM	Alliance for Open Media
AVC	Advanced Video Coding
CD	Compact Disc
CDVS	Compact Descriptors for Visual Search
DASH	Dynamic Adaptive Streaming over HTTP
DVD	Digital Video Disc
GSM	Global System for Mobile communications
HDTV	High-Definition Television
HEVC	High-Efficiency Video Coding
HTTP	HyperText Transfer Protocol
ICME	International Conference on Multimedia & Expo
JPEG	Joint Photographic Experts Group
LiDAR	Light Detection And Ranging

MMS	Multimedia Messaging Service
MP3	MPEG-1 Audio Layer III
MPEG	Moving Picture Experts Group
MVC	Multiview Video Coding
P2P	Peer-to-Peer communications
PCC	Point Cloud Compression
RGB+D	Red, Green, Blue plus Depth
SMS	Short Message Service
VCM	Video Coding for Machines
VVC	Versatile Video Coding
WWW	World Wide Web

Table 2: Select multimedia standards in chronological order of their release

Standard	Description	Initial release
H.120	First digital video coding standard	1984
H.261	Video coding standard, targeted mainly at video telephony	1988
JPEG	First digital image coding standard; JPEG stands for Joint Photographic Experts Group	1992
MPEG-1	Audiovisual coding standard; MPEG stands for Motion Picture Experts Group	1992
MPEG-2	Audiovisual coding standard	1996
MPEG-2 Part 2 (H.262)	Video coding standard	1996
MPEG-4	Audiovisual coding standard	1999
JPEG2000	A wavelet-based image coding standard	2000
MPEG-4 Part 10 (H.264/AVC)	Video coding standard	2004
MVC	Multiview Video Coding, amendment to MPEG-4	2009

	Part 10 (H.264/AVC)	
MPEG-DASH	MPEG Dynamic Adaptive Streaming over HTTP, a video streaming standard	2011
MPEG-H Part 2 (H.265/HEVC)	Video coding standard	2013
3D-HEVC	HEVC-based coding standard for 3D video	2015
HEVC-SCC	HEVC-based coding standard for screen content video	2016
MPEG-I Part 3 (H.266/VVC)	Video coding standard	2020
MPEG-PCC	Point cloud compression standard	2020
MPEG-7 Part 17	A standard for compression of neural network models	2021

## Developments in the last three decades

### The 1990's

The 1990's were the decade of great milestones for digital multimedia. The Web was publicly released in 1991. As the first platform that enabled world-wide sharing of multimedia documents, combining text, images, graphics, audio, and video, it has since transformed the way we work, learn, shop, travel, keep in touch, and virtually all other aspects of our lives. Another pivotal event in 1991 was the launch of the 2<sup>nd</sup> generation (2G) cellular communications based on the Global System for Mobile communications (GSM) standard in Finland. Besides voice communications, 2G systems enabled Short Message Service (SMS) text messages, which later evolved to Multimedia Messaging Service (MMS) messages and laid the foundation for the myriad of today's messaging services. Cellular communications have had an equally transformational effect on our lives, providing the infrastructure over which much of today's multimedia content is being shared.

## Multimedia Signal Processing

- 1980's: First digital media standards (CD, H.120, H.261) and WWW
- 1991: WWW open to public, 2G (GSM) cellular communications
- 1992: JPEG, MPEG-1, MP3
- 1993: First movie streaming and first live streaming over the Internet
- 1996: MPEG-2/H.262
- 1997: Commercial on-demand streaming (VXtreme and RealNetworks)
- 1998: Digital terrestrial TV
- 1999: MPEG-4
- 2000: JPEG2000
- 2001: 3G cellular communications
- 2002: ABR over HTTP
- 2004: MPEG-4 AVC/H.264
- 2005: YouTube launched
- 2006: Amazon Unbox launched  
Google buys YouTube
- 2007: Netflix & Hulu streaming
- 2009: First 4G cellular service launched in Norway and Sweden
- 2009: Apple introduces HTTP Live Streaming; also Multi-View Coding (MVC) extension of H.264/AVC released
- 2011: MPEG-DASH
- 2012: AlexNet wins ILSVRC
- 2013: HEVC
- 2014: Amazon Echo launched
- 2015: IMT-2020 standard requirements for 5G communications
- 2016: HEVC-SCC
- 2018: Waymo launches first fully autonomous taxi service in Phoenix, AZ
- 2020: VVC and MPEG-PCC
- 2021: MPEG-7 part 17: Neural network compression

