SOME LITTLE-KNOWN ASPECTS OF THE HISTORY OF THE JPEG STILL PICTURE-CODING STANDARD, ITU-T T.81 | ISO/IEC 10918-1 (1986-1993)

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Abstract *– The JPEG-1 standard of the Joint Photographic Experts Group (JPEG) whose specification was submitted to and approved by the Consultative Committee for International Telephony and Telegraphy (CCITT; now ITU-T) in 1992 and by ISO/IEC JTC1 in 1994 is still the most successful still-picture compression standard on the market. Much has been written about the standard itself, how the image compression functions, but less about the unique policies and processes of the JPEG, the origins of the requirements of the JPEG-1 format, the common components principle, the fate of the targeted CCITT/ITU applications and the nature of those applications that made JPEG one of the world's most successful standards. It is also not widely known that JPEG is one of the first standards to be followed and supported by an open source software (OSS) project and code – developed and distributed by the Independent JPEG Group (IJG) – that has provided a substantial drive towards market penetration and contributed to the wide acceptance of the JPEG standard. This paper also presents an analysis of the JPEG-IJG co-operation and draws some conclusions about its nature. Finally, the lessons learned are discussed.*

INTRODUCTION

The JPEG Recommendation | International Standard (ITU-T T.81 | ISO/IEC 10918-1 [1]), first published in 1992, is still the most popular and most used picture-coding standard for photographic images. Much has been written about the standard itself (e.g. [2]) and its history (e.g. [3][4]) focusing on:

- the technical design and characteristics of the standard, including the image compression capabilities of the JPEG algorithm;
- the JPEG standardization selection procedure that resulted in a still picture standard based on the discrete cosine transform (DCT).

However, standardization, which is to a certain extent an interdisciplinary exercise, is much broader than that. Thus, this article presents and discusses some additional, perhaps little-known, although noteworthy, aspects of JPEG standardization, with the aim of complementing the comprehensive picture of the history of the JPEG format. These aspects include those relating to organization and process; what the original experts group JPEG was; why the rules and working processes of that group were unique and could never be repeated in the history of standardization; along with the roles of the "parent" organizations of JPEG, namely CCITT/ITU and ISO/IEC. This article describes how the requirements for the JPEG standardization emerged; what the common component concept was; which requirements became part of the standard and which were left to applications; what the targeted applications in CCITT/ITU and ISO/IEC were; the eventual success of those applications; and how unplanned applications, in the end, made JPEG one of the most successful standards worldwide. Finally, the interaction between JPEG and the IJG group, who made a significant contribution to the early market penetration of the standard with their Open Source Code, are described.

1. THE JPEG-1 PROJECT (ITU-T T.81 | ISO/IEC 10918-1) OF CCITT SGVIII AND ISO/IEC JTC1 SC29 AND ITS WORKING RULES AND PROCEDURES

The JPEG-1 Recommendation | International Standard on still image compression was approved in 1992 by ITU-T and in 1993 by ISO/IEC, and was among the first documents with a so-called joint-text adopted by both ITU-T and ISO/IEC JTC1. ITU-T T.81 (1992) | ISO/IEC 10918-1:1993 [1] was also among the first to have connections with the OSS community through the IJG.

Fig. 1 provides an overview of how the JPEG-1 Recommendation | International Standard was created.

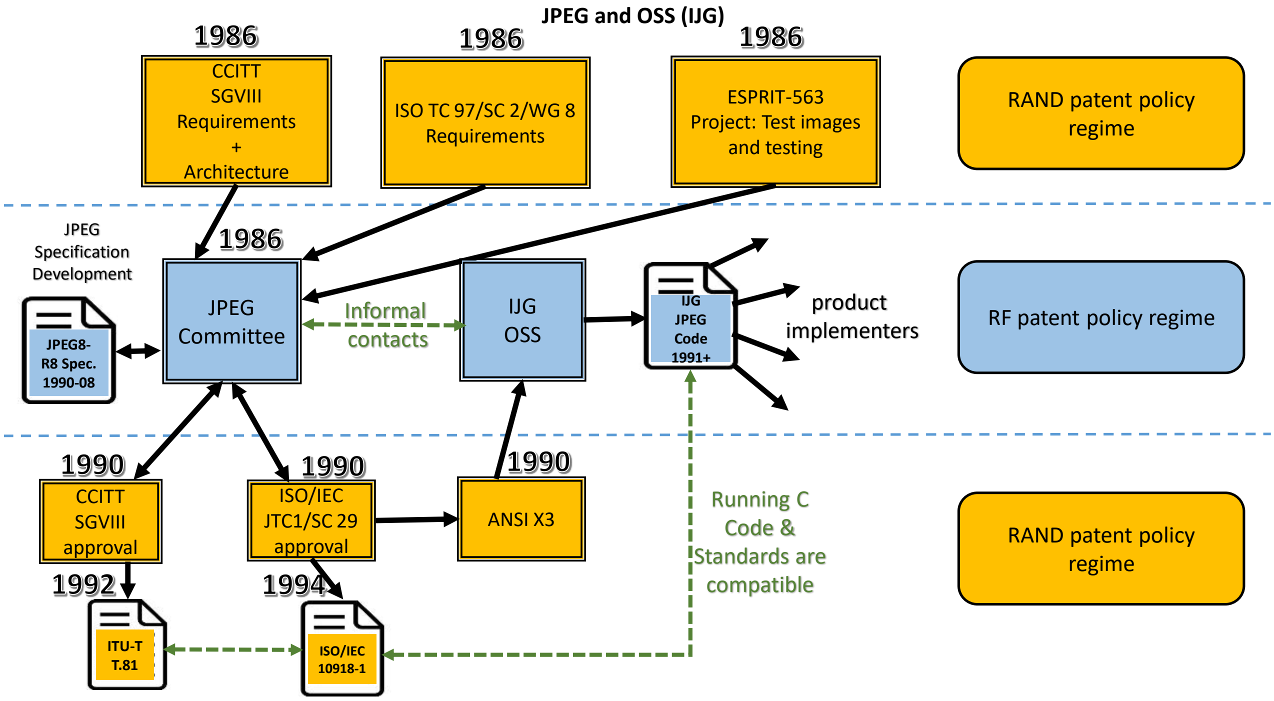


Fig. 1 – Overview of components of JPEG-1 standardization

The draft was prepared by the JPEG Committee, whose members were ITU and ISO individual experts. The JPEG was formally created in November 1986 in Parsippany, NJ, USA. The founding members (about 15) were individuals, but also had formal links to ISO TC97 SC2/WG8 or the CCITT SGVIII NIC (new image communication) group. Among them were the leaders Hiroshi Yasuda (NTT, Japan), convener of SC2/WG8 and Manfred Worlitzer (CCITT SGVIII special rapporteur), who had a substantial role in the initiation (March 1986) and founding of JPEG. The founding members recognized that both SC2/WG8 and the CCITT SGVIII NIC group had similar goals in the development of a still picture compression and coding standard.

Nevertheless, the JPEG:

- was a group of photographic coding experts, created on an *ad hoc* basis, and registered formally nowhere as a formal entity;
- consisted of experts from ISO TC97/SC2/WG8 and (ITU) CCITT SGVIII Q.18 in their individual expert capacities, not representing their companies – these two formal ISO and CCITT groups were the "parents" of JPEG because they were informed about what was going on in JPEG and regular feedback to JPEG was given;
- developed and wrote the JPEG specification (i.e. JPEG-8) that became the basis for ITU-T T.81 (1992) | ISO/IEC 10918-1:1993 [1] and for the open source implementation by the IJG.

So, in that sense JPEG comes rather close to those informal communities that we see today on the Internet, like jnode or Babel as part of the JavaScript standardization community, who have similar links to Ecma TC39, the formal body responsible for ECMAScript (JavaScript) standardization.

Although TC97 SC2/WG8 and CCITT SGVIII were part of ISO and ITU, respectively, their JPEG working rules and policies were rather different from their parent organizations. Such unique working rules and procedures arose because in autumn 1986 no common joint working rules between ISO and CCITT yet existed. Those were invented and implemented a few years later.

The JPEG rules and procedures included the following.

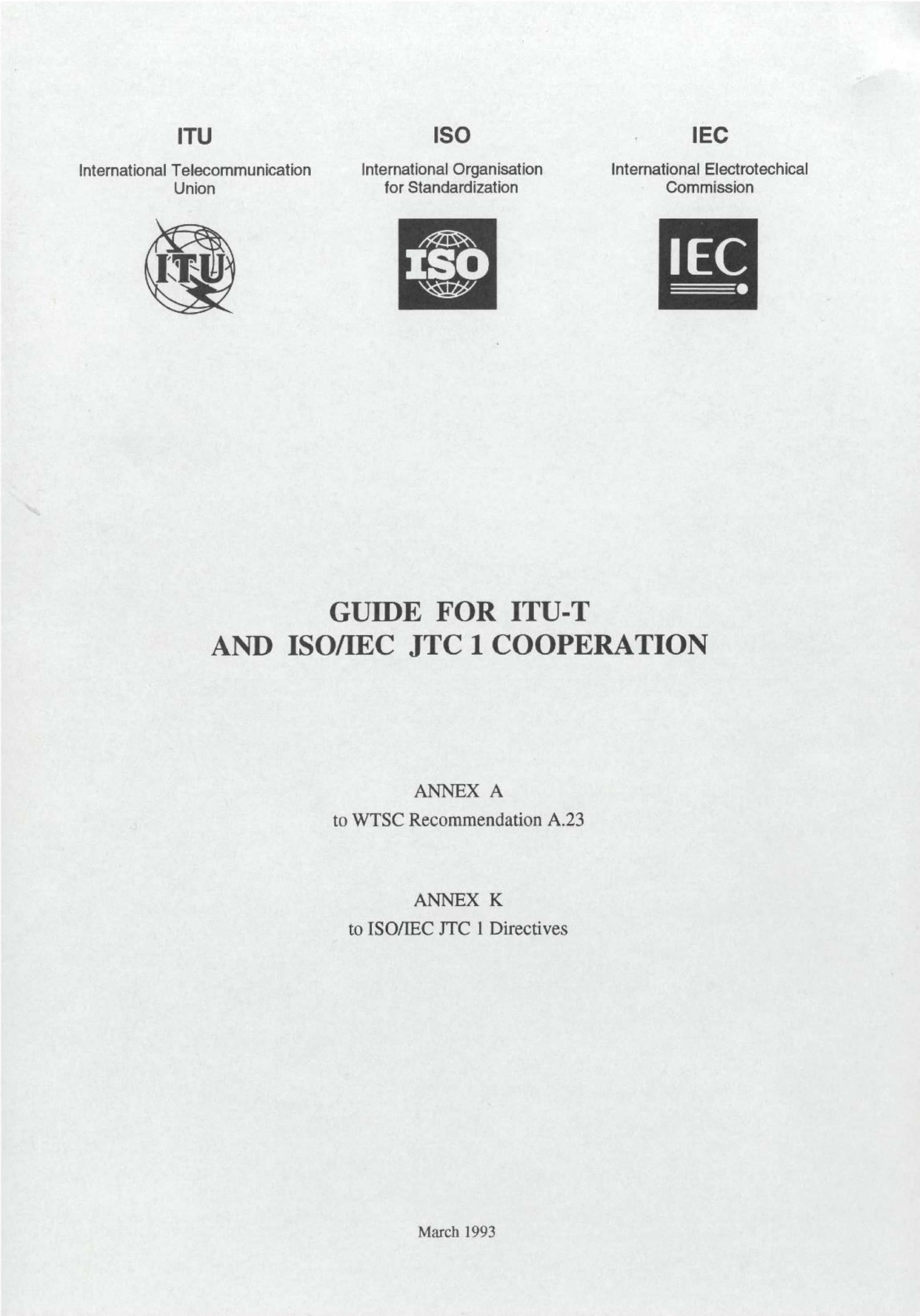
- A simple one-step approval rule based on consensus.
- A separate management structure (e.g., JPEG chair, JPEG subgroups) – the Chairmen until JPEG-1 approval in 1992 were **Graham Hudson** (BT Labs) and **Gregory Wallace** (DEC).
- Membership of individual experts and not member bodies, or ITU member states or sector members.

- Its own separate documentation designation (JPEG-nnn).
- Its own specifications (e.g. JPEG-8, -9) that after JPEG approval were submitted to the parent standards development organizations (SDOs) for independent formal approval as ITU-T and ISO/IEC JTC1 standards.
- Its own intellectual property right (IPR) policies (especially patent policy), with a different tenour to what at that time were still emerging ITU and ISO patent policies. While JPEG was basically royalty-free (RF), ISO and ITU had a reasonable and non-discriminatory (RAND) patent policy. The JPEG collected known patents related to the JPEG format based on information from its members. Such information was then published as Annex L of ITU-T T.81 | ISO/IEC 10918-1 [1], which was unique at that time.

The principles of formal collaboration on information technology, particularly with the ISO/IEC Joint Technical Committee 1 (JTC1), were given later in 1988 in CCITT A.22 [36]. After 1988, JPEG and the new CCITT and ISO committee working on common procedures worked in parallel. ITU later published ITU-T A.23 [5] (Figs. 2 and 3). The same document was also approved and published by ISO/IEC JTC1. However, by that time the work on the JPEG-1 format was already finished.

The JPEG committee was from the very beginning in contact with the group that developed ITU-T A.23 [5], and was one of the first groups that used the common standards template.

Nevertheless, after formal adoption of ITU-T A.23 [5] in 1993 (when JPEG-1 had already been developed), JPEG had *de facto* lost its unique working rules and methods (e.g. the patent policy of an RF baseline mode and RAND optional JPEG components) it earlier enjoyed. So, in 1993 the blue RF patent policy regime zone changed to an orange RAND patent policy regime zone (see Fig. 1). The lack of a common RF patent policy regime across ITU, ISO and IEC later became a persistent issue in the history of JPEG. In addition, the formal three-step approval process by ISO/IEC JTC1 took substantially more time than that required for JPEG to develop its specification.



