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A Java H.263 Decoder Implementation

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Abstract

As the result of the work done as a project for the Image Processing and Communications course in the winter of 1997, this report describes the implementation of a Java H.263 video decoder. The Decoder allows H.263 coded video streams to be decoded and displayed in a window on any Java enabled machine. It shows that it’s possible to create a conferencing environment just using Java Enabled Browsers.

Keywords: ITU-T H.263, Java, ITU-T H.324, Video Codec.

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Chapter I

1. Introduction

People, by their social nature, need to have interaction with others in order to be able to acquire knowledge. With ever advancing of social structure of humanity, there is an increased demand for communication in order to overcome the geographical distances. In order to accommodate the need for communication, several methods were created to facilitate that exchange, starting from the smoke signals exchanged by our ancestors till the actual telecommunication devices, such as the telephone and the Internet.

However, when a meeting among a group of persons is required, to discuss any matter, it is required that all of them relocate to a common place. This introduces lot of problems, such as money spent, security problems, scheduling and other problem. As an example, consider the world meeting ECO 92, held in Rio de Janeiro, Brazil, where the majority of head of states met to discuss ecological issues.

With the objective to improve this scenario, several research groups began studies to develop a set of communication services, called teleconferencing services.

Teleconferencing Services are defined [SoMB 88, Fluc 95] as a set of telecommunication facilities that allow the participants in two or more different places, to establish a bidirectional link through communication electronic devices, while sharing simultaneously their audio-visual environment, by having the impression that they are all in the same place.

The teleconferencing services are classified by the literature [H.200, SoMB 88, Fluc 95], as:

- *Audio Conferencing* - Service where just audio and control signals are exchanged among the participants;
- *Audio-Documentational Conferencing* - Service close to the Audio Conferencing service; however, the treatment of text documents should be supported;
- *Audio-Graphic Conferencing* - Service that allows transmissions of audio, control, text documents and static images;
- *Freeze-Frame Videoconferencing* - Service close to the Audio-Graphic Conferencing, adding the periodic exchange of static images of the participants (a very low frame rate video exchange should be classified as being this service);
- *Tele-seminar* - Service that broadcasts the events (audio and video) from a particular place to all participants; however the return path just allows audio signal transmission;
- *Videoconferencing* - Service similar to the Audio-Graphic Conferencing adding the real time video exchange among the participants.

Some other audiovisual services [H.200], having similar characteristics from the teleconferencing services share the same standards. For instance:

- *Conventional Telephony* - It is included to address the interoperability with the other services;

- *Videophony* - Service that allows bi-directional point-to-point transmission of audio and video between the two participants. Usually, the video quality is lower than the Videoconferencing one;

- *Tele-Surveillance* - Service that allows unidirectional transmission of signals in order to make possible the observation of some environments. At this time, there is no standardization proposed to this service.

The videoconferencing service is worthy of special attention, since all others can be defined as particular cases of videoconferencing, for instance the Audio-Graphic Conferencing can be defined as a videoconferencing without video transmission.

As a result of the research developed in the previous years, some teleconferencing prototypes, particularly videoconferencing, were introduced. However, these prototypes present some limitations. Many of them don’t adhere to accorded standards, and are limited to the audio and video transmission without synchronism.

In order to be able to exchange information with others, a system has to adhere to the established standards for each media, such as audio, video, data, as well as for the multimedia/hypermedia object interchange. The international standardization organizations (ISO[1] and ITU-T[2]) suggest H.261 [H.261] or H.263 [Draft H.263] for real time video codification, MPEG, MPEG-2 or MPEG-4 [Fluc 95] for video storage/retrieval, JPEG [Wall 91] for static image codification, G.711, G.722, G.728, G.723 [G.711, G.722, G.728, Draft G.723], MHEG [MHEG 95]for multimedia/hypermedia interchange. H.221 or H.223 [H.221, H.223] for framing, H.245 [Draft H.245] for multimedia control signaling, as well as security mechanisms [Schn 95]. A more detailed description of the videoconferencing scenario can be found in [Oliv 96].