## Multimedia Signal Processing Technical Committee

- 1996: MMSP TC formed
- 1997: 1<sup>st</sup> MMSP Workshop (Princeton, NJ)
- 1998: 2<sup>nd</sup> MMSP Workshop (Redondo Beach, CA)
- 1999: IEEE Transactions on Multimedia launched
- 2000: First ICME conference (New York, NY)
- 2001: MMSP (Cannes, Fra.)
- 2002: ICME (Lausanne)
- 2003: ICME (Baltimore)
- 2004: MMSP (Siena, Italy)
- 2005: ICME (Amsterdam)
- 2006: MMSP (Victoria, BC)
- 2007: ICME (Beijing)
- 2008: MMSP (Cairns, Australia), ICME (Hannover)
- 2009: MMSP (Rio de Janeiro)  
ICME (New York)
- 2010: ICME introduces double-blind review, 15% acceptance for orals, 30% overall
- 2013: ICME (San Jose, CA)
- 2014: MMSP (Banff, AB)  
ICME (Chengdu)
- 2015: MMSP (Xiamen)  
ICME (Turin, Italy)
- 2017: MMSP (Luton, UK)  
ICME (Hong Kong)
- 2019: MMSP (Kuala Lumpur)  
ICME (Shanghai)
- 2020: First virtual ICME and MMSP Workshop



Figure 1: Multimedia signal processing timeline

The first widely-used multimedia standards were released in 1992. The Joint Photographic Experts Group (JPEG) published part 1 of the JPEG image coding standard [5], the most popular image coding standard to date. The Moving Picture Experts Group (MPEG) issued MPEG-1 [6], the audio-visual coding standard that formed the basis of Video CD and early digital cable and satellite TV. The standard also introduced MPEG-1 Audio Layer III [7], more commonly known as MP3 - a widely popular audio format for music sharing.

1993 was a big year for video streaming. On May 22, the movie called “Wax or the Discovery of Television Among the Bees” became the first movie to be streamed online, at half the standard definition resolution and the frame rate of only two frames per second. The first live streaming over the Internet occurred on June 24, 1993. This was a performance by the band called Severe Tire Damage, streamed from the Xerox Palo Alto Research Center [9]. The video resolution was only 152×76, the frame rate only 8-12 frames per second, and the audio quality no better than a telephone call, but it could be seen as far as Australia [10]. It was a historic event that demonstrated the potential of streaming technology and stimulated much research and development in the decades to follow. Propelled by this success, Severe Tire Damage opened for the Rolling Stones in the second live streaming of a musical event over the Internet on November 18, 1994 [11].

In 1994, DirecTV launched the first commercial digital satellite TV service in the US. This marked the beginning of the transition of TV from analog to digital, which will continue with the introduction of digital cable TV in 1996, and digital terrestrial TV in 1998. MPEG-2 was released in 1996 [6]. It was a very popular coding standard that was used in Digital Video Discs (DVDs), digital TV and High-Definition TV (HDTV). Its Part 7, Advanced Audio Coding (AAC), was released in 1997.

As the Internet reached more users through the 1990's, with increased capacity and higher bit rates, the battle for streaming over the Internet would heat up, especially in the second part of the decade [12]. The big players in this area were Progressive Networks (which became RealNetworks in 1997) and Microsoft, along with a number of startups including Vivo, Xing, VDOnet and VXtreme. Among them, they are responsible for a number of firsts, including the first audio streaming service (RealAudio, 1995), first live audio webcast of a sports game (Seattle Mariners vs. New York Yankees, RealNetworks, 1995), first commercial on-demand video streaming (RealNetworks and VXtreme, 1997), as well as the most popular media players of the time.