ITU
International Telecommunication
Union

ISO
International Organisation
for Standardization

IEC
International Electrotechical
Commission

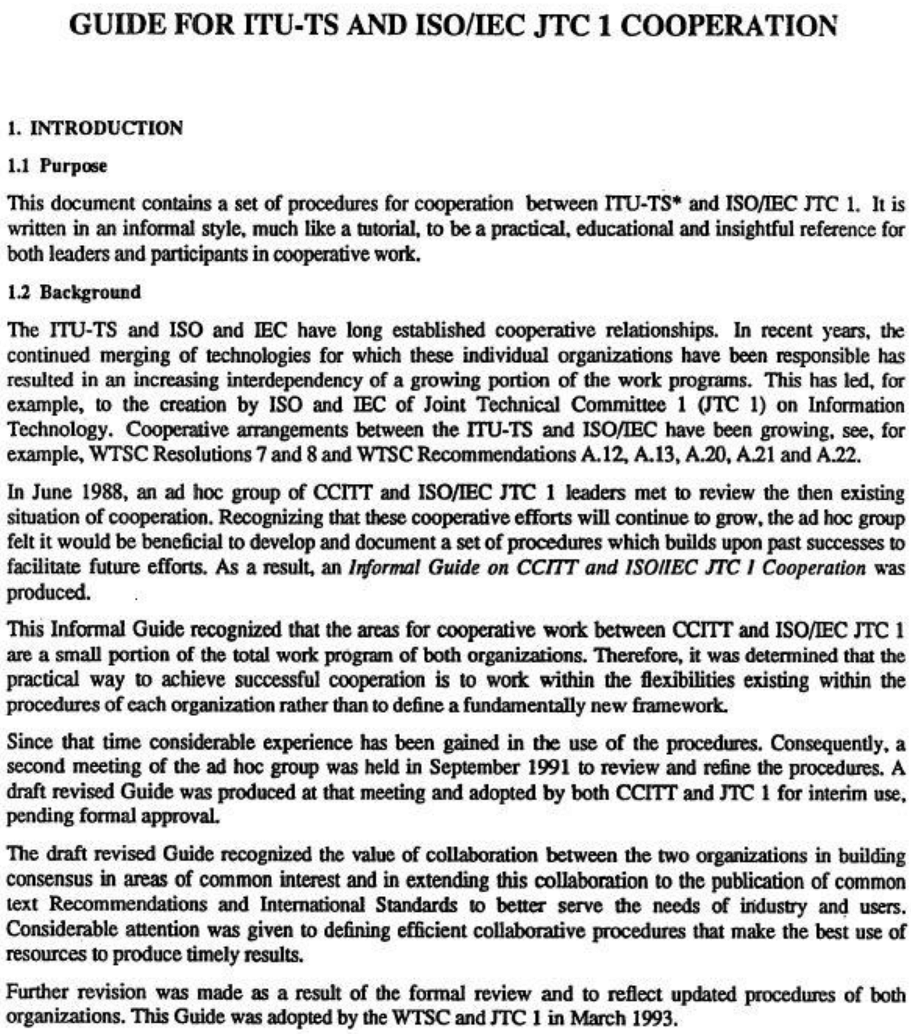
GUIDE FOR ITU-T
AND ISO/IEC JTC 1 COOPERATION

ANNEX A
to WTSC Recommendation A.23

ANNEX K
to ISO/IEC JTC 1 Directives

March 1993

Fig. 2 – In 1993, approved Guide for ITU-TS and ISO/IEC JTC1 Cooperation
(in 1992 interim use, i.e. de jure end of the special JPEG procedures and working rules of 1986)



GUIDE FOR ITU-TS AND ISO/IEC JTC 1 COOPERATION

1. INTRODUCTION

1.1 Purpose

This document contains a set of procedures for cooperation between ITU-TS* and ISO/IEC JTC 1. It is written in an informal style, much like a tutorial, to be a practical, educational and insightful reference for both leaders and participants in cooperative work.

1.2 Background

The ITU-TS and ISO and IEC have long established cooperative relationships. In recent years, the continued merging of technologies for which these individual organizations have been responsible has resulted in an increasing interdependency of a growing portion of the work programs. This has led, for example, to the creation by ISO and IEC of Joint Technical Committee 1 (JTC 1) on Information Technology. Cooperative arrangements between the ITU-TS and ISO/IEC have been growing, see, for example, WTSC Resolutions 7 and 8 and WTSC Recommendations A.12, A.13, A.20, A.21 and A.22.

In June 1988, an ad hoc group of CCITT and ISO/IEC JTC 1 leaders met to review the then existing situation of cooperation. Recognizing that these cooperative efforts will continue to grow, the ad hoc group felt it would be beneficial to develop and document a set of procedures which builds upon past successes to facilitate future efforts. As a result, an *Informal Guide on CCITT and ISO/IEC JTC 1 Cooperation* was produced.

This Informal Guide recognized that the areas for cooperative work between CCITT and ISO/IEC JTC 1 are a small portion of the total work program of both organizations. Therefore, it was determined that the practical way to achieve successful cooperation is to work within the flexibilities existing within the procedures of each organization rather than to define a fundamentally new framework.

Since that time considerable experience has been gained in the use of the procedures. Consequently, a second meeting of the ad hoc group was held in September 1991 to review and refine the procedures. A draft revised Guide was produced at that meeting and adopted by both CCITT and JTC 1 for interim use, pending formal approval.

The draft revised Guide recognized the value of collaboration between the two organizations in building consensus in areas of common interest and in extending this collaboration to the publication of common text Recommendations and International Standards to better serve the needs of industry and users. Considerable attention was given to defining efficient collaborative procedures that make the best use of resources to produce timely results.

Further revision was made as a result of the formal review and to reflect updated procedures of both organizations. This Guide was adopted by the WTSC and JTC 1 in March 1993.

Fig. 3 – In 1993, approved Guide for ITU-TS and ISO/IEC JTC1 Cooperation document (introduction page)

Table 1 shows the timeline of events, with dates and “what happened” columns. It also shows how complicated in practice the interactions of the different groups were.

Co-operation between ITU-T SG8 and ISO/IEC JTC1 SC29 became simpler after the approval of the JPEG-1 format. However, the original JPEG committee then practically disappeared having been merged *de facto* into JTC1 SC29/WG1 and ITU-T SG8. First the co-operation continued according to the ITU-T A.23 [5] joint rules with ITU-T SG8 by means of the so-called collaborative interchange and in 1997 or so by the creation of a collaborative team. The JPEG2000 standardization effort was done under such a regime.

However, what both ISO/IEC JTC1 and ITU-T lost was the flexible, fast and effective working of the original JPEG with its unique procedures and working methods.

Table 1 – Timeline of standardization-related important dates and events during the development of ITU-T T.81 (1992) | ISO/IEC 10918-1:1993 [1]

Dates	What happened
8-19 October 1984	CCITT - VIIIth Plenary Assembly (Málaga-Torremolinos, 1984), Spain Study Group VIII "Terminal equipment for telematic services (facsimile, Teletex, Videotex, etc.)" with Study Question: "18/VIII New forms of image formation, communication, storage and presentation" Special Rapporteurs: Manfred Worlitzer until June 1987, then István Sebestyén
November 1986	Creation of JPEG; First JPEG meeting in Parsippany, NJ Graham Hudson elected as JPEG Chair
March 1987	JPEG meeting in Darmstadt – Registration of JPEG candidate techniques
June 1987	1. testing and selection meeting at KTAS, Copenhagen Reduction from 12 proposals to 3 group proposals for refinement
17-20 Nov 1987, Tokyo	ISO TC97 became ISO/IEC JTC1 ISO TC97 SC2 became ISO/IEC JTC1 SC2
January 1988	2. testing and selection meeting at KTAS, Copenhagen Selection of the ADCT technique for basis of the JPEG standard
September 1988	JPEG Torino Meeting. First meeting of Gregory Wallace as JPEG Chair
14-25 November 1988	CCITT - IXth Plenary Assembly (Melbourne, 1988) 14-25 November 1988 - Melbourne, Australia Reestablishment of Study Group VIII "Terminals for telematic services" with Study Question: "16/VIII Common components for image communications" Special Rapporteur: István Sebestyén"
February 1989	JPEG meeting in Livingstone – Consensus on JPEG "RF baseline" and RAND "Options". Specification JPEG8-Rev. 0 created.
June 1989	CCITT and ISO/IEC have long established cooperative relationships. In June 1989, an *ad hoc* group of CCITT and ISO/IEC JTC1 leaders met to review the then existing situation of cooperation.
October 1989	JPEG Meeting in Japan. JPEG8-Rev. 5 was prepared and released in December 1989 for external peer review.
March 1990	Hiroshi Yasuda proposal to SC2 to create "SC29" (WG8/N971)
April 1990	Split off from ISO TC97 SC2 WG8 to new WGs WG9 JBIG (Y. Yamazaki) WG10 JPEG (G. Wallace) WG11 MPEG (L. Chiariglione) WG12 MHEG (F. Collaitis, Kretz)
April 1990	JPEG8-Revision 5 SC2 approval to register the JPEG CD as ISO CD 10918
April 1990	JPEG Editing meeting in Budapest (JPEG-8 – Rev. 6)
August 1990	JPEG8-Rev. 8 – basis for final version for CD ballot
Nov.-Dec. 1990	JPEG8-Rev. 8 was picked up by the IJG (Tom Lane) to start the IJG Code
February 20, 1991	JPEG CD Part 1 submitted to JTC1/SC2 Secretariat for CD ballot
March 1, 1991	JPEG CD (ISO/IEC CD 10918-1) Registered
April-May 1991	Informal contacts between JPEG and the IJG started
September 1991	Publication of the 1st IJG Code for JPEG
September 1991	Collaborative Group on CCITT and JTC1 Cooperation. The results were conveyed to the October 1991 meetings of JTC1 and the CCITT *ad hoc* Resolution No. 18 Group
October 21, 1991	ISO/IEC CD 10918-1 approved
October 1991	JTC1 approval of SC29; WGs moved from SC2 to SC29
November 1991	First SC29 Plenary Meeting in Tokyo
January 7, 1992	DIS ballot on JPEG (DIS 10918-1) started in ISO/IEC JTC1
January 1992	Joint drafting rules for ITU/ISO/IEC common text were applied on an experimental basis first and came into force in 1992
April 30, 1992	CCITT SGVIII Votes to start 3 months Accelerated Voting on CCITT T.81
July 7, 1992	DIS ballot on JPEG (DIS 10918-1) ended in ISO/IEC JTC1
July 1992	JPEG Toronto meeting (Editing JPEG DIS to FDIS International Standard)

Dates	What happened
September 18, 1992	Approval of CCITT T.81 (JPEG) Recommendation by ITU
7 December - 22 December 1992 - Geneva, Switzerland	APP-92 Additional Plenipotentiary Conference (Geneva, 1992) streamlined ITU into three Sectors: Telecommunication Standardization (ITU-T), Radiocommunication (ITU-R), and Telecommunication Development (ITU-D).
February 1993	JPEG in the first web browsers
1-12 March 1993	WTSC-93 World Telecommunication Standardization Conference. Helsinki, Finland ITU-T A.23 [5] formally approved Study Group 8 – "Terminals for telematic services" with Question: "16/8 Common Component for Image Communication" Rapporteur: István Sebestyén
January 28, 1994	FDIS ballot closes: Approval of International Standard ISO/IEC 10918-1
February 1994	Publication of ISO/IEC 10918-1

2. REQUIREMENTS OF ITU-T T.81 (1992) |ISO/IEC 10918-1:1993 [1] AND ITS TOOLBOX NATURE

The JPEG-1 standard itself was of the toolbox type, i.e. a bit like a set of different building bricks from which many different types of still picture codecs and applications could be assembled according to the needs of the different type of imaging applications. Examples of such applications include digital photos, videotex, colour facsimile, medical images, web-images and high-resolution, digital images of museum paintings), which build on different components, e.g. lossy vs. lossless and sequential vs. progressive image build up, scaling in image size and image quality. Not all components needed for a complete application (like colour facsimile) were defined by JPEG. So, no file format was standardized – that was left to each application; also, JPEG was colour blind, leaving the selection of colour model to applications.

Nevertheless, the flexibility of design means that even today popular motion image engines and applications can still be put together, like the motion-JPEG that had more to do with the Next project of Steve Jobs, than with the still picture-coding mandate of the JPEG group.

The JPEG obtained the original requirements for the JPEG-1 image compression standard from three sources:

- (ITU) CCITT SGVIII Q.18 (New image communications) with special rapporteurs **Manfred Worlitzer** (DBP) from 1985 to 1987, and **István Sebestyén** (Siemens) from 1987 to 2000;
- ESPRIT 563 [6] photovideotex image compression algorithm (PICA) [7] research project on integrated service digital network (ISDN) photo-videotex under chair, **Graham Hudson** (BT Research Labs);
- ISO TC97 SC2/WG8 under convener, **Hiroshi Yasuda** (NTT).

The **ESPRIT 563** [6] **PICA** [7] **research project** on ISDN photo-videotex concentrated on that application, which was rather close to the type of text and photos seen on the web. The PICA [7] project brought to JPEG several important components, like several candidate algorithms (one being the winning adaptive discrete cosine transform (ADCT) method), several test and selection images, and the testing and selection infrastructure (test and selection at Københavns Telefonselskab (KTAS), Copenhagen).

The requirements from TC97 SC2/WG8 were rather limited due to the fact that SC2 only had a limited scope to coding of various types, like coded characters, mosaic graphics and musical notation, some but not much for image coding, and especially for switching from one form to the other (e.g. from character to graphic). However, even for still image coding, the compression and coding, like that for facsimile (modified Huffman (MH), modified READ (relative element address designate) (MR), modified modified READ (MMR)), came from CCITT. JPEG also had contacts with some other ISO committees like TC97 SC18 and ITU-T SG8 on Office document architecture (ODA), which had interests in the raster-graphic type of still image as an application.

The most comprehensive sets of requirements were provided by the NIC Group of CCITT [8]. The author analysed the (at that time existing) different CCITT-applications and -services, e.g. videotex photographic mode, colour facsimile, hard and soft copy facsimile, office document architecture (actually another common text project with ISO TC97), teleconferencing, videotelephony still picture mode and digital phototelegraphy.

In a contribution [8] to the CCITT SGVIII Q.18 NIC group, NIC capable terminals and servers were defined with functionality very similar to that which a well-equipped personal computer (PC) would have a few years later on the Internet. Interworking among the various CCITT services and applications was also an important requirement (see Fig. 4).