Portability is a very common problem that occurs when a multimedia system is being implemented. Usually, a version for each machine has to be written, and it is really hard to manage this kind of code: for instance, imagine if after finishing the coding for ten different machines, some improvement is going to be done in the system; unfortunately, this modification has to be done in each of the ten codes, which is not a trivial task. Some few years ago, Sun Microsystems introduced a new language that eliminates the portability problem. This language, called JAVA, allows a program to be written just once and to run on the ten machines with no modifications in the code. Because of this, that improvement can be easily done, since there is just one code to be updated.

This project report presents an H.263 Java decoder that can be used to allow the required standard video transmission by any Java enabled machine. This decoder was written

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[1] International Standardization Organization.

[2] International Telecommunication Union, Telecommuncation Standardization Sector — previously CCITT.

during the 1997 winter term for the Image Processing and Communication course given at the Electrical and Computer Engineering at the University of Ottawa and lectured by Prof. Dr. Sethuraman Panchanathan.

This document is organized as follows: an overview of the ITU-T H.324 recommendation set is presented in the second chapter. This overview addresses, but is not limited to, H.324×H.320, H.261×H.263 (the next chapter covers this in depth), H.223×H.221, H.245×H.242+H.230 and H.723×H.711+H.722+H.725+H.728 recommendations. The third chapter presents an in depth analysis of the ITU-T H.263 recommendation. In the following chapter (fourth), the Java paradigm is presented, with a discussion of its advantages and disadvantages. Then, in chapter five, the Java H.263 Decoder is introduced, including some evaluation of the decoder as well as a contrast between the ITU-T H.261 and H.263 video codec recommendations. Finally, the report presents some conclusions and the references quoted through the text.

Chapter II

2. The ITU-T H.324 Recommendation

In 1990 the ITU-T released the H.320 [H.320] recommendation which was updated in 1993. This recommendation defined a set of recommendations, stated also in [H.200], for an audiovisual service implementation. This recommendation defined the H.261 recommendation to be used for video coding, G.711 compulsory and G.722, G.728 optional for audio coding, and G.221 for framing among others. However, this set of recommendations was defined for transmissions from 64KB/sec to 2MB/sec, which is not possible through a network like the Internet. After this first definitions, the ITU-T Study Group 16 began developing a new set of recommendations addressing a very low bit rate videoconferencing environment. This standardization group is still working; however several drafts were already released and some of then, very recently some of them evolved into recommendations. This has happened with one of the H.324 draft that became a recommendation, but the study group already did some changes and a new draft is now available, even though the recommendation is still in the publication process [Draft H.324]. This section presents an overview of this recommendation based on its last published Draft (June 11, 1996).

2.1. Scope

This Recommendation covers the technical requirements for very low bitrate multimedia telephone terminals operating over the General Switched Telephone Network (GSTN), It is easier to use this recommendation than H.320 set on the Internet, since the H.324 was developed for low bit-rate terminals.

A diagram block for this recommendation can be seen in the Figure 2.1, where it becomes clear the recommendation set involved in it.

