MPEG: A Video Compression Standard for Multimedia Applications

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The development of digital video technology in the 1980s has made it possible to use digital video compression for a variety of telecommunication applications: teleconferencing, digital broadcast codec and video telephony.

Standardization of video compression techniques has become a high priority because only a standard can reduce the high cost of video compression codecs and resolve the critical problem of interoperability of equipment from different manufacturers. The existence of a standard is often the trigger to the volume production of integrated circuits (VLSI) necessary for significant cost reductions. An example of such a phenomenon—where a standard has stimulated the growth of an industry—is the spectacular growth of the facsimile market in the wake of the standardization of the Group 3 facsimile compression algorithm by the CCITT. Standardization of compression algorithms for video was first initiated by the CCITT for teleconferencing and videotelephony [7]. Standardization of video compression techniques for transmission of contribution-quality television signals has been addressed in the CCIR[1] (more precisely in CMTT/2, a joint committee between the CCIR and the CCITT).

Digital transmission is of prime importance for telecommunication, particularly in the telephone network, but there is a lot more to digital video than teleconferencing and visual telephony. The computer industry, the telecommunications industry and the consumer electronics industry are increasingly sharing the same technology—there is much talk of a convergence, which does not mean that a computer workstation and a television receiver are about to become the same thing, but certainly, the technology is converging and includes digital video compression. In the view of shared technology between different segments of the information processing industry, the International Organization for Standardization (ISO) has undertaken an effort to develop a standard for video and associated audio on digital storage media, where the concept of digital storage medium includes conventional storage devices CD-ROM, DAT, tape drives, winchesters, writable optical drives, as well as telecommunication channels such as ISDNs, and local area networks.

This effort is known by the name of the expert group that started it: MPEG—Moving Picture Experts Group—and is currently part of the ISO-IEC/JTC1/SC2/WG11. The MPEG activities cover more than video compression, since the compression of the associated audio and the issue of audio-visual synchronization cannot be worked independently of the video compression: MPEG-Video is addressing the compression of video signals at about 1.5 Mbits, MPEG-Audio is addressing the compression of a digital audio signal at the rates of 64, 128 and 192 kbits/s per channel, MPEG-System is addressing the issue of synchronization and multiplexing of multiple compressed audio and video bit streams. This article focuses on the activities of MPEG-Video. The premise of MPEG is that a video signal and its associated audio can be compressed to a bit rate of about 1.5 Mbits/s with an acceptable quality.

Two very important consequences follow: Full-motion video becomes a form of computer data, i.e., a data type to be integrated with text and graphics; Motion video and its associated audio can be delivered over existing computer and telecommunication networks.

Precompetitive Research

The growing importance of digital video is reflected in the participation of more and more companies in standards activities dealing with digital video; MPEG is a standard that responds to a need. In this situation a standards committee is a forum where precompetitive research can take place, where manufacturers meet researchers, where industry meets academia. By and large, because the problem to be solved was perceived as important, the technology developed within MPEG is at the forefront of both research and industry. Now that the work of the MPEG committee has reached maturity (a "Committee Draft" was produced in September 1990), the VLSI industry is ready and waiting to implement MPEG's solution.

MPEG Standard Activities

The activity of the MPEG committee was started in 1988 with the goal of achieving a draft of the standard by 1990. In the two years of MPEG activity, participation has increased tenfold from 15 to 150 participants. The MPEG activity was not started without due consideration to the related activities of other standard organizations. These considerations are of interest, not only because it is important to avoid duplication of work between standards committees but most of all, because these activities provided a very important background and technical input to the work of the MPEG committee.

Background: Relevant Standards

The JPEG Standard. The activities of JPEG (Joint Photographic Experts Group) [10] played a considerable role in the beginning of MPEG, since both groups were originally in the same working group of ISO and there has been considerable overlap in membership. Although the objectives of JPEG are focused exclusively on still-image compression, the distinction between still and moving image is thin; a video sequence can be

[1] CCIR is the International Consultative Committee on Broadcasting: CCITT is the International Committee on Telegraph and Telephones. CMTT is a joint committee of the CCITT and the CCIR working on issues relevant to television and telephony.

thought of as a sequence of still images to be coded individually, but displayed sequentially at video rate. However, the "sequence of still images" approach has the disadvantage that it fails to take into consideration the extensive frame-to-frame redundancy present in all video sequences. Indeed, because there is a potential for an additional factor of three in compression exploiting the temporal redundancy, and because this potential has very significant implications for many applications relying on storage media with limited bandwidth, extending the activity of the ISO committee to moving pictures was a natural next step.

CCITT Expert Group on Visual Telephony. As previously mentioned, most of the pioneering activities in video compression were triggered by teleconferencing and videotelephony applications. The definition and planned deployment of ISDN (Integrated Service Digital Network) was the motivation for the standardization of compression techniques at the rate of px64 kbits/s where p takes values from one (one B channel of ISDN) to more than 20 (Primary rate ISDN is 23 or 30 B channels). The Experts Group on visual telephony in the CCITT Study Group XV addressed the problem and produced CCITT Recommendation H.261: "Video Codec for Audiovisual Services at px64 kbits" [7, 9]. The focus of the CCITT expert group is a real-time encoding-decoding system, exhibiting less than 150 ms delay. In addition, because of the importance of very low bit-rate operation (around 64 kbits/s), the overhead information is very tightly managed.