Amidst all these developments, the Multimedia Signal Processing Technical Committee (MMSP TC) was formed in 1996, under the leadership of the first TC Chair, Tsuhan Chen. The TC organized its first workshop, the MMSP Workshop, in June 1997 in Princeton, NJ. The Workshop attracted 95 papers, including eight demonstrations. The next two Workshops were held in Redondo Beach, CA, (1998) and Copenhagen, Denmark (1999). The second TC Chair (1999-2001) was K. J. Ray Liu, the 2022 IEEE President.

Owing to the interdisciplinary nature of multimedia, MMSP TC has collaborated with other TCs within the IEEE Signal Processing Society and other IEEE Societies since its inception. A notable result of such collaboration was the launch of the IEEE Transactions on Multimedia in 1999. With an impact factor of 8.18, the journal is now considered among the top publication venues in the field of multimedia.

## **The 2000's**

If the 1990's demonstrated the potential of multimedia technologies, the 2000's were the decade when the technology reached the level of maturity that made it not only commercially viable, but highly successful. This was aided by the development of 3<sup>rd</sup> generation (3G) cellular



communications, first commercially launched in 2001 by NTT DoCoMo in Japan. In addition, new ideas emerged both from industry and academia. One of these ideas was peer-to-peer (P2P) file sharing, pioneered by Napster.

Napster initially launched in 1999 and quickly became a very popular platform for MP3 audio file sharing, especially among college students. It was soon sued over copyright infringement [13] and had to shut down in 2001. Despite its brief existence, Napster left a lasting legacy in the multimedia world. Its P2P distribution paradigm generated enormous interest in the research community and became popular not only as a way to share files, but also in media streaming. At the same time, the music industry saw the potential for distributing content in digital form without physical media, which laid the foundation for subsequent online music stores such as iTunes and products such as iPod.

At the turn of the millennium, MMSP TC was also busy launching new initiatives. The International Conference on Multimedia and Expo (ICME) was launched as a collaboration with the sister TCs in the IEEE Circuits and Systems, Communications, and Computer Societies. The first edition of the conference was held in New York in July-August 2000, and attracted over 400 papers. Since then, ICME has established itself as a flagship IEEE conference in the field of multimedia: it has a rank of A according to the Australian CORE rankings and is among top 10 venues (among both journals and conferences) in the field of multimedia, according to Google Scholar metrics.

An important milestone at the turn of the millennium was the standardization of JPEG2000 [14]. This was the first coding standard based on wavelets [15]. JPEG2000 introduced tools for resolution- and quality-scalable coding and decoding, Region-of-Interest (RoI) coding, precise rate control, and a number of other features that made it suitable for high-quality imaging applications. A related image coding approach called ICER is used for encoding and sending back images from the Mars rovers [16]. In 2004, Motion JPEG2000, an extension of JPEG2000 to video, was adopted for Digital Cinema applications in the film industry.

Another major milestone was the development of the MPEG-4 Part 10 video coding standard, better known as H.264/AVC [17] in 2003. One of the main motivations behind H.264/AVC was to support various network-based video services, such as video streaming to heterogeneous clients. Hence, scalability also played an important role, and was materialized through the scalable extension of H.264/AVC [18], which enabled video coding and decoding at a number of resolutions, frame rates, and qualities to support a wide variety of client devices. H.264/AVC is used in Blu-ray discs and is still the most common format in online video streaming.

Although online video existed in various forms even in the 1990's, the first major video streaming service - YouTube - was launched in 2005, fueled by the development of H.264/AVC. YouTube allowed users to upload their own videos, which could then be searched and streamed to a wide audience. This quickly made YouTube very popular, leading to its purchase by Google for \$1.65 Billion in 2006, less than a year after its official launch. Commercial streaming services appeared around the same time. Amazon Unbox (now Amazon Prime video) launched in 2006, followed by Netflix and Hulu streaming services in 2007. As the customers' home Internet service speeds improved, the popularity of streaming services grew, and streaming now accounts for more viewing time than cable TV in the US market. These streaming services, and many more that have followed since, became successful businesses, some even launching their own production studios to create exclusive content.