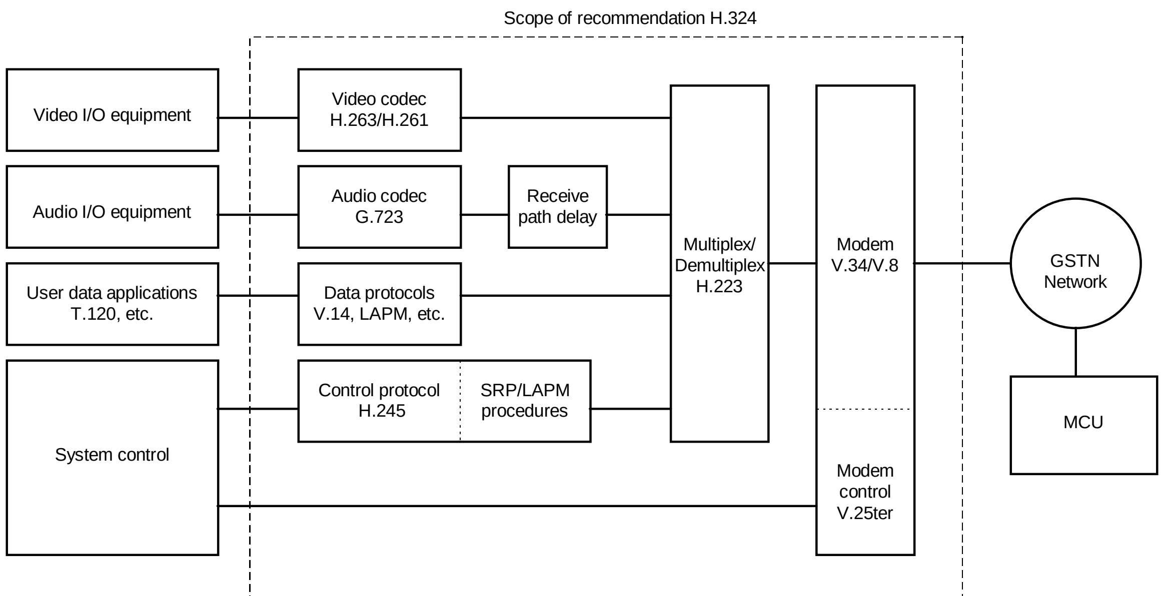


Figure 2.1: Block Diagram for H.324 Multimedia Systems

In order to be possible to check the differences between the H.324 and the previous H.320 recommendations, the Figure 2.2 present the same block diagram presented in the Figure

2.1, but for the H.320 recommendation, as one can see, the scope of the H.320 recommendation includes devices such as video and audio I/O equipment.

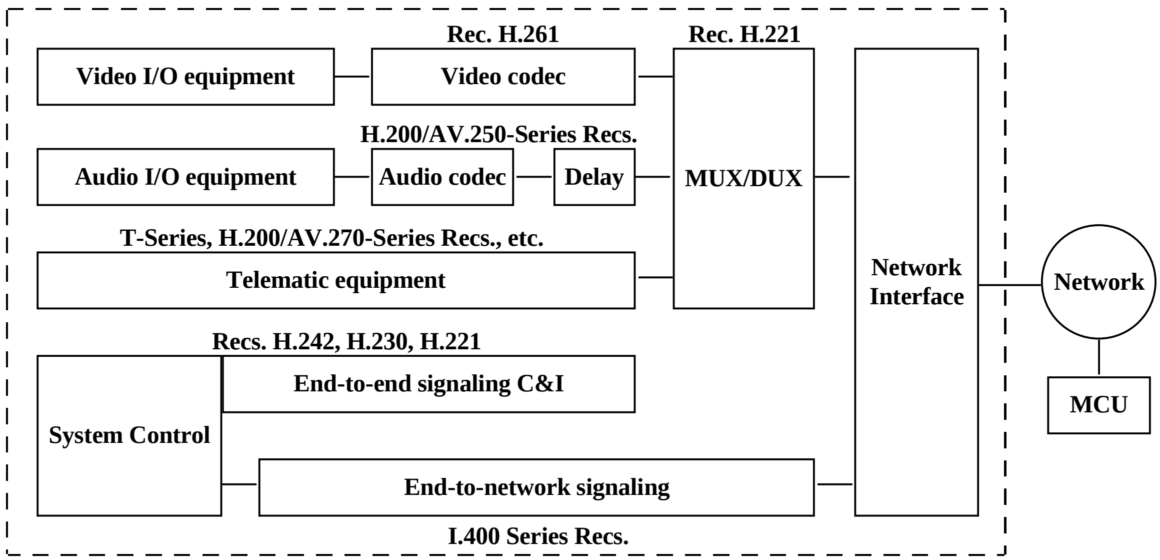


Figure 2.2: Block Diagram for H.320 Multimedia Systems

2.2. Functional Elements

The scope of Recommendation H.324 is indicated by the elements within the dashed line of Figure 2.1, which include:

- The Video Codec (H.263 or H.261) carries out redundancy reduction coding and decoding for video streams. The H.320 recommendation just present the H.261 Video Codec. Figure 2.3 presents the video resolutions adopted by both the H.263 and H.261 recommendations. Detailed analysis of the video codecs will be presented in the following chapter.

PICTURE FORMAT	LUMINANCE PIXELS	ENCODER		DECODER	
		H.261	H.263	H.261	H.263
SQCIF	128 x 96 for H.263[3]	Optional[3]	Required[1,2]	Optional[3]	Required[1]
QCIF	176 x 144	Required	Required[1,2]	Required	Required[1]
CIF	352 x 288	Optional	Optional	Optional	Optional
4CIF	704 x 576	Not defined	Optional	Not defined	Optional
16CIF	1408 x 1152	Not defined	Optional	Not defined	Optional

NOTE 1 - Optional for H.320 interworking adapters.