After careful consideration by the MPEG committee, it was perceived that while the work of the CCITT expert group was of very high quality, relaxing the constraint on very low delay and the focus on extremely low bit rates could lead to a solution with increased visual quality in the range of 1 to 1.5 Mbits/s. On the other hand, the contribution of the CCITT expert group has been extremely relevant and the members of MPEG have strived to maintain compatibility, introducing changes only to improve quality or to satisfy the need of applications. Consequently, the emerging MPEG standard, while not strictly a superset of CCITT Recommendation H.261, has much commonality with that standard so that implementations supporting both standards are quite plausible.

CMTT/2 Activities. If digital video compression can be used for videoconferencing or videotelephony applications, it also can be used for transmission of compressed television signals for use by broadcasters. In this context the transmission channels are either the high levels of the digital hierarchy, H21 (34 Mbits/s) and H22 (45 Mbits/s) or digital satellite channels. The CMTT/2 addressed the compression of television signals at 34 and 45 Mbits/s [4]. This work was focused on contribution quality codecs, which means that the decompressed signal should be of high enough quality to be suitable for further processing (such as chromakeying). While the technology used might have some commonalities with the solutions considered by MPEG, the problem and the target bandwidth are very different.

MPEG Standardization Effort

The MPEG effort started with a tight schedule, due to the realization that failure to get significant results fast enough would result in potentially disastrous consequences such as the establishment of multiple, incompatible *de facto* standards. With a tight schedule came the need for a tight methodology, so the committee could concentrate on technical matters, rather than waste time in dealing with controversial issues.

Methodology. The MPEG methodology was divided in three phases: Requirements, Competition and Convergence:

Requirements. The purpose of the requirement phase was twofold: first, precisely determine the focus of the effort; then determine the rules of the game for the competitive phase. At the time MPEG began its effort, the requirements for the integration of digital video and computing were not clearly understood, and the MPEG approach was to provide enough system design freedom and enough quality to address many applications. The outcome of the requirement phase was a document "Proposal Package Description" [8] and a test methodology [5].

Competition. When developing an international standard, it is very important to make sure the trade-offs are made on the basis of maximum information so that the life of the standard will be long: there is nothing worse than a standard that is obsolete at the time of publication. This means the technology behind the standard must be state of the art, and the standard must bring together the best of academic and industrial research. In order to achieve this goal, a competitive phase followed by extensive testing is necessary, so that new ideas are considered solely on the basis of their technical merits and the trade-off between quality and cost of implementation.

In the MPEG-Video competition, 17 companies or institutions contributed or sponsored a proposal, and 14 different proposals were presented and subjected to analysis and subjective testing (see Table 1). Each proposal consisted of a documentation part, explaining the algorithm and documenting the system claims, a video part for input to the subjective test [5], and a collection of computer files (program and data) so the compression claim could be verified by an impartial evaluator.

Convergence. The convergence phase is a collaborative process where the ideas and techniques identified as promising at the end of the competitive phase are to be integrated into one solution. The convergence process is not always painless; ideas of considerable merit frequently have to be abandoned in favor of slightly better or slightly simpler ones. The methodology for convergence took the form of an evolving document called a simulation model and a series of fully documented experiments (called core experiments). The experiments were used to resolve which of two or three alternatives gave the best quality subject to a reasonable implementation cost.

TABLE 1.

Participation: Companies and Institutions having contributed an MPEG Video Proposal

Company	Country	Proposer
AT&T	USA	AT&T
Bellcore	USA	Bellcore
Intel	USA	Bellcore
GCT	Japan	Bellcore
C-Cube Micro	USA	C-Cube Micro.
DEC	USA	DEC
France Telecom	France	France Telecom
Cost 211 Bis	EUR	France Telecom
IBM	USA	IBM
JVC Corp	Japan	JVC Corp
Matsushita EIC	Japan	Matsushita EIC
Mitsubishi EC	Japan	Mitsubishi EC
NEC Corp.	Japan	NEC Corp.
NTT	Japan	NTT
Philips CE	Netherlands	Philips CE
Sony Corp.	Japan	Sony Corp.
Telenorma/U. Hannover	Germany	Telenorma/U. Hannover

TABLE 2.

Storage Media and Channels where MPEG could have Applications

CD-ROM
DAT
Winchester Disk
Writable Optical Disks
ISDN
LAN
Other Communication Channels

Schedule. The schedule of MPEG was derived with the goal of obtaining a draft of the standard (Committee Draft) by the end of 1990. Although the amount of work was considerable, and staying on schedule meant many meetings, the members of MPEG-Video were able to reach an agreement on a Draft in September 1990. The content of the draft has been "frozen" since then, indicating that only minor changes will be accepted, i.e., editorial changes and changes only meant to correct demonstrated inaccuracies. Figure 1 illustrates the MPEG schedule for the competitive and convergence phases.