While certain forms of online games existed as far back as the 1970s, the era of massively multiplayer online gaming started in 2000's with the wider availability of fast Internet service. Gaming consoles such as Microsoft Xbox, Sony PlayStation, Nintendo, and Wii gradually became more popular, interfacing with cloud gaming platforms like Xbox Live and PlayStation Network. Increased interactivity in games and consoles' specialized hardware also incentivised the development of more sophisticated game controllers like Microsoft Kinect, which would have a major impact on both gaming and multimedia signal processing research in the following decade.

The 2000's also saw the birth of social media, with the founding of LinkedIn in 2002, Facebook in 2004, and Twitter in 2006. A phenomenon that took the world by storm, social media allowed users to upload their own media content and share it with a circle of friends, or a wider audience. Social media has since transformed marketing and market research, recruitment, news industry, and many other aspects of our lives. It has also facilitated phenomena like trending, influencing, fake news, etc. On the technical side, the immense amount of user-supplied content ushered in the era of Big Data and set the stage for further technical developments in the coming decades. As an example, user-supplied photos and associated tags enabled Facebook to create a highly successful facial recognition system, which launched in 2010 but has since been scaled back due to ethical and privacy concerns.

The end of the decade was equally exciting in terms of technological developments. The 4th generation (4G) cellular service was first launched in Norway and Sweden in 2009. With increased bit rates offered to the users, the demand for online media and streaming services will rapidly increase in the next decade. The same year, Apple introduced HyperText Transfer Protocol (HTTP) Live Streaming, which is currently the most popular streaming format. Also, the Multiview Video Coding (MVC) extension of H.264/AVC was introduced.

In the meantime, MMSP TC was busy building up the MMSP community and organizing related events. MMSP Workshops took place in Cannes, France (2001); St. Thomas, US Virgin Islands (2002); Siena, Italy (2004); Shanghai, China (2005), Victoria, Canada (2006); Chania, Greece (2007); Cairns, Australia (2008); and Rio de Janeiro, Brazil (2009). ICME conferences took place in New York, USA (2000); Tokyo, Japan (2001); Lausanne, Switzerland (2002); Baltimore, USA (2003); Taipei, Taiwan (2004); Amsterdam, the Netherlands (2005); Toronto, Canada (2006); Beijing, China (2007); Hannover, Germany (2008); and again in New York, USA (2009). During this period, MMSP TC Chairs were K.-J. Ray Liu (1999-2001), John. A. Sørensen (2002-2003), Yu Hen Hu (2004-2005), Ingemar J. Cox (2006-2007), and Anthony Vetro (2008-2009).

## **The 2010's**

During this decade, 4G communications spread throughout the world, increasing the demand for online media. Mobile screen resolutions increased sufficiently that users could watch full HD video on their devices. Interactive media also became more popular; people could now have a reasonable videoconference on the go.

In 2011, MPEG Dynamic Adaptive Streaming over HTTP (DASH) became an international standard. MPEG-DASH and related technologies like Apple's HTTP Live Streaming provided an incentive to consumer electronics companies to incorporate streaming apps into their devices, which in turn gave a boost to the streaming industry. Smart TVs and streaming devices like Apple TV, Amazon Fire TV, Roku, and many others, gradually started supplementing and then replacing traditional cable and satellite TV services.

Another type of application that became popular in 2010's is mobile visual search [19], where users could take a photo of an object or a location and then retrieve additional information about it, possibly in the form of augmented reality. Audio search apps like Shazam were already established by that time, but an efficient mobile visual search required a good camera and sufficiently powerful hardware for fast feature extraction. All of it came together during the early 2010's. The MPEG Compact Descriptors for Visual Search (CDVS) standard [20] was released in 2015 and it provided an interoperable way to compress and transmit visual features that facilitate image search and matching. While most multimedia compression standards code data for human consumption, this is a rare example of a standard for visual data coding for machine use, namely visual search; the trend of coding for machines is becoming very popular at the time of writing this article.