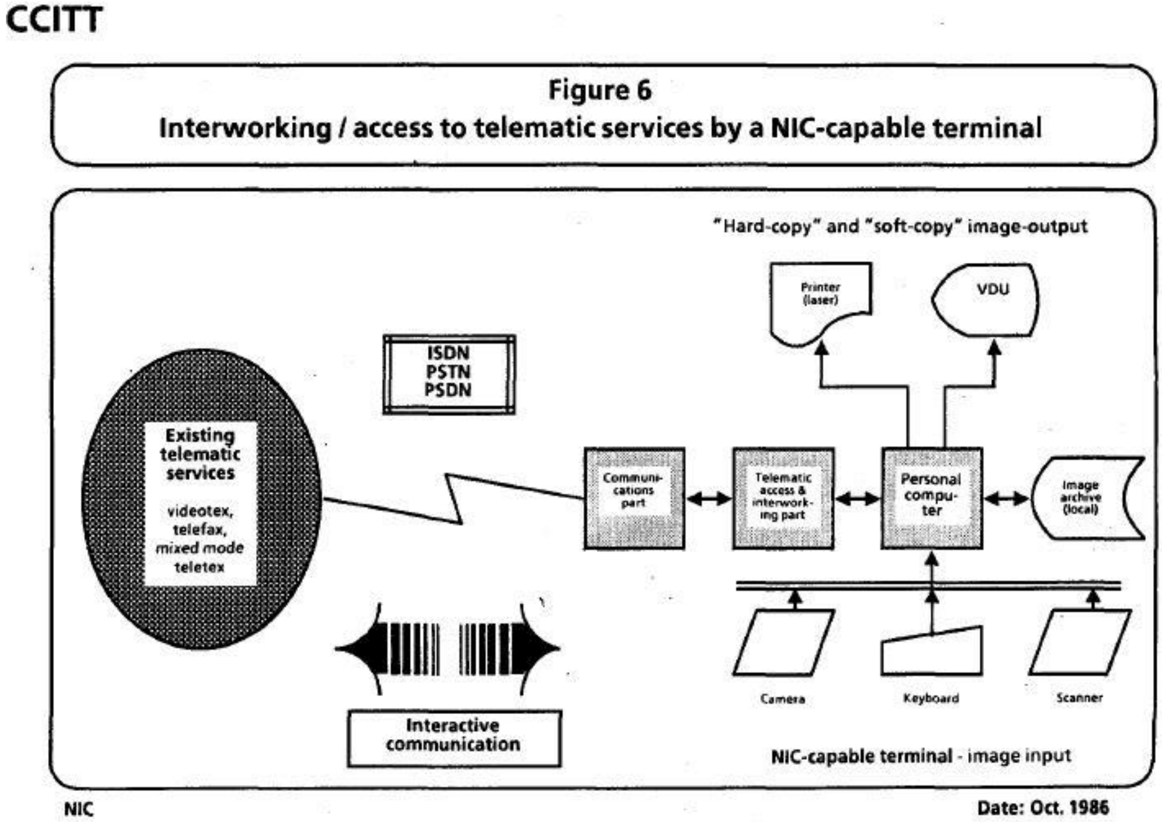
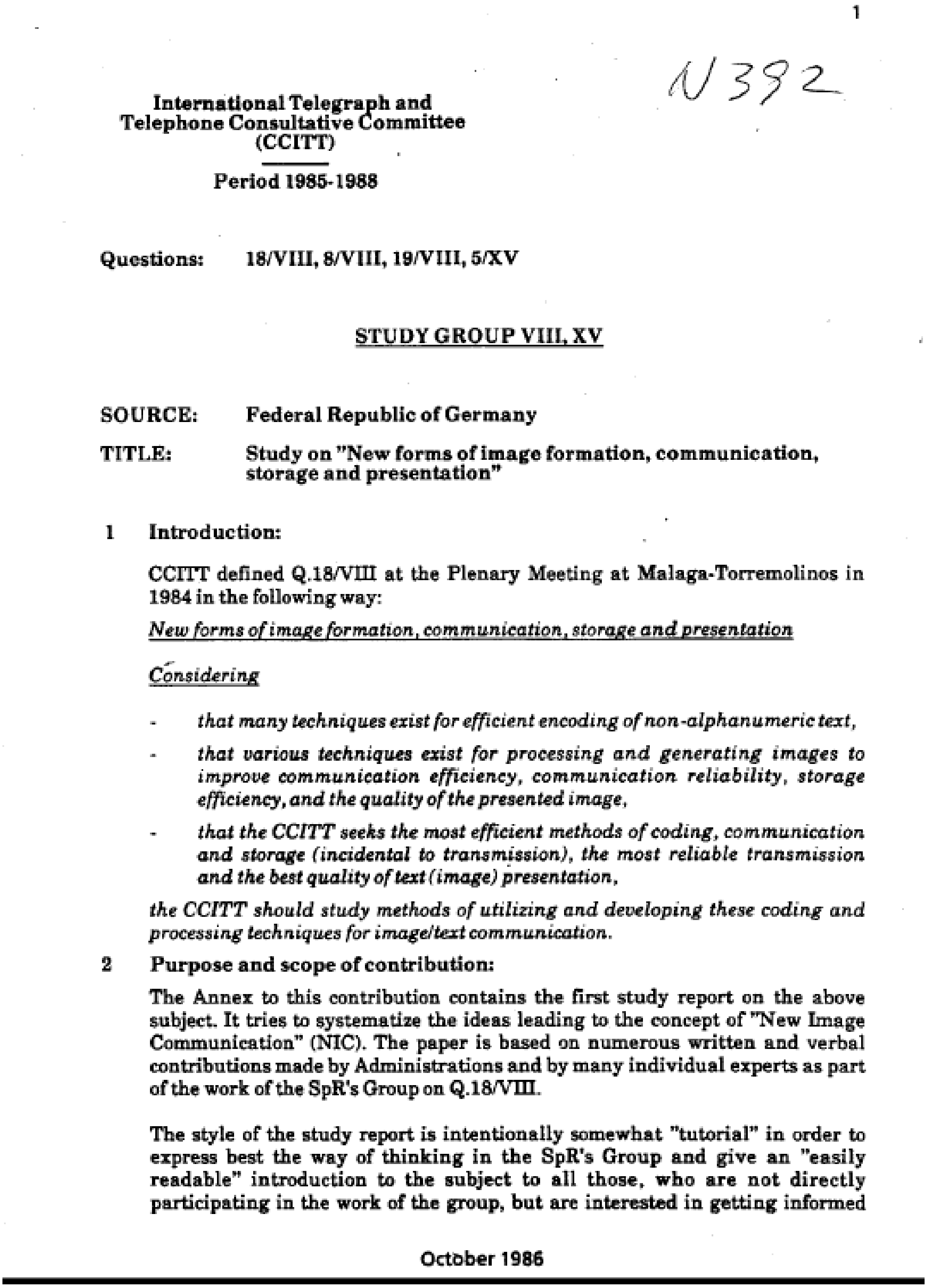


Fig. 4 – Interworking with existing telematics services is always an ITU requirement, thus a NIC-capable terminal had to do it too.

Out of all these requirements came the toolbox concept that first Q.18 NIC Group and later JPEG adopted. That concept was followed by several other ISO/IEC JTC1 and ITU-T still and motion image coding standardization projects, e.g. JPEG2000, which started in 1997. Even ISO/IEC JTC1/SC29 MPEG (Moving Pictures Expert Group) has taken over that concept for several of their projects.

In the following, some pages and figures from [8] are included (Figs. 5 to 9).



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N392

International Telegraph and Telephone Consultative Committee (CCITT)

Period 1985-1988

Questions: **18/VIII, 8/VIII, 19/VIII, 5/XV**

STUDY GROUP VIII, XV

SOURCE: **Federal Republic of Germany**

TITLE: **Study on "New forms of image formation, communication, storage and presentation"**

1 Introduction:

CCITT defined Q.18/VIII at the Plenary Meeting at Malaga-Torremolinos in 1984 in the following way:

New forms of image formation, communication, storage and presentation

Considering

- *that many techniques exist for efficient encoding of non-alphanumeric text,*
- *that various techniques exist for processing and generating images to improve communication efficiency, communication reliability, storage efficiency, and the quality of the presented image,*
- *that the CCITT seeks the most efficient methods of coding, communication and storage (incidental to transmission), the most reliable transmission and the best quality of text (image) presentation,*

the CCITT should study methods of utilizing and developing these coding and processing techniques for image/text communication.

2 Purpose and scope of contribution:

The Annex to this contribution contains the first study report on the above subject. It tries to systematize the ideas leading to the concept of "New Image Communication" (NIC). The paper is based on numerous written and verbal contributions made by Administrations and by many individual experts as part of the work of the SpR's Group on Q.18/VIII.

The style of the study report is intentionally somewhat "tutorial" in order to express best the way of thinking in the SpR's Group and give an "easily readable" introduction to the subject to all those, who are not directly participating in the work of the group, but are interested in getting informed

October 1986

Fig. 5 – Cover page of the CCITT contribution [8] describing NIC properties

Options	Properties of photographic images					
	Motion TV	Still image TV	Videotex	Facsimile	Mixed mode teletex	NIC
Motion image, freeze frame	Motion	Freeze frame	Freeze frame	Freeze frame	Freeze frame	Freeze frame
Black/White, multilevel, color	Multilevel, color	Multilevel, color	Multilevel, color (restricted)	Black/white	Black/white	Black/white, multilevel, color
Soft-copy, hard-copy	Soft-copy	Soft-copy	Soft-copy	Hard-copy	Hard-copy	Soft-copy, hard-copy
Progressive-, sequential build-up	Sequential	Sequential	both, but preferably progressive	Sequential	Sequential	Progressive
Symmetrical, asymmetrical encoding-, decoding	Asymmetrical	Asymmetrical	Asymmetrical	Symmetrical	Symmetrical	Symmetrical asymmetrical
Information preserving, non-preserving	Non-preserving	Non-preserving	Preserving	Preserving	Preserving	Preserving
Unified, individual algorithm	individual	individual	Unified (could be in principle)	individual	individual	Unified

Table 4
Summary of picture properties for selected photographic image communication applications/services

October 1986

Fig. 6 – Summary of picture properties of some CCITT image communication applications [8]

In Fig. 6, columns 2 and 3, headed Motion TV and Still image TV, respectively, were covered by CCITT SGXV (future ITU-T H.320 [9], ITU-T H.261 [10]) while the right hand columns were covered by CCITT SGVIII (telematic applications and services). Please note that some applications were left out (e.g. ODA, teleconferencing and phototelegraphy). The NIC capable terminals and applications showed similarities to some applications on the web, which emerged a few years later.

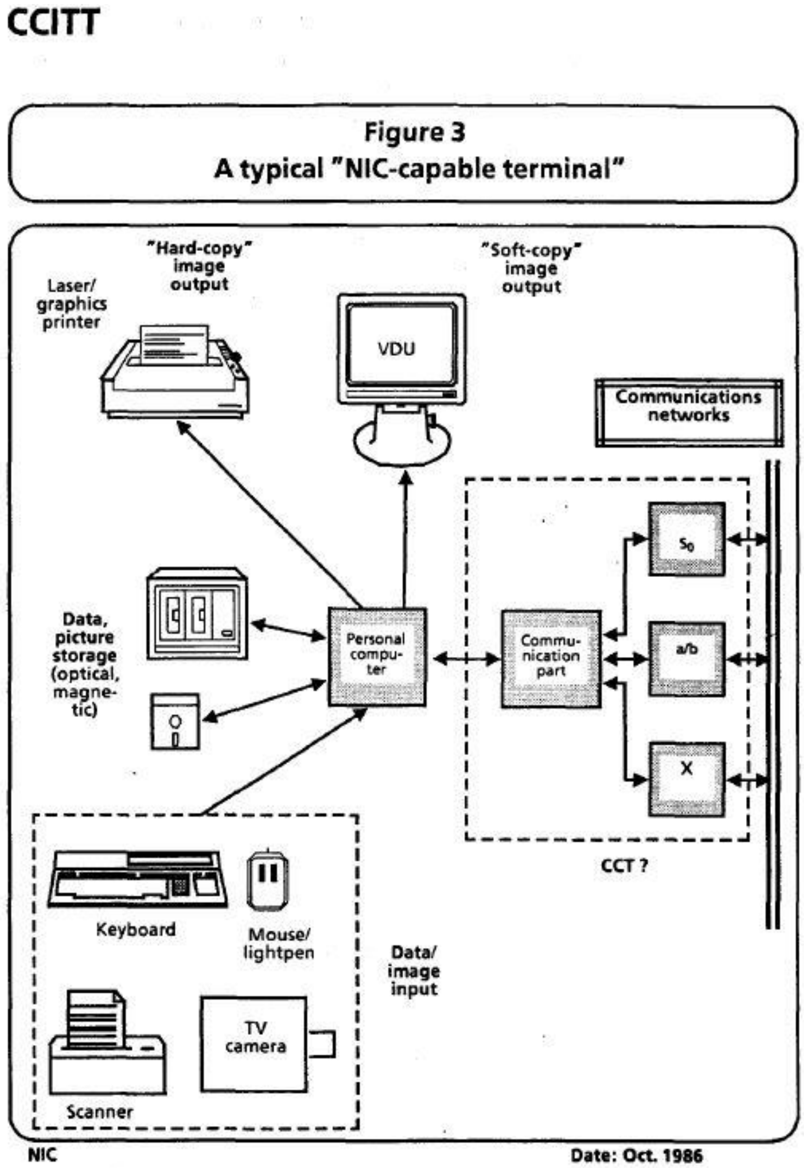


Fig. 7 – In [8], this is a typical configuration of an NIC-capable terminal. A typical PC configuration of the 1990s as seen in 1986

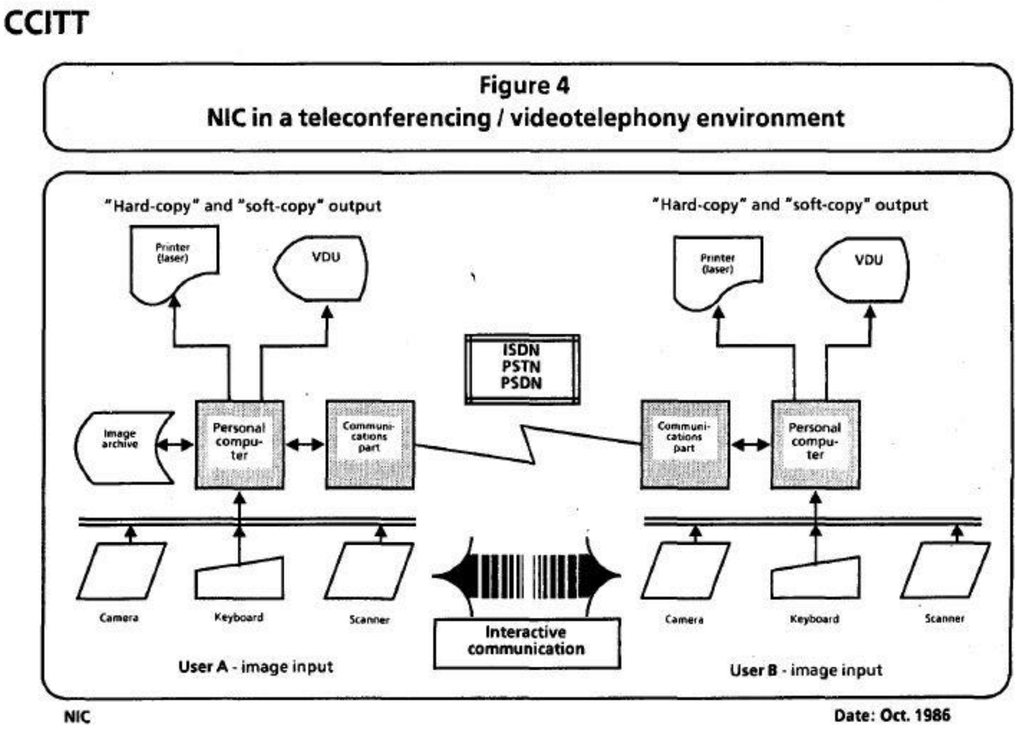


Fig. 8 – In [8], teleconferencing applications were seen as a major NIC application