MPEG-Video Requirements

A Generic Standard

Because of the various segments of the information processing industry represented in the ISO committee, a representation for video on digital storage media has to support many applications. This is expressed by saying that the MPEG standard is a *generic* standard. Generic means that the standard is independent of a particular application; it does not mean however, that it ignores the requirements of the applications. A generic standard possesses features that make it somewhat universal—e.g., it follows the toolkit approach; it does not mean that all the features are used all the time for all applications, which would result in dramatic inefficiency. In MPEG, the requirements on the video compression algorithm have been derived directly from the likely applications of the standard.

Many applications have been proposed based on the assumption that an acceptable quality of video

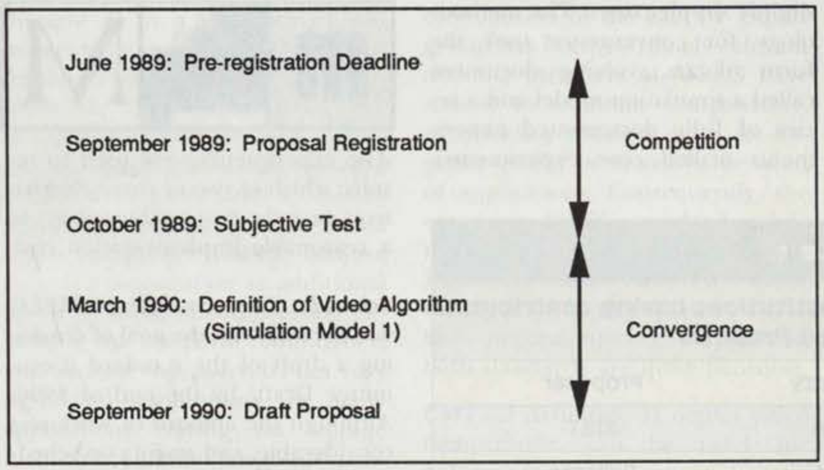

FIGURE 1.
MPEG Schedule for the Competitive and Convergence Phases

can be obtained for a bandwidth of about 1.5 Mbits/second (including audio). We shall review some of these applications because they put constraints on the compression technique that go beyond those required of a videotelephone or a videocassette recorder (VCR). The challenge of MPEG was to identify those constraints and to design an algorithm that can flexibly accommodate them.

Applications of Compressed Video on Digital Storage Media

Digital Storage Media. Many storage media and telecommunication channels are perfectly suited to a video compression technique targeted at the rate of 1 to 1.5 Mbits/s (see Table 2). CD-ROM is a very important storage medium because of its large capacity and low cost. Digital audio tape (DAT) is also perfectly suitable to compressed video; the recordability of the medium is a plus, but its sequential nature is a major drawback when random access is required. Winchester-type computer disks provide a maximum of flexibility (recordability, random access) but at a significantly higher cost and limited portability. Writable optical disks are expected to play a significant role in the future because they have the potential to combine the advantages of the other media (recordability, random accessability, portability and low cost).

The compressed bit rate of 1.5 Mbits is also perfectly suitable to computer and telecommunication networks and the combination of digital storage and networking can be at the origin of many new applications from video on Local area networks (LANs) to distribution of video over telephone lines [1].

Asymmetric Applications. In order to find a taxonomy of applications of digital video compression, the distinction between symmetric and asymmetric applications is most useful. Asymmetric applications are those that require frequent use of the decompression process, but for which the compression process is performed once and for all at the production of the program. Among asymmetric applications, one could find an additional subdivision into electronic publishing, video games and delivery of movies. Table 3 shows the asymmetric applications of digital video.

Symmetric Applications. Symmetric applications require essentially equal use of the compression and the decompression process. In symmetric applications there is always production of video information either via a camera (video mail, videotelephone) or by editing prerecorded material. One major class of symmetric application is the generation of material for playback-only applications; (desktop video publishing); another class involves the use of telecommunication either in the form of electronic mail or in the form of interactive face-to-face applications. Table 4 shows the symmetric applications of digital video.

TABLE 3.

Asymmetric Applications of Digital Video
Electronic Publishing
Education and Training
Travel Guidance
Videotext
Point of Sale
Games
Entertainment (movies)

TABLE 4.

Symmetric Applications of Digital Video
Electronic Publishing (production)
Video Mail
Videotelephone
Video Conferencing

Features of the Video Compression Algorithm

The requirements for compressed video on digital storage media (DSM) have a natural impact on the solution. The compression algorithm must have features that make it possible to fulfill all the requirements. The following features have been identified as important in order to meet the need of the applications of MPEG.

Random Access. Random access is an essential feature for video on a storage medium whether or not the medium is a random access medium such as a CD or a magnetic disk, or a sequential medium such as a magnetic tape. Random access requires that a compressed video bit stream be accessible in its middle and any frame of video be

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