NOTE 2 - Mandatory to encode one of the picture formats QCIF and SQCIF; optional to encode both formats.

NOTE 3 - H.261 SQCIF is any active size less than QCIF, filled out by a black border, coded in QCIF format.

Figure 2.3: ITU-T Picture Formats

- The Audio Codec (G.723) encodes the audio signal from the microphone for transmission, and decodes the audio code which is output to the speaker. Optional delay in the receiving audio path compensates for the video delay, so as to maintain audio and video synchronization, the G.723 bitrate is as low as 5.3 or 6.5 Kbit/sec. The H.320 recommendation accepts a whole set of audio Codecs, such as G.711 (which is compulsory and consists on the standard 64Kbits/sec PCM), G.722, and G.728, as presented in [H.320, H.200]. The bitrate ranges from 16Kbits/sec to 64Kbits/sec. Reader may see, the H.324 uses a lower bitrate for audio transmission than the H.320, the same thing occurs with the video transmission, that’s why the H.324 is more suitable for use on the Internet, for instance.

- The Data Protocols support data applications such as electronic whiteboards, still image transfer, file exchange, database access, audiographics conferencing, remote device control, document exchange, etc. Other applications and protocols may also be used via H.245 negotiation. The H.320 recommendation includes definition of the Audio/Video equipment, as shown in the Figure 2.2.

- The Control Protocol (H.245) provides end-to-end signaling for proper operation of the H.324 terminal, and signals all other end-to-end system functions, while the H.320 recommendation uses end-to-end signaling through H.242, H.230, H.221 as well.

- The Multiplex Protocol (H.223) multiplexes transmitted video, audio, data and control streams into a single bit stream, and demultiplexes a received bit stream into various multimedia streams. In addition, it performs logical framing, sequence numbering, error detection, and error correction by means of retransmission, as appropriate to each media type. The H.320 uses the H.221 Multiplex protocol, that has similar functions.

- The Modem (V.34) converts the H.223 synchronous multiplexed bit stream into an analog signal that can be transmitted over GSTN, and converts the received analog signal into a synchronous bit stream that is sent to the Multiplex/Demultiplex protocol unit. V.25ter is used to provide control/sensing of the modem/network interface, when the modem with network signaling and V.8/V.8bis functional elements is a separate physical item, this protocol should be suppressed when on the Internet, since the H.223 stream can be transmitted directly, inside TCP packets or UDP datagrams.

Chapter III

3. The ITU-T H.263 Recommendation

3.1. Historic

In 1984, the CCITT[3], began to study video transmission at m*384 Kbits/s, with $m \in [1..5]$. Later, CCITT decided to include transmissions at n*64 Kbits/sec, with $n \in [1..5]$. In 1988 the CCITT published a unified standard for video transmission at p*64 Kbits/sec, where $p \in [1..30]$, which gives a constant bit rate from 64Kbits/sec to 1920 Kbits/sec, almost 2Mbits/sec. This standard was known as CCITT recommendation H.261.

In 1993, the CCITT, IFRB[4] and CCIR[5] joined, creating the actual ITU[6], where the ITU-T[7] is the previous CCITT and the ITU-R[8] is the IFRB and CCIR together. In the same year, the ITU-T released a new version of its recommendation H.261. The ITU-T H.261 recommendation was used for the development of several prototypes, such as:

[3] Comité Consultatif International de Télégraphique et Téléphonic

[4] International Frequency Registration Board

[5] Comité Consultatif International des Radio Communications

[6] International Telecommunication Union

[7] ITU - Standardization Sector

[8] ITU - Radio Communication Sector

- The ViC [McJa 95], developed by Steven McCane and Van Jacobson at the Lawrence Berkeley Laboratory and University of California, Berkeley, USA. The system has the flexibility as goal and has implementation for the UNIX environment. The interface, developed in Tcl/Tk, is presented in the Figure 3.1;