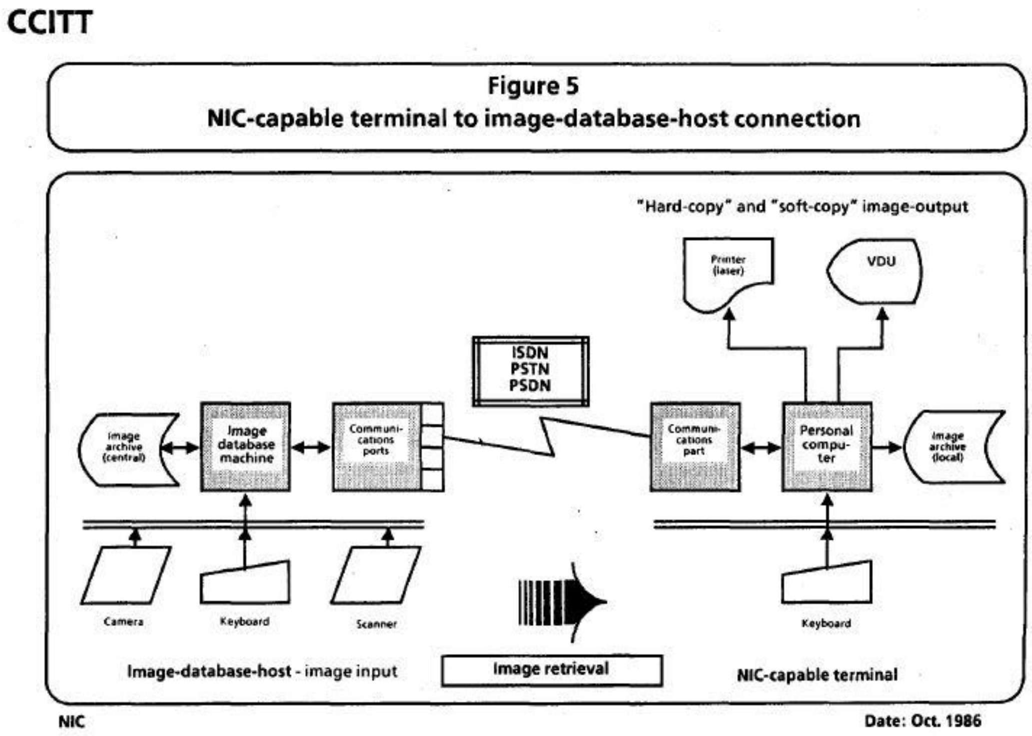
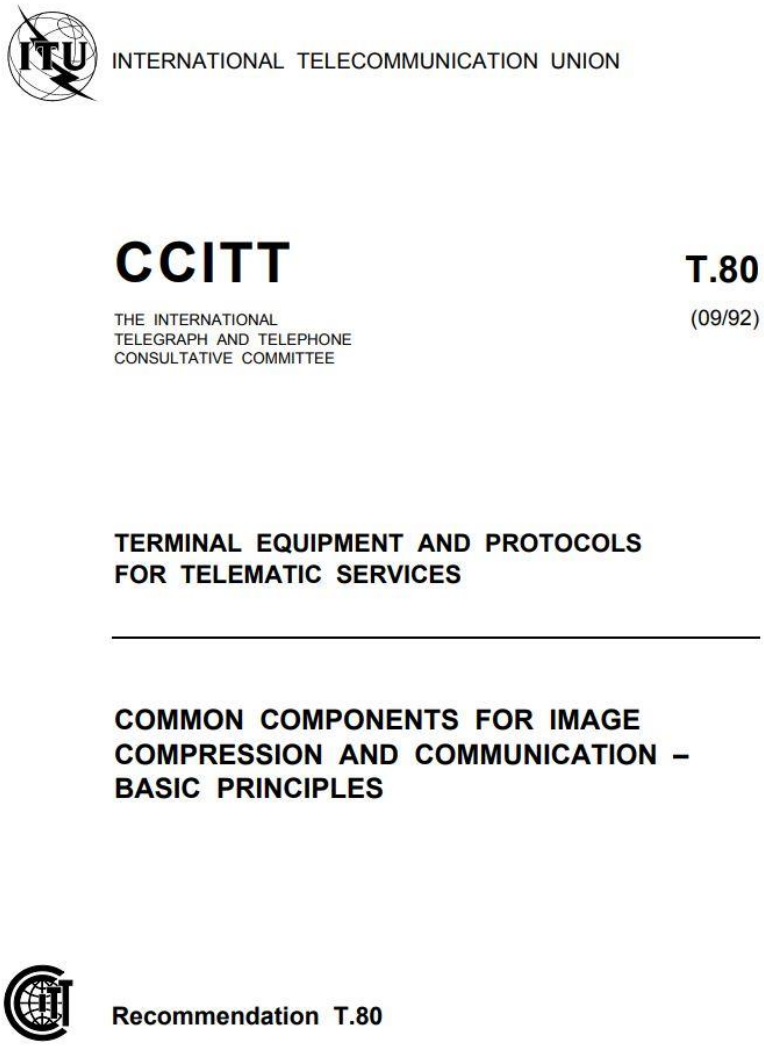


Fig. 9 – In [8], access to image databases (the future web) were seen as other major NIC applications

The foregoing studies in CCITT have resulted in the concept of common components of image communication and the resulting CCITT requirements vis-a-vis JPEG. How this was solved in the JPEG draft specifically is summarized in Fig. 11.

Note that on the CCITT side, this concept has been described by a separate Recommendation written by the author as special rapporteur and editor, ITU-T T.80 [11]. This Recommendation is adopted by CCITT/ITU-T only; unlike some other standards in the area of still picture coding, ISO/IEC JTC1 has not taken it over.

The cover page of ITU-T T.80 [11] is shown in Fig. 10.


INTERNATIONAL TELECOMMUNICATION UNION

CCITT **T.80**

THE INTERNATIONAL TELEGRAPH AND TELEPHONE CONSULTATIVE COMMITTEE (09/92)

TERMINAL EQUIPMENT AND PROTOCOLS FOR TELEMATIC SERVICES

COMMON COMPONENTS FOR IMAGE COMPRESSION AND COMMUNICATION – BASIC PRINCIPLES

Recommendation T.80

Fig. 10 – Title page of ITU-T T.80 [11]

ITU-T T.80 [11] describes the toolkit (common components) advantages/disadvantages as follows,

> *"5.6.1 Toolkit (Common components) concept*
>
> *Requirements are to be applicable to practically any kind of continuous-tone multi-level, limited-level, bi-level digital source images (i.e. for most practical purposes not to be restricted to images of certain dimensions, colour spaces, pixel aspect ratios, etc.) and not to be limited to classes of imagery with restrictions on scene content (such as line drawing and/or text in case of Recommendations T.4 and T.6), including complexity, range of colours and statistical properties.*
>
> *To achieve the above goal, the concept of using for image compression "Common components" from a Toolkit shall be a basic requirement.*
>
> *Note – Advantages:*
>
> – *various requirements of different imaging applications can be satisfied in a flexible way;*
>
> – *use of common hardware/software components when implementing imaging application, make implementation easier and more economical;*
>
> – *easier harmonization of different imaging for CCITT and ISO/IEC applications;*
>
> – *easier implementation of interworking among imaging applications;*

Disadvantages:

- *Imaging applications using Recommendation T.81 and/or T.82 are not necessarily compatible;*
- *the T.80-Series Toolkit is flexible, but very comprehensive;*
- *the employment of the T.80-Series compression methods in concrete application (including selection of proper parameters, defining resolutions, color models, interleave structure, pixel aspect ratio, communication protocols for transmission, etc.) is still a major task."*

2.1 JPEG: An architecture for image compression

Pennebaker and Mitchell [2] describe the common components and the toolbox nature of the JPEG-1 format,

> *"JPEG is more than an algorithm for compressing images. Rather, it is an architecture for a set of image compression functions. It contains a rich set of capabilities that make it suitable for a wide range of applications involving image compression.*
>
> *In one respect, however, JPEG is not a complete architecture for image exchange. The JPEG data streams are defined only in terms of what a JPEG decoder needs to decompress the data stream. Major elements are lacking that are needed to define the meaning and format of the resulting image. The JPEG committee recognized that these aspects are quite controversial and would probably have delayed the decision-making process needed to complete JPEG. They decided that, necessary as these parameters and constraints are, they are more properly the domain of application standards. The committee therefore deliberately did not include them in JPEG."*

2.2 JPEG baseline and extended systems

JPEG has defined a baseline capability that must be present in all JPEG modes of operation that use DCT, which is the common core that enables easier interoperability among applications.

To ensure progressive image build up for certain applications, several modes are supported:

In the progressive DCT modes in the spectral selection mode, the DCT coefficients are grouped into spectral bands, where for all 8 × 8 blocks the lower-frequency bands are sent first and then the higher frequency ones. In the successive approximation, the information is first sent with lower precision and then refined in later scans with higher precision data. In the hierarchical mode, the resolution of the image increases with the progressing stages. The best type of progressivity to use depends entirely on the application (Fig. 11).

While the earlier modes provide lossy images that can be used for many applications and result in higher compression rates, there are applications that require lossless image compression (e.g. for medical diagnosis images). The compression rate there is obviously worse.

On the entropy coding level, Huffman coding is mandatory for all images; optionally, arithmetic coding can be used. Essential characteristics of JPEG coding processes are shown in Fig. 12.

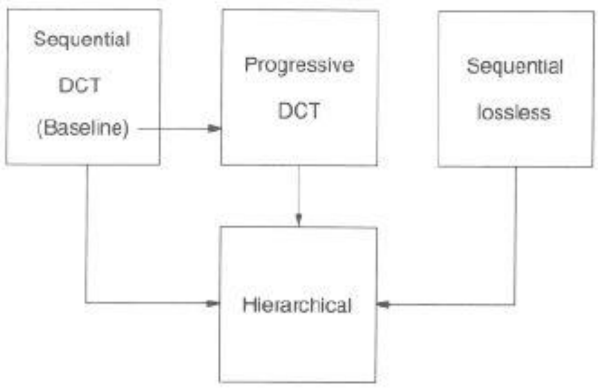


Fig. 11 – JPEG modes of operation [2]

Accordingly, ITU-T T.81 | ISO/IEC 10918-1 [1] summarizes the different JPEG modes in Fig. 12.

Table 1 – Summary: Essential characteristics of coding processes

Baseline process (required for all DCT-based decoders)
• DCT-based process • Source image: 8-bit samples within each component • Sequential • Huffman coding: 2 AC and 2 DC tables • Decoders shall process scans with 1, 2, 3, and 4 components • Interleaved and non-interleaved scans

Extended DCT-based processes
• DCT-based process • Source image: 8-bit or 12-bit samples • Sequential or progressive • Huffman or arithmetic coding: 4 AC and 4 DC tables • Decoders shall process scans with 1, 2, 3, and 4 components • Interleaved and non-interleaved scans

Lossless processes
• Predictive process (not DCT-based) • Source image: P-bit samples ($2 \leq P \leq 16$) • Sequential • Huffman or arithmetic coding: 4 DC tables • Decoders shall process scans with 1, 2, 3, and 4 components • Interleaved and non-interleaved scans

Hierarchical processes
• Multiple frames (non-differential and differential) • Uses extended DCT-based or lossless processes • Decoders shall process scans with 1, 2, 3, and 4 components • Interleaved and non-interleaved scans

22 CCITT Rec. T.81 (1992 E)

Fig. 12 – Essential characteristics of the JPEG-1 coding processes: the baseline process is mandatory in all JPEG applications to assure compatibility. Extended DCT-based processes, lossless processes and hierarchical processes are optional components to cover certain application areas [1]

2.3 JPEG patent policy

As previously mentioned, the informal JPEG decided from the very beginning that its patent policy should be RF. In February 1989 (at the Livingstone, NJ, USA, JPEG meeting), the patent policy was refined:

- for the baseline mode – common to all JPEG implementations – JPEG must be RF;
- however, for optional components, either RF or RAND components, e.g. for arithmetic coding, are allowed.

The reason is that the new JPEG algorithm had to compete with other already existing and very popular still picture CCITT coding Recommendations, e.g. for facsimile (MH, MR, MMR), which were all RF.

In addition, in JPEG standardization, the majority of participating companies were telecommunication carriers or from the telecom industry, both of whom were at that time generous with their IPRs in standards.

How was this possible so close to ITU (CCITT) and ISO (later JTC1)? Well, JPEG-1 development started in summer 1986 and ended in 1992 to 1993; however, the technically stable standard had been finished in 1990. At that time, ITU (then CCITT) and ISO (later JTC1) had no policy for common work and common text standards, let alone common patent policy.

Certainly, the tenour of the patent policies of the SDOs were still different in 1986 to 1990 when JPEG was developed and drafted. In ISO, the tenour was that patents and licences were only allowed in exceptional cases, when no other way was possible to arrive at an International Standard. In the CCITT, Director T. Irmer was just about to formulate a CCITT code of practice on patented items with a RAND-based patent policy regime. However, in its first application, ITU-T H.261 [10], all participants and patent holders had an understanding (though it was formally never documented) to keep that standard *de facto* licence fee free. With the later ISO MPEG format, this policy practice completely changed. From the MPEG-1 standard onwards, licences on a RAND basis were the normal practice; however, in JPEG, the desire and plan for an RF baseline in several subsequent standards still remained. Nevertheless, the RAND-based patent policy regime of ISO, IEC and ITU could not guarantee an RF baseline, so that it always remained an uncertain undertaking.

Information about possible patents was a persistent topic in the JPEG committee. More interactions concerned information sharing (what experts had heard back from their companies' IPR experts) than discussion about individual patents, e.g. whether a patent really applied to the JPEG specification. In that spirit, Annex L became an informal part of ITU-T T.81 | ISO/IEC 10918-1 [1],

> ***"L.1 Introductory remarks***
> *The user's attention is called to the possibility that – for some of the coding processes specified in Annexes F, G, H, and J – compliance with this Specification may require use of an invention covered by patent rights. By publication of this Specification, no position is taken with respect to the validity of this claim or of any patent rights in connection therewith. However, for each patent listed in this annex, the patent holder has filed with the Information Technology Task Force (ITTF) and the Telecommunication Standardization Bureau (TSB) a statement of willingness to grant a license under these rights on reasonable and non-discriminatory terms and conditions to applicants desiring to obtain such a license.*
> *The criteria for including patents in this annex are:*
> *a) the patent has been identified by someone who is familiar with the technical fields relevant to this Specification, and who believes use of the invention covered by the patent is* required *for implementation of one or more of the coding processes specified in Annexes F, G, H, or J;*
> *b) the patent-holder has written a letter to the ITTF and TSB, stating willingness to grant a license to an unlimited number of applicants throughout the world under reasonable terms and conditions that are demonstrably free of any unfair discrimination.*
> *This list of patents shall be updated, if necessary, upon publication of any revisions to the Recommendation | International Standard."*

This was unique at that time in a Recommendation | International Standard, but understandable, because at that time the patent database of ITU-T and ISO/IEC simply did not yet exist.