2010's were a decade when immersive technologies took a big step forward. This was facilitated by improvements in sensing and display technologies over the years, but also computing infrastructure needed to process the increased amount of data required for high-quality

immersive experience. Representative technologies for 3D visual immersion include multi-view video, RGB plus depth (RGB+D), and point clouds, while audio counterparts include ambisonics and wave field synthesis. Haptic technologies also moved forward, finding new applications in wearable devices.

Another major event of the 2010's was a sharp rise in the popularity of deep learning with neural networks. Although the benefits of learning with many-layered models were already known in the 1960's [21] and the term *deep learning* dates back to the 1980's [22], it was the success of deep neural networks in acoustic modeling [23] and image classification [24], as well as the availability of large datasets and powerful computing infrastructure, that sparked the renewed interest in the topic, and subsequently transformed many technical fields, including multimedia signal processing. This is in part due to the ability of deep neural networks to effectively model relationships in multimodal data [25].

Among the emerging applications that were greatly facilitated by deep learning is autonomous driving, where multiple sensors - cameras, LiDAR, radar, microphones - collect information from the vehicle's surroundings to help it navigate the road. Processing signals from multiple modalities has traditionally been challenging. However, with the help of deep models, one can learn the complex relationships between different modalities from data, to enable their joint processing and analysis. In 2018, Waymo launched the first autonomous taxi service in Phoenix, AZ. Another AI/deep learning-driven trend is that of "smart" sensors and devices, such as smart speakers and cameras, whose capabilities have gone beyond capture and low-level processing of signals towards understanding and interaction with their environment.

On the video coding front, a major milestone was the 2013 release of the High Efficiency Video Coding (HEVC) standard, also known as H.265 or MPEG-H Part 2. Besides the usual 50% coding efficiency gain over the predecessor (H.264/AVC), it was targeted at higher resolutions and allowed for higher bit-depth, thus facilitating high dynamic range (HDR) display. It is currently the second most-widely used video coding format, after H.264/AVC. Despite the high adoption of

standard codecs in various industries, especially by hardware developers, the research community felt that there is a strong need for royalty-free codecs. Hence, the Alliance for Open Media (AOM) was formed in 2015, with the goal of developing royalty-free video coding technology whose performance would be comparable to that of standard video codecs. Starting with Google's VP9 video codec, initially mainly used on YouTube, AOM has released AOMedia Video 1 (AV1) video coding format in 2018. Royalty-free coding formats like VP9 and AV1 tend to be better supported in web browsers and streaming apps compared to standard coding formats.

Major revamping of the ICME conference took place during the 2010's. First, in 2010, ICME introduced double-blind review process, a departure from traditional single-blind review that is still common in signal processing. Moreover, the target acceptance rate was set to 30%, with the top 15% percent of papers being selected for oral presentation. Starting with 2012, ICME Workshops - which were introduced in 2009 to provide more focused satellite events and to foster new and emerging topics - have been published in separate proceedings. These innovations, and of course the hard work of many volunteers, helped ICME become what it is today - a flagship IEEE conference in multimedia.

Besides ICME, the MMSP TC has also been organizing MMSP Workshops, which took place in Saint Malo, France (2010); Hangzhou, China (2011); Banff, Canada (2012); Pula, Italy (2013); Jakarta, Indonesia (2014); Xiamen, China (2015); Montréal, Canada (2016); Luton, UK (2017); Vancouver, Canada (2018); and Kuala Lumpur, Malaysia (2019). ICME conferences were held in Singapore (2010); Barcelona, Spain (2011); Melbourne, Australia (2012); San Jose, USA (2013); Chengdu, China (2014); Turin, Italy (2015); Seattle, USA (2016); Hong Kong (2017); San Diego, USA (2018); and Shanghai, China (2019). During this decade, MMSP TC was chaired by Philip Chou (2010-2011), Oscar Au (2012-2013), Dinei Florencio (2014-2015), Enrico Magli (2016-2017), and Frédéric Dufaux (2018-2019).