3. JPEG AND THE INDEPENDENT JPEG GROUP CONTACTS

While the requirements came from CCITT and ISO, the JPEG group worked autonomously. The specification created by the group (JPEG-8) was introduced to both SDOs and they were independently approved in parallel by both ITU-T SG8 and ISO/IEC JTC1 SC29, as ITU-T T.81 (1992)| ISO/IEC 10918-1:1994 [1].

The reason for the long time lag between the technically stable JPEG-8 and JPEG-9 specifications and the finally approved and published ITU and ISO/IEC JTC1 standards was that:

- the JPEG specification format had to be adapted to the new common ITU/ISO/IEC standard format (ITU-T T.81 was one of the first standards using the common text format);
- the formal SDO approval and publication procedures on the ISO/IEC side take too much time.

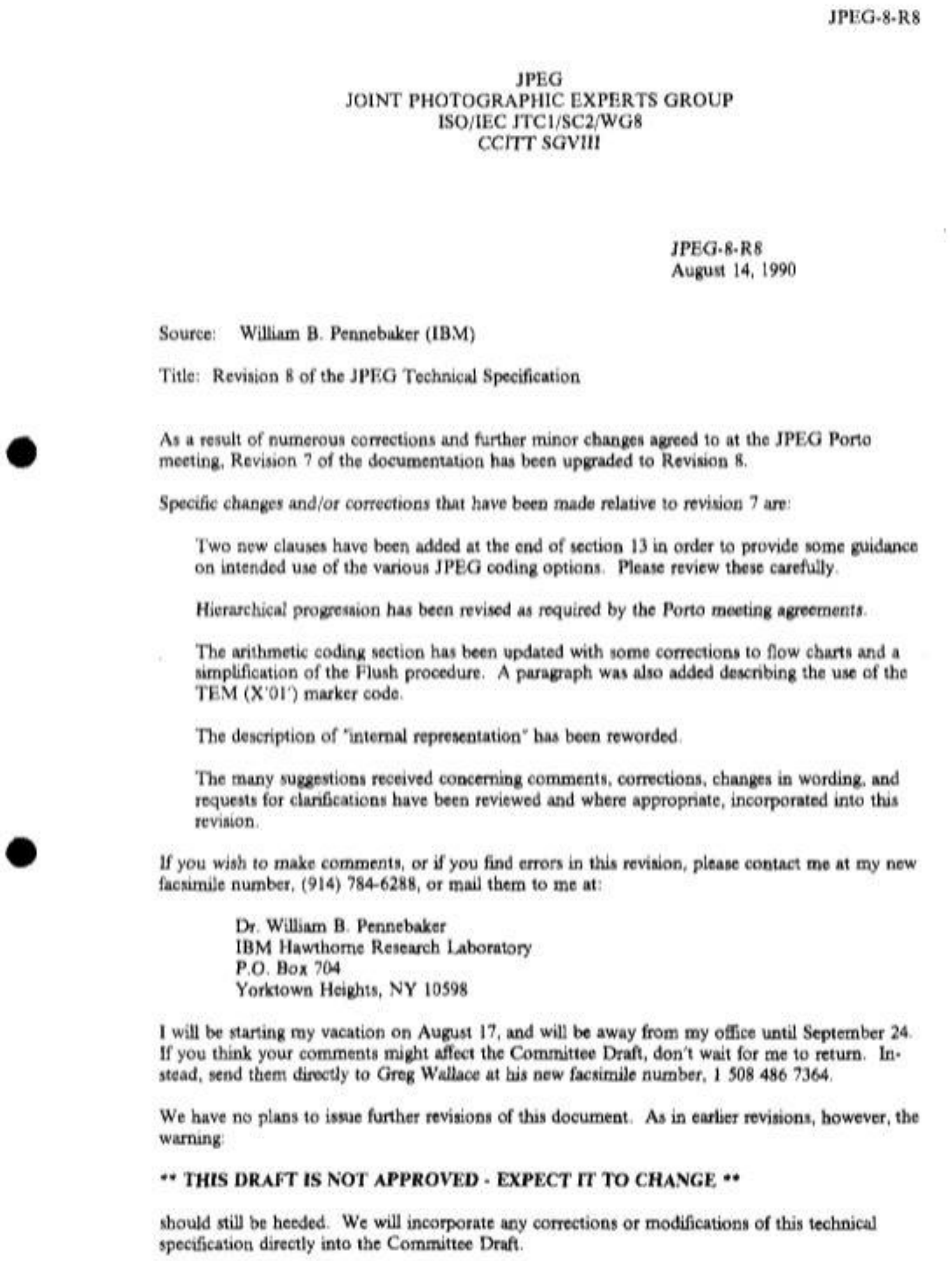
The JPEG-8 specification was a stable document from about the fall of 1990 (Fig. 13). That was also the time when JPEG passed the specifications to CCITT and JTC1 to start their approval procedures (e.g. the JTC1 committee draft (CD) was registered in April 1990 with the draft technical specification JPEG-8 revision 5 and in August 1990 revision 8 [12]).

JPEG-8 was also the specification ready for early implementations and testing. Via the relationship of JPEG to the parent SDOs, the drafts were available both to the ITU-T membership (CCITT SGVIII) and to ISO/IEC JTC1 member bodies.

JPEG Technical Specification

Revision 8

DRAFT: Subject to revision



JPEG-8-R8

JPEG
JOINT PHOTOGRAPHIC EXPERTS GROUP
ISO/IEC JTC1/SC2/WG8
CCITT SGVIII

JPEG-8-R8
August 14, 1990

Source: William B. Pennebaker (IBM)

Title: Revision 8 of the JPEG Technical Specification

As a result of numerous corrections and further minor changes agreed to at the JPEG Porto meeting, Revision 7 of the documentation has been upgraded to Revision 8.

Specific changes and/or corrections that have been made relative to revision 7 are:

Two new clauses have been added at the end of section 13 in order to provide some guidance on intended use of the various JPEG coding options. Please review these carefully.

Hierarchical progression has been revised as required by the Porto meeting agreements.

The arithmetic coding section has been updated with some corrections to flow charts and a simplification of the Flush procedure. A paragraph was also added describing the use of the TEM (X'01') marker code.

The description of "internal representation" has been reworded.

The many suggestions received concerning comments, corrections, changes in wording, and requests for clarifications have been reviewed and where appropriate, incorporated into this revision.

If you wish to make comments, or if you find errors in this revision, please contact me at my new facsimile number, (914) 784-6288, or mail them to me at:

Dr. William B. Pennebaker
IBM Hawthorne Research Laboratory
P.O. Box 704
Yorktown Heights, NY 10598

I will be starting my vacation on August 17, and will be away from my office until September 24. If you think your comments might affect the Committee Draft, don't wait for me to return. Instead, send them directly to Greg Wallace at his new facsimile number, 1 508 486 7364.

We have no plans to issue further revisions of this document. As in earlier revisions, however, the warning:

**** THIS DRAFT IS NOT APPROVED - EXPECT IT TO CHANGE ****

should still be heeded. We will incorporate any corrections or modifications of this technical specification directly into the Committee Draft.

Fig. 13 – Cover and "Read me" page of JPEG-8 revision 8 – the input document to CCITT SGVIII and ISO/IEC JTC1 SC2 for the formal approval process and to the IJG for OSS implementation

It was then rather incidental that the JPEG-8 specification was picked up from the USA JTC1 member body ANSI by **Tom Lane** who had founded the IJG. The aim was to take the JPEG specification, develop an open source code and make it available to everyone free of charge.

This occurred completely independently of the JPEG committee and the parent SDOs. At that time, the JPEG committee hardly knew what OSS was and nothing about the IJG.

It was also purely coincidental that the modular toolbox type of JPEG design was perfect for open source implementations (for the IJG, it was enough first to build those components that were felt most essential for their target applications), and the RF nature of the standard helped to avoid any licensing troubles with possible patent holders. Open source advocates are very often individuals with no or little information and communications technology (ICT) company background.

With Tom Lane, the author had the following email exchange, 4 August 2018:

> *"a) Was JPEG-8-R the first JPEG specification and when was it picked up by the IJG? And when?*
>
> ***As far as I can tell from digging around in old email, we obtained paper copies of JPEG-8-R8 from the X3 Secretariat in November or December 1990, which is more or less when the group started working.***
>
> *b) The first IJG Code of September 1991 corresponded to which JPEG-8-R specification?*
>
> ***We had copies of JPEG-9-R6 by February 1991, and that would have probably been what we were working from for "v1", though I found some mail questioning whether 9-R6 was actually any more authoritative than 8-R8. (BTW, my files show IJG's "v1" public release as being dated 7 October 1991.)***
>
> *c) When did IJG implement the finally approved JPEG standard (which was approved by CCITT in 1992 first and which was quite close to the earlier JPEG-8 last version)?*
>
> ***I do not recall that we had to make any standards-compliance changes after the v1 release, although we gradually implemented larger fractions of the spec (12-bit depth came later, I think, and progressive mode was definitely much later). But this was a lot of years ago, so I might've forgotten something.***
>
> *d) Who was your main contact in the JPEG team? I just remember reports about the progress of IJG, but I cannot remember who presented that (maybe it was Greg Wallace the JPEG Chairman at that time)?*
>
> ***I was in touch with Greg from about May of 1991. I also seem to have been in contact with William Pennebaker from Jan 1991, though I don't have any actual emails to/from him till much later (maybe the early contacts were by phone? or I'm just looking in the wrong archive?). It looks like Greg was by far the most helpful, though. I don't recall talking to any other committee members besides them and Joan Mitchell; and most of my interactions with Joan were later, when she was working on the pink book.***
>
> *e) Particularly interesting was the implementation of the arithmetic coder, that was included in one version (which one?), but then taken out in the next version (which one?).*
>
> ***It was already gone in v1. I do have a "tarball" (sort of ZIP) of a prototype from May 3 1991 that appears to have a non-stub arith.c file in it."***

It should be added that the IJG chose a sort of Berkeley Software Distribution (BSD) OSS licence (from the IJG software version jpeg-6b) for its code:

```
-----------------------------------

"This software is copyright (C) 1991-1998, Thomas G. Lane.

All Rights Reserved except as specified below.

Permission is hereby granted to use, copy, modify, and distribute this
software (or portions thereof) for any purpose, without fee, subject to
these conditions:

(1) If any part of the source code for this software is distributed, then
this README file must be included, with this copyright and no-warranty
notice unaltered; and any additions, deletions, or changes to the original
files must be clearly indicated in accompanying documentation.

(2) If only executable code is distributed, then the accompanying
```

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documentation must state that "this software is based in part on the work of the Independent JPEG Group".

(3) Permission for use of this software is granted only if the user accepts full responsibility for any undesirable consequences; the authors accept NO LIABILITY for damages of any kind.

These conditions apply to any software derived from or based on the IJG code, not just to the unmodified library. If you use our work, you ought to acknowledge us.

Permission is NOT granted for the use of any IJG author's name or company name in advertising or publicity relating to this software or products derived from it. This software may be referred to only as "the Independent JPEG Group's software".

We specifically permit and encourage the use of this software as the basis of commercial products, provided that all warranty or liability claims are assumed by the product vendor."

----------------------------
```

As previously noted, the JPEG also had its own patent policy. The so-called baseline mode (which was common to all JPEG variants to enable interoperability among all JPEG coders) had to be RF. On JPEG, optional feature RAND licensing was permitted. The arithmetic coder mentioned in paragraph e) was such a RAND component. It was only optional, so it could be left out from a given use and implementation. The IJG first implemented the arithmetic coder, but when they found out that it was a royalty-bearing component, they immediately removed it from the open source code.

```
-----------------------------

From IJG Software Library "Readme" file by Tom Lanes

"It appears that the arithmetic coding option of the JPEG spec is covered by patents owned by IBM, AT&T, and Mitsubishi. Hence, arithmetic coding cannot legally be used without obtaining one or more licenses. For this reason, support for arithmetic coding has been removed from the free JPEG software. (Since arithmetic coding provides only a marginal gain over the unpatented Huffman mode, it is unlikely that very many implementations will support it.) So far as we are aware, there are no patent restrictions on the remaining code."
```

Author's note – All JPEG-1 patents have now expired.

This was a very important lesson to learn very early on: OSS does not like components that are not royalty free. The JPEG Recommendation | International Standard was formally approved by ISO/IEC JTC1 and ITU-T, respectively, under the ISO, IEC and ITU-T RAND joint patent policy regime. However, *de facto* the baseline mode of JPEG remained RF. We see today the same phenomenon when some fast-track and publicly available specification (PAS) drafts come to JTC1. The specification is first developed by an SDO or consortium (e.g. the World Wide Web Consortium (W3C), Organization for the Advancement of Structured Information Standards (OASIS), Ecma International) under an RF patent policy regime, but then later also approved by JTC1 under RAND one. Of course, with the limitation that the JTC1 approval can from a technical point of view be either "yes" or "no" (but no technical modification). With JPEG-1, *de facto* this was the case too.

Feedback into the standardization cycle: This is theoretically possible, and in many cases actually useful. However, for JPEG-1 this was not the case. Some members of the JPEG Committee themselves had a few early JPEG-1 implementations in both software and hardware. Those experiences have been shared with other JPEG committee members and provided the necessary feedback to the standardization part of JPEG. Nevertheless, in other standardization projects, this might be an interesting asset.

3.1 Conclusions and take aways on JPEG and the IJG OSS process

i) Standardization first by an SDO, forum or consortium and subsequent implementation of the standard in OSS is a useful project, and was done in the JPEG-1 standardization project. Nevertheless, standardization and product development must be close in time to each other, so that the relationship between standard setting and implementation can be established.

ii) OSS implementation is helpful in the verification of the standard, providing feedback into the standardization project.

iii) OSS implementation first helps to promote the standard and to ensure market acceptance. In the case of JPEG-1, the worldwide and free availability of the IJG code that could be built in into various applications free of charge contributed significantly to the success of the JPEG-1 Recommendation | International Standard.

iv) OSS prefers to take standards for implementation that are patent RF. However, the patent policy of ITU, ISO and IEC only guarantees RAND. RF declarations on patents in the standard are not enough, because all contributors are permitted to submit contributions under RAND too, plus there is always a remaining third party left-out part that is RAND. There are organizations with RF patent policy options (e.g. W3C, OASIS, Ecma International) that also have real RF-based patent policy regimes. So co-operating with them on such projects is beneficial. Fast tracking of or a PAS for such standards in JTC1 is also a good solution too.

v) The co-operation between IJG and JPEG worked well for about 10 years. First, the JPEG Committee was absorbed by ITU-T SG8 and ISO/IEC JTC1 SC29. This was the case after the ITU/ISO/IEC co-operation for joint work and joint text Recommendation | International Standard document had been formalized in 1993. Then JPEG continued to work according to ITU-T and JTC1 policies and rules, and lost some special components (like the JPEG IPR policy) that were rather OSS friendly. The informal liaison between JPEG and IJG was never formalized (IJG had no legal status). However, until about 2000, the IJG gradually also implemented further ITU-T T.81 (1992) ISO/IEC 10918-1:1993 [1] components (like progressive coding modes), changed their direction slightly and started to fork from the ITU-T/ISO/IEC Recommendation | International Standard. Moreover, a new generation of leadership and membership took over the IJG work, which had slightly different goals from the starting IJG generation. Such unpredictability in the long-term relation to OSS is a reality and should be taken into consideration.

4. PLANNED AND NOT DIRECTLY PLANNED (BUT SUCCESSFUL) JPEG APPLICATIONS

As pointed out in section 2, the most detailed requirements for the JPEG toolbox came from CCITT SGVIII. Consequently, after the JPEG-1 Recommendation was approved in 1992, work continued in ITU-T to include ITU-T T.81 in ITU-T applications. These are briefly described in 4.1.

Furthermore, for other JPEG experts, like Pennebaker and Mitchell [2] it was clear that this toolbox had many possible other uses besides communication, PC-images, printing, medical images etc. However, as [2] explains, those were left to other applications and remained outside of the JPEG-1 Recommendation | International Standard. This section describes a few examples of these.

4.1 ITU-T JPEG applications

It is an irony of standardization that the requirements and the toolbox came from telecommunication use cases to support a new generation of ITU-T imaging telecommunication applications. However, many of these applications are, from today's historic perspective, less successful and rather unimportant.

Colour facsimile group 4 (4.1.2) never reached the market, videotex (4.1.3) has been completely replaced by the worldwide web, ODA (4.1.5) never became really popular, and was replaced with hypertext on the web and other office document applications like office open extensible markup language (OOXML) or open document format (ODF), which themselves became ISO/IEC International Standards.

Other applications like colour facsimile group 3 (4.1.1) have even today some limited use, but in importance far beyond, for example, a JPEG image attached to an email. Computer conferences (4.1.4) with ITU-T T.120 [13] were popular in the 1990s and in the early 2000s, but it is difficult to estimate what market share remains today. ISDN videophone (ITU-T H.320 [9] and ITU-T H.261 [10]) saw some modest use in the past, but no longer.

Note that all of these applications had their own communication protocols, file formats, colour models, etc. This was the reason, from the CCITT side, why these components were not required and so not included in the JPEG-1 standard.

4.1.1 Colour facsimile group 3: Annex E of ITU-T T.30 [14]; Annex E of ITU-T T.4 [15]

Facsimile group 3 was especially popular during the 1980s, but in the 1990s the Internet and the worldwide web gradually replaced this service. It has still some advantages; however, when colour facsimile group 3 was implemented in products, interest in this application was already in decline. Annex E of ITU-T T.30 [14] opens,

> *"This annex describes the additions to ITU-T Rec. T.30 to enable the transmission of continuous-tone (multilevel) colour and gray-scale images for Group 3 facsimile mode of operation.*
>
> *The objective is to enable the efficient transmission of high quality, full colour and gray-scale images over the general switched telephone network and other networks. The images are normally obtained by scanning the original sources with scanners of 200 pels/25.4 mm or higher, and bit depths of eight bits per picture element per colour component or higher. The original sources are typically colour or gray-scale photographs or hard copies from high-quality printing systems.*
>
> *The method specified here performs well on full-colour images, but for transmission of multi-colour images such as business graphics, other methods may be more efficient. Two such methods would be the transmission of images using ITU-T Recs T.434 (Binary File Transfer) and T.82 (JBIG encoding). This annex does not address the encoding of multi-colour images. This topic is left for further study.*
>
> *The encoding methodology for continuous-tone (multilevel) images is based on the JPEG (ITU-T Rec. T.81 | ISO/IEC 10918-1) image encoding standard. The JPEG image coding method includes both a lossy mode and a lossless mode of encoding. This annex adopts the lossy mode of encoding which is based on the Discrete Cosine Transform.*
>
> *The technical features of encoding and decoding the continuous-tone colour and gray-scale image data are described in Annex E/T.4. It describes two modes of image encoding (lossy gray-scale and lossy colour) which are defined using ITU-T Rec. T.81."*

ITU-T T.30 [14] is actually in use because facsimile group 3 terminals that were popular before the web era are still around, along with colour printers with facsimile sending and receiving capability. Nevertheless, its importance is substantially less than that of, for example, web pages with photographic content.

4.1.2 Colour group 4 facsimile: ITU-T T.563 [16]; ITU-T T.42 [17]

Clause 2.5 of ITU-T T.563 [16] reads,

> *"For the continuous tone colour image, the continuous tone colour representation method for G4 facsimile is defined in Recommendation T.42."*

Clause 6.1 of ITU-T T.42 [17] reads,

> *"In order to represent continuous-tone colour data accurately and uniquely, a device-independent interchange colour space is needed. This colour image space should encode the range of hard copy image data the range of soft copy image data.*

> *The following represents an example for the use of this model: a Sender scans an original colour image using a specific device-dependent colour space which may depend on the illuminant and/or filters of a particular scanner system. The Sender converts the device-dependent colour data to the interchange colour representation. The Sender then encodes the data using a coding algorithm such as ITU-T Rec. T.81 (JPEG). The Receiver receives the encoded data. The data is decoded and converted to the colour space which is device dependent. In order to define the colour representation, it is necessary to specify the white point, illuminant and gamut range used in the interchange data representation."*

ITU-T T.563 [16] – though published – is practically not used and most likely has never been implemented. Facsimile group 4 (including so called mixed mode terminals) existed only on paper and in the Recommendation. The failure of facsimile group 4 had to do with: a) the different options in the network layers (public switched telephone network (PSTN), packet switched data network (PSDN), circuit switched data network (CSDN), ISDN – none of them too popular); b) damaging discussion on the incompatibility on ISDN between facsimile groups 3 and 4. That was enough to kill the potential market.

4.1.3 Videotex: Annex F of ITU-T T.101 [18]

Actually, this application comes closest to what is today presented on web pages with photographic content. Part of Annex F of ITU-T T.101 [18] reads,

> *"This annex defines a data syntax to be used for conveying photographic data in a Videotex environment. The necessary tools are provided for the transfer of photographic data, typically from a Videotex Host to a Videotex terminal. This data syntax is equally applicable to either storage or communication applications and is independent of physical device or transmission media.*
> *This annex does not deal with the visible appearance of the displayed pictures, however all the necessary source image information is provided to make the proper physical adaptation at the receiving side. The specification of post-processing techniques is left to the implementers and is, therefore, outside the scope of this annex….*
> *…. In particular, the …-Joint Photographic Experts Group (JPEG) compression algorithm, based on the discrete cosine transform (DCT), the facsimile ITU-T Recommendation T.4 and CCITT Recommendation T.6 coding algorithms are used. In this annex the algorithms or compression techniques themselves are not described, references are provided."*

ITU-T T.101 [18] was also adopted by the European Conference of Postal and Telecommunications Administrations (CEPT) [19] and European Telecommunications Standards Institute (ETSI). About 5 000 terminals were built and put into operation in France alone. Today all videotex services worldwide have been replaced by the web. Videotex was killed by: a) incompatibility of the major world regional standards; b) its terminals were mostly dedicated (not PCs) and had no other functionality. Thus, it came one or two generations too early.

Nevertheless, videotex is important from a historic point of view. Many concepts seen today on the web had an early videotex variant, e.g. photo-videotex or tele-software (early and similar versions of web scripting languages like ECMAScript and JavaScript.

4.1.4 Multimedia conferencing: ITU-T T.120 [13]; ITU-T T.126 [20]

ITU-T T.120 [13] (including ITU-T T.126 [20]) is one of the ITU-T Recommendations utilizing JPEG-1 and implemented very often. The system architecture of ITU-T T.120 [13] is shown in Fig. 14. Screen sharing, sharing of photographic images via internet and web-linked PC stations are classical uses. Thus, ITU-T T.120 [13] using JPEG-1 has been successful.

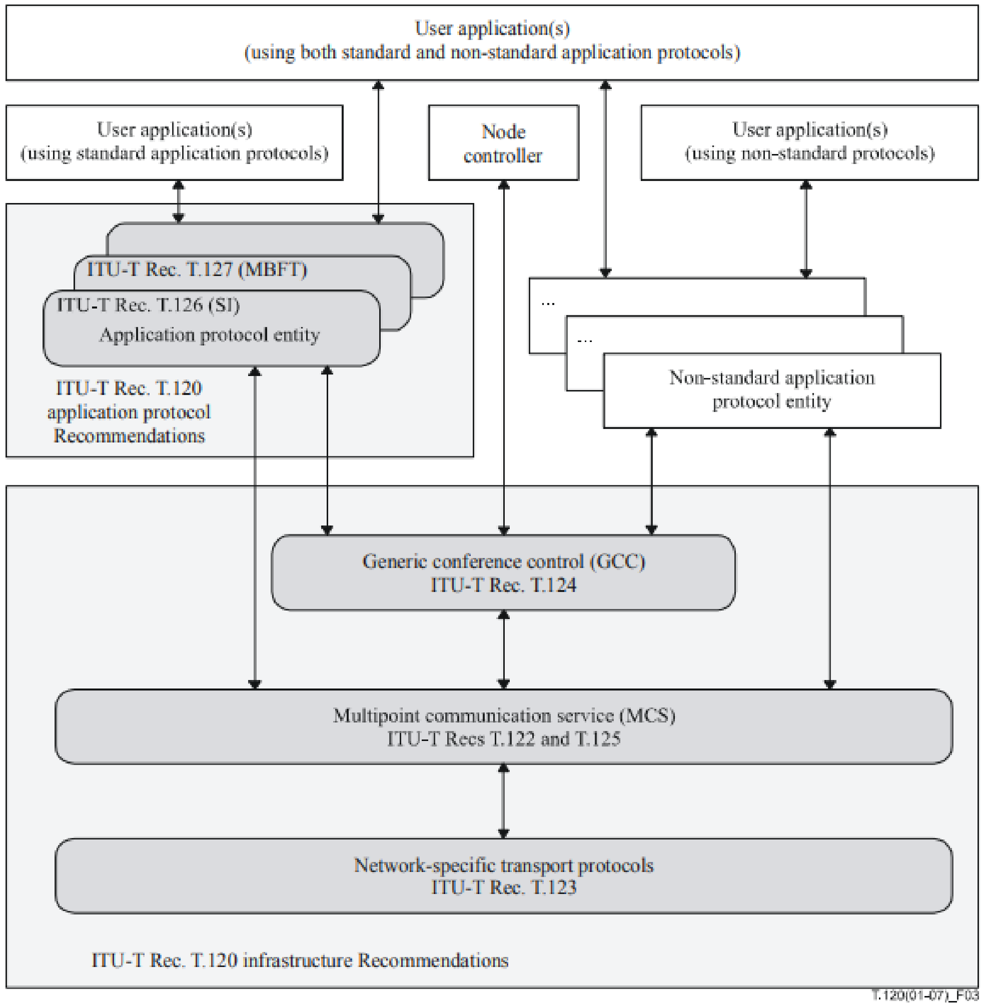

Figure 3 – T.120 system model

Fig. 14 – The situation of the still image (SI) standard within the ITU-T T.120 [13] system architecture

4.1.5 Open document architecture (ODA) raster graphics content architecture: ITU-T T.417 | ISO/IEC 8613-7 [21]

Amendment 1 to ITU-T T.417 | ISO/IEC 8613-7 [21] supports the use of joint bi-level image experts group (JBIG) and JPEG colour in applications using raster graphics content,

> *"The JPEG encoding schemes defined in CCITT Rec. T.81 | ISO/IEC 10918-1 specify two classes of coding processes: lossy (not information preserving) and lossless (information preserving). The lossy procedures are all based on the Discrete Cosine Transform (DCT) and the lossless are based on a predictive technique. Four modes of encoding are defined: the sequential DCT-based mode, the progressive DCT-based mode, the sequential lossless mode, and the hierarchical mode.*
>
> *In the sequential DCT-based mode 8 × 8 blocks of pixels are transformed. The resulting coefficients are quantized and then entropy coded (losslessly) by Huffman or arithmetic coding. The pixel blocks are typically formed by scanning the image (or image component) from left to right, and then block row by block row from top to bottom. The allowed sample precisions are 8 and 12 bits per component sample. Of the DCT-based methods, the sequential DCT-based mode requires the least amount of storage as a file.*
>
> *For the progressive DCT-based mode, the quantized coefficients for the complete image component are determined, stored, and processed by either spectral selection or successive approximation. These two techniques may be used separately or may be combined in various ways.*

The sequential lossless mode is not based on DCT but is a predictive coding technique. The predicted value of each pel position is calculated from up to three of its nearest neighbours above and to the left, and the difference between the predicted value and the actual value is entropy encoded losslessly. For the lossless mode of operation, sample precisions from 2 bits per sample to 16 bits per sample are allowed.

In the hierarchical mode, an image (or image component) is transmitted with increasing spatial resolution between progressive stages by first downsampling the image a number of times to produce a reference stage, which is transmitted by one of the other three modes of operation. The output of each hierarchical stage is used as the prediction for the next stage and the difference is coded. The coding of the differences may be done using only DCT-based processes, only lossless processes or DCT-based processes with a final lossless process for each component.

All decoders that include any DCT-based mode of operation shall provide a default decoding capability, referred to as the baseline sequential DCT process. This is a restricted form of the sequential DCT-based mode, using Huffman coding and 8 bits per sample precision for the source image."

This quote is a very good description of what the JPEG toolkit does, but in practice ITU-T T.417 | ISO/IEC 8613-7 [21] including the raster graphic content architecture was too complex, with not many implementations. On the web, hypertext markup language (HTML) standards including JPEG-1 dominate.