## **The 2020's**

The current decade started with an event that impacted the world in many ways - the COVID-19 pandemic. As people retreated to their homes and started working remotely, the importance of multimedia suddenly grew. The demand for streaming services spiked, and videoconferencing became the norm for business meetings and presentations, education, and simply socializing and keeping in touch with friends and family. Before the pandemic, multimedia technology was mostly driven by entertainment. Now, it has become part of the infrastructure of our society. Even as the pandemic-related restrictions get removed, the concept of remote work and collaboration are staying.

Although the decade is still young, several important technological milestones have already occurred. The latest video coding standard, Versatile Video Coding (VVC) [26], also known as H.266 or MPEG-I Part 3, was released in 2020. Besides the usual improvement in compression efficiency over its predecessor, VVC was developed to support a broad set of resolutions, up to 16K, a variety of color formats, as well as 360° video. Another important standard released in 2020 was MPEG Point Cloud Compression (PCC). Targeting applications like augmented, virtual and mixed reality, MPEG PCC provides compression technology for video-based and geometry-based point cloud compression [27]. A related standard that is still being developed is JPEG Pleno [28], whose goal is to provide compression support for plenoptic imaging modalities such as light fields, holography, and point clouds.

As noted earlier, learning-based technologies are playing an increasingly important role in many areas, including multimedia signal processing. But the benefit is mutual. In 2021, MPEG released a standard for neural network compression (MPEG-7 part 17) whose purpose is to enable compression of neural network models for efficient storage and transport. While its purpose is to compress networks rather than multimedia signals, the standard was built upon the knowledge base developed over the years in image and video compression. Neural network compression is useful in federated learning where model weights need to be transmitted between the clients and the server during the network training process.

Broader technological trends, such as the deployment of 5th generation (5G) communication systems, the growing Internet of Things (IoT), and advances in AI, are opening up possibilities for “smart” homes, buildings, factories, and cities. In applications like these, automation is a necessity, since the amount of data captured and communicated is far too much for humans to take note of. For example, most of the video captured by surveillance cameras will never be seen by humans, only “seen” by machines. As a result, several standardization efforts have been initiated to create media compression formats suitable for machine use, or combined human and machine use. One of these is JPEG AI [29] whose goal is to develop learning-based compression technology that supports conventional image decoding as well as a number of image processing and machine vision tasks. The other is MPEG Video Coding for Machines (VCM) [30], which targets both machine-only and human-machine tasks. Completion of these standards will facilitate improved efficiency of many technologies already in use, such as video monitoring, autonomous navigation, and multimedia database management, and create fertile ground for new and yet-to-be-imagined applications.

Due to the pandemic, MMSP TC activities in the 2020's were mostly virtual so far. MMSP Workshops took place virtually in Tampere, Finland in 2020, again in Tampere, Finland, as a hybrid event in 2021, and virtually in Shanghai, China, in 2022. ICME was a virtual event in London, UK, in 2020, and in Shenzhen, China, in 2021, and was organized as a hybrid event in Taipei, Taiwan, in 2022. During this period, MMSP TC Chairs were Marta Mrak (2020-2021) and Ivan Bajić (2022-2023).

## **Conclusions**

Starting as a mostly entertainment-driven technology, multimedia signal processing has come a long way to become a part of the very fabric of our society. It has enabled highly successful businesses, provided critical infrastructure at the time of need, and reached virtually everyone in



some form or another. MMSP TC has been a part of that story over the last two and a half decades.

So what does the future of multimedia signal processing look like? As the saying goes, “making predictions is difficult, especially about the future.” In the near term, the trends are clear: data-driven approaches in the form of AI/deep learning are pushing the boundaries of what is possible with multimedia signals, and laying the foundation for the next generation of multimedia applications, products and services. Beyond that, who knows - perhaps quantum multimedia?

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Conference on Multimedia and Expo, joining efforts from multiple IEEE societies. Tsuhan was appointed the Editor-in-Chief for IEEE Transactions on Multimedia in 2002-2004.

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