4.1.6 ISDN Videophone still image transmission: ITU-T H.261 [10]

Annex D of ITU-T H.261 [10] reads,

"This annex describes the procedure for transmitting still images within the framework of this Recommendation. This procedure enables an H.261 video coder to transmit still images at four times the normal video resolution by temporarily stopping the motion video. Administrations may use this optional procedure as a simple and inexpensive method to transmit still images. However, Recommendation T.81 (JPEG) is preferred when the procedures for using T.81 within audiovisual systems are standardized."

ITU-T H.261 [10], which became the mother of all later video coding standards in the ITU (and also ISO/IEC JTC1/SC29 MPEG), was specified in CCITT SGXV by the so-called Okubo Group. JPEG had liaison and contacts with the Okubo group and some harmonization effort took place, e.g. on Huffman coding. However, it was completely coincidental that both the Okubo Group and JPEG found in the tests and selection that a DCT-based image-coding standard provided the best quality images and should be the base for both standards. Nevertheless, it was not easy for SGXV to accept that in Annex D of ITU-T H.261 [10], they should give preference to the JPEG format. However, in practice, there are only a few use cases of ITU-T H.320 [9] ISDN videophones, e.g. in Germany; however, the few thousand implementations cannot compete with web-based videophones, e.g. Skype and Zoom, etc.

4.2 JPEG file interchange format

The development of the JPEG file interchange format (JFIF) [22][23] was a most useful and successful gap-filling activity for the ISO/IEC JTC1 side. While in the ITU-T there was, from the very beginning, a clear strategy to include ITU-T T.81 in several ITU-T applications (see 4.1), on the JTC1 side this was completely ignored. So, it had to be filled by an *ad hoc* activity from members of the IT Industry:

Wikipedia [23] reads,

"*Development of the JFIF document was led by Eric Hamilton of C-Cube Microsystems, and agreement on the first version was established in late 1991 at a meeting held at C-Cube involving about 40 representatives of various computer, telecommunications, and imaging companies. For nearly 20 years, the latest version available was v1.02, published September 1, 1992*

In 1996, RFC 2046 specified that the image format used for transmitting JPEG images across the internet should be JFIF. The MIME type of "image/jpeg" must be encoded as JFIF. In practice, however, virtually all Internet software can decode any baseline JIF image that uses Y or YC_bC_r components, whether it is JFIF compliant or not.

> *As time went by, C-Cube was restructured (and eventually devolved into Harmonic Inc., LSI Logic, Magnum Semiconductor, Avago Technologies, Broadcom Limited, and GigOptix, GigPeak, etc.), and lost interest in the document, and the specification had no official publisher until it was picked up by Ecma International and the ITU-T/ISO/IEC Joint Photographic Experts Group around 2009 to avoid it being lost to history and provide a way to formally cite it in standard publications and improve its editorial quality.*
>
> *It was published by ECMA in 2009 as Technical Report number 98 (TR/98) to avoid loss of the historical record, and it was formally standardized by ITU-T in 2011 as its Recommendation T. and by ISO/IEC in 2013 as ISO/IEC 10918-5. The newer publications included editorial improvements but no substantial technical changes."*

The JFIF [22][23] is a minimal file format that enables the exchange of JPEG encoded images (according to ITU-T T.81 | ISO/IEC 10918-1 [1]) having one or three colour channels and 8 bits per colour channel between a wide variety of platforms and applications. This minimal format does not include some advanced features found in various other specified file formats. The optional inclusion of thumbnail images for rapid browsing is also supported.

Instead of the JFIF, between 1993 and 1996, ISO/IEC and ITU-T developed (under the JTC1 SC29/WG1 convenorship of Eric Hamilton,) ITU-T T.84 | ISO/IEC 10918-3 [24], which defined extensions [including variable quantization, selective refinement, composite tiling, and a still picture interchange file format (SPIFF)] to JPEG-1. Added to that, ITU-T T.86 [25] covers registration of JPEG profiles, SPIFF profiles, SPIFF tags, SPIFF colour spaces, APPn markers, SPIFF compression types and registration authorities (REGAUT).

The SPIFF extension provides for the interchange of image files between application environments. It is a generic file format intended for interchange only and does not include many of the features found in application-specific formats. The interchange format omits certain parameters, e.g. aspect ratio and colour space designation, because they are not strictly required for decoding the image component values. SPIFF is a complete coded image representation, i.e. it includes all parameters necessary to reconstruct and present the decoded picture accurately on an output device.

SPIFF was designed to be backwards compatible to JFIF. It was recognized by JPEG from the very beginning that without backwards compatibility SPIFF would have no chance to succeed on the market. Unfortunately, even with that policy it did not succeed. It was too complex and too late. Thus, JFIF and their formal versions in Ecma International (TR/98) [26], ISO/IEC and ITU-T is still *the* file format standard for JPEG-1 images.

4.3 M-JPEG

As described in Pennebaker and Mitchell [2], one of the earliest implementers of the JPEG Recommendation | International Standard was C-Cube Microsystems Inc., which developed the CL550 JPEG codec chip in 1990 [27]. This was the world's first real-time JPEG codec capable of compressing and decompressing image frames fast enough to permit use in full-motion video.
Cockroft and Hourvitz [28] reported the NeXT project of Steve Jobs in 1991,

> *"NeXT Inc is using the Joint Photographic Experts Group (JPEG) draft image compression standard in several of its products. NeXTstep is the standard operating environment on NeXT computers and uses Tag Image File Format (TIFF) as its standard image format. NeXTstep supports TIFF file use through the NXImage class. Version 2.0 of the operating system offers JPEG standard support to all TIFF reading and writing facilities. All applications using the NXImage class can now read JPEG-compressed TIFF files, which are read transparently to applications.* ***The company also introduces hardware JPEG processing on its NeXTdimension graphics board, letting standard-resolution video be compressed or decompressed at real-time rates. Video frames can be compressed and transferred to hard disks at a rate of 30 frames per second. Playback can also be read from the disk and decompressed. Users can then display the playback in a sub-window of a megapixel display or direct into a video output jack****."*

Thus, early on, JPEG video applications were implemented and this was the first step to M-JPEG becoming a *de facto* standard, still used today especially for video editing.

The JPEG did not also target motion image applications because it was a disciplined standards group whose limits of standardization were clearly defined by its parent SDOs. In CCITT, JPEG was responsible for photographic still images, while CCITT SGXV was responsible for developing a video coding standard for an ISDN videophone and later to other type of networks. In ISO/IEC JTC1/SC2 and later SC29, JPEG was also responsible for photographic still images and then in 1988 the emerging MPEG became responsible for videos on digital storage media (like compact discs in MPEG-1). MPEG-2 digital TV was not even on the horizon (that came in the early 1990s).

Therefore, there is no standard that defines a single exact format that is universally recognized as a complete specification for motion JPEG for use in all contexts. This raised compatibility concerns about file outputs from different manufacturers. However, each particular file format usually has a standard on how M-JPEG is encoded. For example, Microsoft documents their standard format to store M-JPEG in AVI files, Apple documents how M-JPEG is stored in QuickTime files and IETF RFC 2435 [29] describes how M-JPEG is implemented in an RTP stream.

According to Wikipedia [30],

> *"Motion JPEG (M-JPEG or MJPEG) is a video compression format in which each video frame or interlaced field of a digital video sequence is compressed separately as a JPEG image. The JPEG still image compression standard can be applied to video by compressing each frame of video as an independent still image and then transmitting them in series. Video that has been coded this way is defined as a Motion JPEG.*
>
> *M-JPEG is an intraframe-only compression scheme (compared with the more computationally intensive technique of interframe prediction). Whereas modern interframe video formats, such as MPEG1, MPEG2 and H.264/MPEG-4 AVC, achieve real-world compression ratios of 1:50 or better, M-JPEG's lack of interframe prediction limits its efficiency to 1:20 or lower, depending on the tolerance to spatial artifacting in the compressed output. Because frames are compressed independently of one another, M-JPEG imposes lower processing and memory requirements on hardware devices.*
>
> *As a purely intraframe compression scheme, the image quality of M-JPEG is directly a function of each video frame's static (spatial) complexity. Frames with large smooth transitions or monotone surfaces compress well and are more likely to hold their original details with few visible compression artifacts. M-JPEG-compressed video is also insensitive to motion complexity, i.e. variation over time. It is neither hindered by highly random motion (such as the water-surface turbulence in a large waterfall), nor helped by the absence of motion (such as static landscape shot by tripod), which are two opposite extremes commonly used to test interframe video formats.*
>
> *M-JPEG enjoys broad client support — most major web browsers and players provide native support, and plug-ins are available for the rest. Minimal hardware is required because it is not computationally intensive."*

Originally developed for multimedia PC applications, M-JPEG is now used by video-capture devices such as digital cameras, Internet protocol (IP) cameras, and webcams, as well as by non-linear video editing systems.

So, a motion JPEG standard takes advantage of the toolbox nature of JPEG to achieve its functionalities, but that needs to be extended for practical implementation.

It is surprising that M-JPEG is still used in several applications and systems today.

4.4 Exchangeable image file format

The use of JPEG-1 in digital photography is one of the most important applications today. In mobile phones alone, there are about 4 billion photo-cameras. Today smart phones dominate the photo-camera market. Each camera takes about 260 JPEG pictures per year, resulting in 1 trillion (1 000 000 million) JPEG photos each year. Taking all images, including the analogue images that have been taken over the more than 150 years since the invention of photography, the estimated total is 5,7 trillion pictures. JPEG pictures have practically dominated all pictures taken worldwide since the introduction of the format (All stats are from Ahonen [31]).

With such a background, it may sound strange that although the JPEG committee saw that digital photography would be a very important use case one day in the future, it did not see:

a) that it would come within 10 years from the development of the JPEG-1 standard;

b) that it would kill the analogue photography by the early 2000s);

c) the emergence of mobile communication and with that the appearance of mobile phones (especially smart phones) as the dominant digital photo camera type – JPEG especially did not see the emergence of high resolution colour displays on smart phones (e.g. the iPhone) that had a completely new type of display device for photos;

d) last but not least, JPEG also did not see that on smart phones animated still images (with 1-2 s animation on average) would become an important enhancement for digital still pictures – on animated JPEG at least there are now plans to have a new JPEG-1 standard extension specifying the old JPEG-1 format for animated images.

For the aforementioned reasons, the JPEG Committee neglected in the early 1990s to develop JPEG file format standardization suitable for digital cameras. It was in 1993 when the first drafts of the SPIFF file format (see section 4.2) were drafted. The JPEG committee tried to harmonize the SPIFF standard with the exchangeable image file format (EXIF), the future file format for digital cameras, but it failed: JPEG invited to its 1993 Tokyo meeting the Chair of the EXIF standardization committee and conducted discussions on how to harmonize the future SPIFF and EXIF standards with a common solution. In the meeting, an agreement was reached to have a single standard; however, unfortunately, the EXIF side later dropped the agreement and went ahead with the EXIF standard. It was too late for harmonization. The initial release of EXIF by the Japan Electronic Industries Development Association (JEIDA) was in 1995, while SPIFF was 1996. For digital photography, clearly EXIF was the winner, because it has been supported on the market by emerging digital cameras.

What is exactly EXIF?

> *Exchangeable image file format (officially Exif, according to JEIDA/JEITA/CIPA specifications) is a standard that specifies the formats for images, sound, and ancillary tags used by digital cameras (including smartphones), scanners and other systems handling image and sound files recorded by digital cameras. The specification uses the following existing file formats with the addition of specific metadata tags: JPEG discrete cosine transform (DCT) for compressed image files, TIFF Rev. 6.0 (RGB or YCbCr) for uncompressed image files, and RIFF WAV for audio files (Linear PCM or ITU-T G.711 μ-Law PCM for uncompressed audio data, and IMA-ADPCM for compressed audio data). [38]*

Background:

According to Wikipedia, JEIDA produced the initial definition of EXIF. Version 2.1 of the specification is dated 12 June 1998. JEITA established EXIF version 2.2 (also known ae EXIF print), dated 20 February 2002 and released in April 2002 Version 2.21 (with Adobe RGB support) is dated 11 July 2003, but was released in September 2003 following the release of DCF 2.0. The latest, version 2.3, released on 26 April 2010 and revised in May 2013 (and updated to 2.3.1 in 2016), was jointly formulated by JEITA and the Camera and Imaging Products Association (CIPA). EXIF is supported by almost all camera manufacturers.

The metadata tags defined in the EXIF standard cover a broad spectrum:

- date and time information: digital cameras will record the current date and time and save this in the metadata;
- camera settings: this includes static information such as the camera model and make, and information that varies with each image, such as orientation (rotation), aperture, shutter speed, focal length, metering mode, and ISO speed information;
- a thumbnail for previewing the picture on the camera's liquid crystal display (LCD) screen, in file managers or in photo manipulation software;
- descriptions;
- copyright information.

The EXIF tag structure is borrowed from tagged image file format (TIFF) files. On several image specific properties, there is a large overlap between the tags defined in the TIFF, EXIF, tagged image file format/electronic photography (TIFF/EP), and design rule for camera file (DCF) standards. For descriptive metadata, there is an overlap between EXIF, International Press Telecommunications Council (IPTC) information interchange model and extensible metadata platform (XMP) info, which can also be embedded in a JPEG file. The Metadata Working Group has guidelines on mapping tags between these standards.

When EXIF is employed for JPEG files, the EXIF data are stored in one of JPEG's defined utility application segments, the APP1 (segment marker 0xFFE1), which in effect holds an entire TIFF file.

4.5 Web HTML

This application proved to be one of the killer applications in the success of JPEG: high quality photographic type images on web pages. Nevertheless, the results of development of a videotex photographic mode as shown in section 4.1.3 are very similar to this application, so the results from there could be easily adopted.

As early as February 1993, JPEG was already included in the first web browser in the famous Mosaic (Fig. 15). Note that this was only 6 months after the formal approval of the JPEG draft by CCITT and one year before that in ISO/IEC JTC1. So, most likely, the IJG code was taken.

NCSA Mosaic Technical Summary

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Abstract

We describe a networked information system targeted at wide-area distributed asynchronous collaboration and hypermedia-based information discovery and retrieval currently being designed and built at NCSA. The system, called Mosaic, provides powerful capabilities for dealing with scientific data in an asynchronous collaboration context and integrates cleanly into existing data sources and environments.

1 Introduction

The National Center for Supercomputing Applications at the University of Illinois is developing an environment to facilitate wide-area network-based information discovery and retrieval and asynchronous collaborative work. The environment, called Mosaic, provides a portal into a broad universe of network-based and standalone information, and any information thus accessible to Mosaic becomes a potential part of a user's asynchronous collaboration environment — including information not under Mosaic's direct control or on servers too simple to support complex collaboration-based activities.

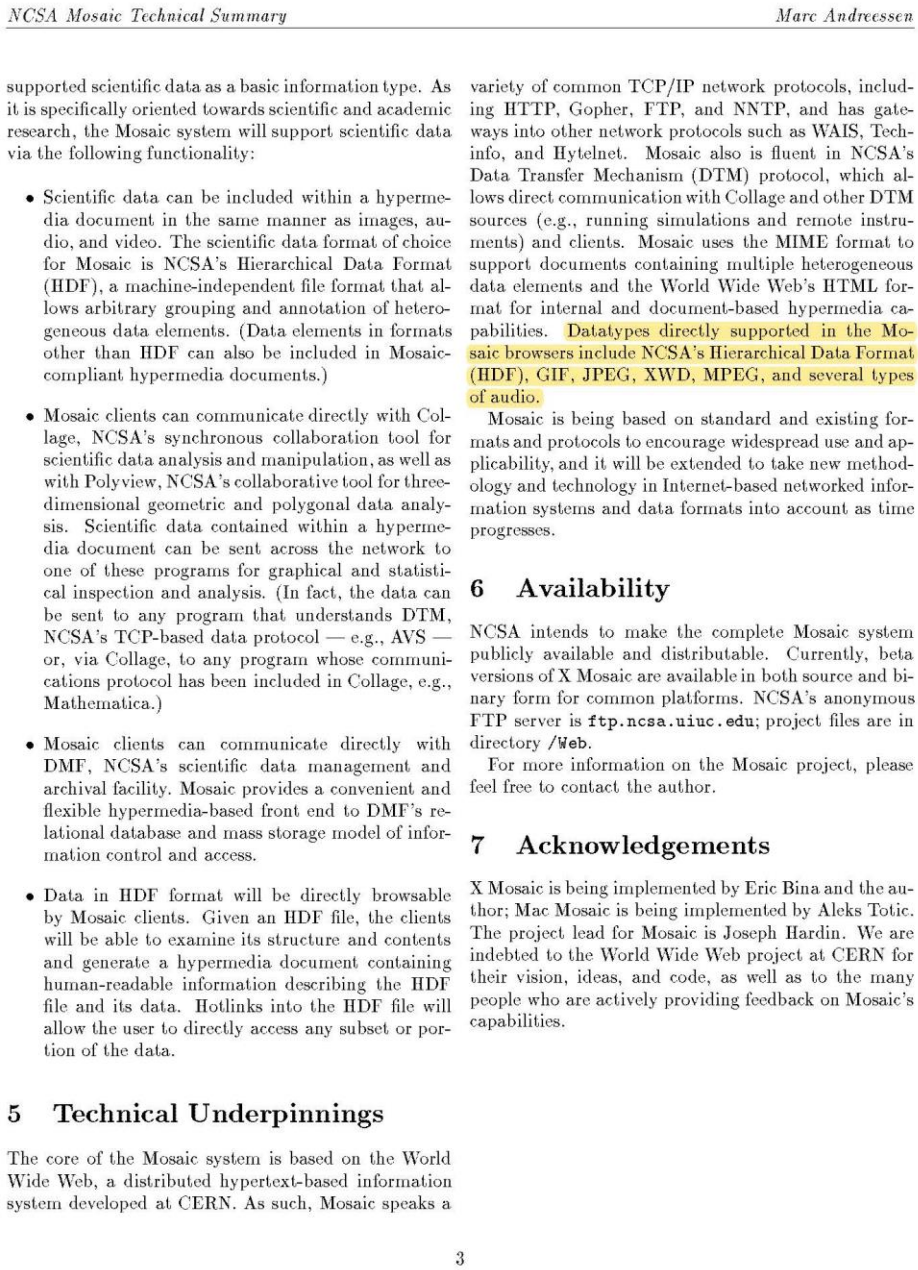
Mosaic uses a blend of distributed hypermedia, hierarchical organization, and search functionality for information discovery and retrieval. In addition, Mosaic is fully capable of dealing with scientific data as a standard component type within its information space. Further, Mosaic is designed to be fully distributed across a wide-area network, in part by supporting a wide variety of common information protocols and formats and by providing simple, convenient methods for expanding the domain of information upon which Mosaic can operate.

2 Mosaic Clients

The user interface into the Mosaic system is provided by clients currently being developed at NCSA. These clients, X Mosaic and Mac Mosaic, are designed for the X Window System and the Apple Macintosh respectively. (Currently, the first version of X Mosaic is in beta release and Mac Mosaic is nearing alpha.)

The initial versions of the Mosaic clients will have the following functionality:

- Graphical display of plain text, rich (formatted) text, and hypertext, as well as inlined display of graphs, images, audio clips, video sequences, and scientific data as sections of multimedia and hypermedia documents.
- Information space navigation and history-tracking facilities.
- Support for "hotlists" of interesting documents that can be monitored for changes over time.
- Complex search capabilities including those required to access WAIS databases.
- Support for the asynchronous collaboration mechanisms described below.
- Full TCP/IP-based communications support (including native HTTP, Gopher, FTP, and NNTP protocol support).
- DTM communications support, for integration with NCSA Collage and other network-based DTM clients and information servers.
- DMF communications support, for exploring and retrieving data stored in NCSA's Data Management Facility.



NCSA Mosaic Technical Summary — Marc Andreessen

supported scientific data as a basic information type. As it is specifically oriented towards scientific and academic research, the Mosaic system will support scientific data via the following functionality:

- Scientific data can be included within a hypermedia document in the same manner as images, audio, and video. The scientific data format of choice for Mosaic is NCSA's Hierarchical Data Format (HDF), a machine-independent file format that allows arbitrary grouping and annotation of heterogeneous data elements. (Data elements in formats other than HDF can also be included in Mosaic-compliant hypermedia documents.)
- Mosaic clients can communicate directly with Collage, NCSA's synchronous collaboration tool for scientific data analysis and manipulation, as well as with Polyview, NCSA's collaborative tool for three-dimensional geometric and polygonal data analysis. Scientific data contained within a hypermedia document can be sent across the network to one of these programs for graphical and statistical inspection and analysis. (In fact, the data can be sent to any program that understands DTM, NCSA's TCP-based data protocol — e.g., AVS — or, via Collage, to any program whose communications protocol has been included in Collage, e.g., Mathematica.)
- Mosaic clients can communicate directly with DMF, NCSA's scientific data management and archival facility. Mosaic provides a convenient and flexible hypermedia-based front end to DMF's relational database and mass storage model of information control and access.
- Data in HDF format will be directly browsable by Mosaic clients. Given an HDF file, the clients will be able to examine its structure and contents and generate a hypermedia document containing human-readable information describing the HDF file and its data. Hotlinks into the HDF file will allow the user to directly access any subset or portion of the data.

5 Technical Underpinnings

The core of the Mosaic system is based on the World Wide Web, a distributed hypertext-based information system developed at CERN. As such, Mosaic speaks a variety of common TCP/IP network protocols, including HTTP, Gopher, FTP, and NNTP, and has gateways into other network protocols such as WAIS, Techinfo, and Hytelnet. Mosaic also is fluent in NCSA's Data Transfer Mechanism (DTM) protocol, which allows direct communication with Collage and other DTM sources (e.g., running simulations and remote instruments) and clients. Mosaic uses the MIME format to support documents containing multiple heterogeneous data elements and the World Wide Web's HTML format for internal and document-based hypermedia capabilities. Datatypes directly supported in the Mosaic browsers include NCSA's Hierarchical Data Format (HDF), GIF, JPEG, XWD, MPEG, and several types of audio.

Mosaic is being based on standard and existing formats and protocols to encourage widespread use and applicability, and it will be extended to take new methodology and technology in Internet-based networked information systems and data formats into account as time progresses.

6 Availability

NCSA intends to make the complete Mosaic system publicly available and distributable. Currently, beta versions of X Mosaic are available in both source and binary form for common platforms. NCSA's anonymous FTP server is `ftp.ncsa.uiuc.edu`; project files are in directory `/Web`.

For more information on the Mosaic project, please feel free to contact the author.

7 Acknowledgements

X Mosaic is being implemented by Eric Bina and the author; Mac Mosaic is being implemented by Aleks Totic. The project lead for Mosaic is Joseph Hardin. We are indebted to the World Wide Web project at CERN for their vision, ideas, and code, as well as to the many people who are actively providing feedback on Mosaic's capabilities.

3

Fig. 15 – Cover page and page 3 of the NCSA mosaic technical summary [32] showing that JPEG was included in the web from the very beginning

HTML is the standard markup language for creating Web pages, which are capable of far more than text. If a web page is built with HTML, images can be added in a variety of file types, including .jpg, .gif, and .png.

The registered multipurpose Internet mail extensions (MIME) type for JPEG JFIF images is the image/jpeg of 1993 (IETF RFC 1521 [33]),

"7.5 The Image Content-Type

A Content-Type of "image" indicates that the body contains an image.

> *The subtype names the specific image format. These names are case insensitive. Two initial subtypes are "jpeg" for the JPEG format, JFIF encoding, and "gif" for GIF format [GIF].*
>
> *The list of image subtypes given here is neither exclusive nor exhaustive, and is expected to grow as more types are registered with IANA, as described in Appendix E.*
>
> *The formal grammar for the content-type header field for data of type image is given by image-type:= "image" "/" ("gif" / "jpeg" / extension-token)"*

4.6 Standards in medical image communications

The use of JPEG-1 and the many subsequent formats (e.g. JPEG-LS, JPEG2000) of ISO/IEC JTC1 SC29 have been always of great interest to the medical imaging community. Representatives of the American College of Radiology-National Electrical Manufacturers Association (ACR-NEMA) standardization body came occasionally to early JPEG meetings. They showed interest both in the requirements (e.g. "lossy" image for a fast diagnosis and "lossless" for confirmation and archival) and the formats, but they never wanted to be part of the ITU-T ISO/IEC JTC1 image standardization community. They always had ACR-NEMA and took over much of the JPEG or MPEG work. This is definitely a great success for JPEG.

Section 4 of Liu *et al*. [34] reads

> *"In the early 1980s, the digital medical imaging industry was rapidly growing and the need for the development of standards for digital communication of medical images was evident. In 1983, two organizations—the American College of Radiology (ACR) which is a professional society of radiologists, radiation oncologists, and clinical medical physicists in the United States, and the National Electrical Manufacturers Association (NEMA) which is a trade association representing manufacturers came together to form the Digital Imaging and Communications Standards Committee. The committee published the first version of its standard (ACR-NEMA 300-1985) in 1985. The standardization effort continued to evolve as participation from outside of the United States as well as from medical specialties beyond radiology grew and the medical imaging industry transitioned to networked operations. In 1993, the name of the committee was changed to Digital Imaging and Communications in Medicine (DICOM) and a substantially revised standard, also known as DICOM, was released."*

4.7 JPEG as a military standard

This applications area and the success of JPEG as a military standard came as a surprise to the author and the members of the original JPEG Development Team. As previously mentioned, the toolbox element-defining applications of JPEG originated in requirements from telecommunications, and the PC and printing-industries, but none from the military.

Thus, requirements derived from purely civilian applications and use cases. JPEG simply did not have on its radar that the defined "toolbox" was flexible and powerful enough to apply, for example, for high-resolution military areal images.

Nevertheless, the specification developed by JPEG was picked up for part of the US Government's National Imagery Transmission Format Standards (NITFS) system in the early 1990s and apparently was found also useful to be in their application space.

The NITFS version of JPEG was documented in MIL-STD-188/198 [35]:

> *"This standard establishes the requirements to be met by systems complying with NITFS when image data are compressed using the JPEG image compression algorithm as described in DIS 10918-1,* Digital compression and coding of continuous-tone still images*."*

MIL-STD-188/198 was based on the draft International Standard for ITU-T T.81 (1992) | ISO 10918-1:1994 [1]. This is basically the final version that was approved by CCITT in September 1992.

The North Atlantic Treaty Organization (NATO) has also been using JPEG in its standards.

5. CONCLUSIONS

The author, who has participated in the JPEG design and development effort throughout and who has witnessed the incredible success of the JPEG format, has the following conclusions:

- The design concept to create a toolbox type of standard for JPEG was an excellent decision. The fact that the common components were derived mostly from CCITT/ITU telecommunication and emerging PC applications actually did not influence the wide applicability of the toolbox standard concept in applications that had not been envisaged originally by the JPEG team. The selection of toolbox elements in successful M-JPEG applications, which was definitely outside the scope of JPEG, is a good example of that.
- The fact that some components, e.g. file format and colour model selection, were left out of the toolbox by design was in the end not a limiting factor. Each application has found the right solution to fill those gaps. Actually, for similar applications, ranging from the videotex photographic mode to the much more successful worldwide web solution, to incorporate just the core JPEG components into a new protocol environment was actually a useful feature.
- It is an irony of standardization that the majority of the originally targeted CCITT/ITU JPEG applications in the end were not successful, but due to the flexibility of the toolbox principle new applications, e.g. digital photography, web pages with photographic content and medical imaging, have played a role as JPEG killer applications.
- Out of the JPEG toolkit, the definition of a JPEG baseline profile common to all applications and images was a very good decision, and not only helped easier interoperability, but also provided a stable basis for good quality images.
- High-quality photographic images on web pages proved to be one of the killer applications for the success of JPEG. Nevertheless, the results of the development of a videotex photographic mode, as shown in section 4.1.3, are very similar to this application, so could be easily adopted.
- It is fair to say that the first killer application was the inclusion of JPEG on the Internet and then in the worldwide web. JPEG was included in web browsers from as early as February 1993. Thus, the boom in the web was parallel to the popularity of JPEG. In the second half of the 1990s, another killer application was digital photography, which got an additional killer application in the early 2000s, namely digital photography by mobile and from 2007 smart phones.
- The patent policy of JPEG, which could only happen within an independent group with own rules and procedures, was a very lucky choice: RF JPEG baseline with the possibility for some RAND options. That JPEG patent policy then *de facto* disappeared after 1993 when the joint ITU and ISO/IEC rules for collaborating work (ITU-T A.23 [5]) were approved. Then *de jure* a RAND patent policy was adopted for all new standards, although JPEG informally often set targets to develop RF baseline standards.
- In general, JPEG derived benefit from the fact that until 1993 it operated according to its own rules in a sort of vacuum, while its parents were much regulated SDOs, i.e. CCITT/ITU and ISO/IEC. That freedom allowed effective, fast and innovative standardization work in JPEG, while the formal approval and publication of standards by both SDOs after the completion of the JPEG specification took some time.
- The *de facto* collaboration of the IJG and JPEG was a lucky coincidence. The toolbox nature of the standard and its RF policy were key requirements for the open source code implementation of JPEG by the IJG. The IJG, after picking up the stable specification in 1990, could take the JPEG format as a baseline, and combine it with JFIF for the missing components. The first code appeared in 1991, before the formal approval of JPEG by CCITT/ITU in 1992. Later, it added further components, e.g. for progressive image build up.

ACKNOWLEDGEMENTS

Thanks to the original JPEG group (1986 to 1992) of 15 to 20 experts and its Chairmen who directly contributed to the development of the JPEG Recommendation | International Standard.

Thanks also to the parents of the JPEG: CCITT SGVIII and ISO/IEC JTC1 SC2/WG8. These expert groups set the requirements for the JPEG draft, founded JPEG with its own pragmatic rules and procedures and, after completion of the work, picked up the JPEG-8 revision 8 specification and turned it into one of the first joint text Recommendation | International Standard documents, ITU-T T.81 (1992) | ISO/IEC 10918-1:1993 [1].

Gratitude is due to the ESPRIT 563 [6] PICA [7] project on photovideotex image compression algorithms, which developed several compression algorithm proposals**,** test images and the JPEG test- and selection infrastructure (KTAS, Copenhagen).

Gratitude is also due to Tom Lane, founder and chair of the IJG, for picking-up the JPEG-8 Specification in 1990 and releasing the first IJG software code in September 1991.

Credit is owed to the various application groups who successfully incorporated the JPEG format into their different applications, thus making JPEG one of the most used and most successful standards in the world.

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