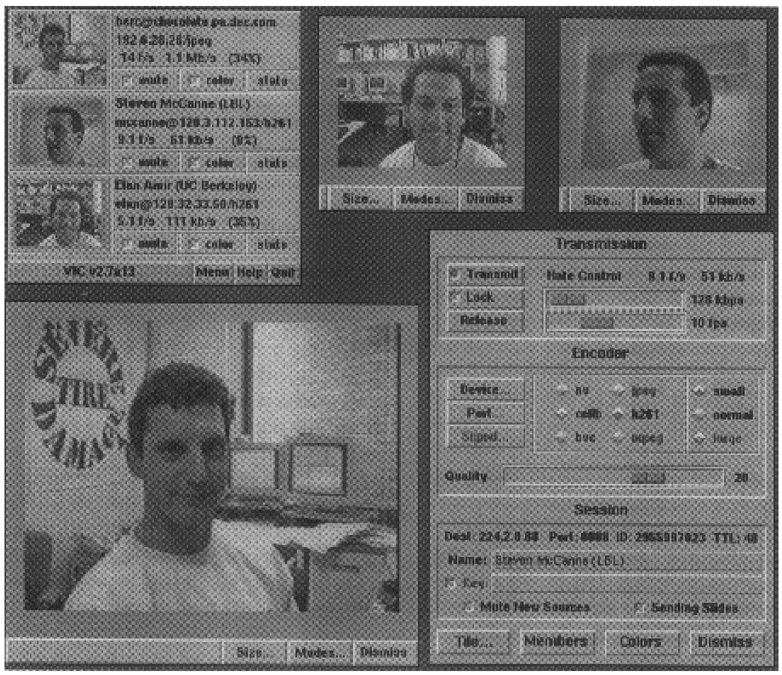


Figure 3.1: Interface LBL-UCB/ViC

- The IVS[9] [Turl 93, Turl 94, Turl 95], developed by Thierry Turletti at the Inria, Sophia-Antipolis, France. The System has implementation for several UNIX based machines. The interface is presented in the Figure 3.2;

- O TVS[10] [Oliv 96] was developed by myself while at the TeleMídia Laboratory, PUC-Rio, Brazil. The interface, developed using the IUP library, is presented in

[9] Inria Videoconferencing System

[10] TeleMídia Videoconferencing System

the Figure 3.3. The IUP library was also developed at PUC-Rio [Levy 93] and provides an easy toolkit for interface definition.

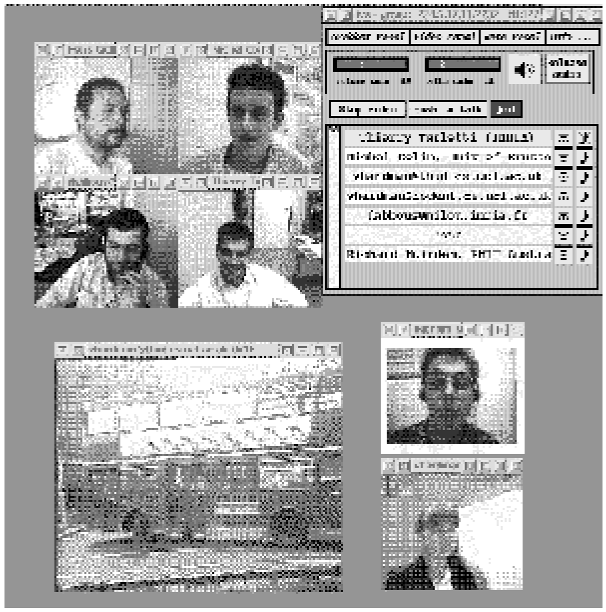


Figure 3.2: Interface Inria/IVS

All this systems have a very modest framerate, and proved that the H.261 is not adequate to be used on the Internet, where just low bitrate is available. In the last few years, the ITU-T began studies on Low bitrate real time video transmission. This recommendation is still in development stage. Its first draft was published in May 2nd, 1996.

All remarks that follows in this report are based on the May 2nd, 1996 ITU-T H.263 Draft Recommendation and 1993 ITU-T H.261 Recommendation. In the next sections, the structure of the H.263 bitstream is presented as well as a set of characteristics of this recommendation. Most of the time, characteristics of the H.261 recommendation are also presented in comparison.

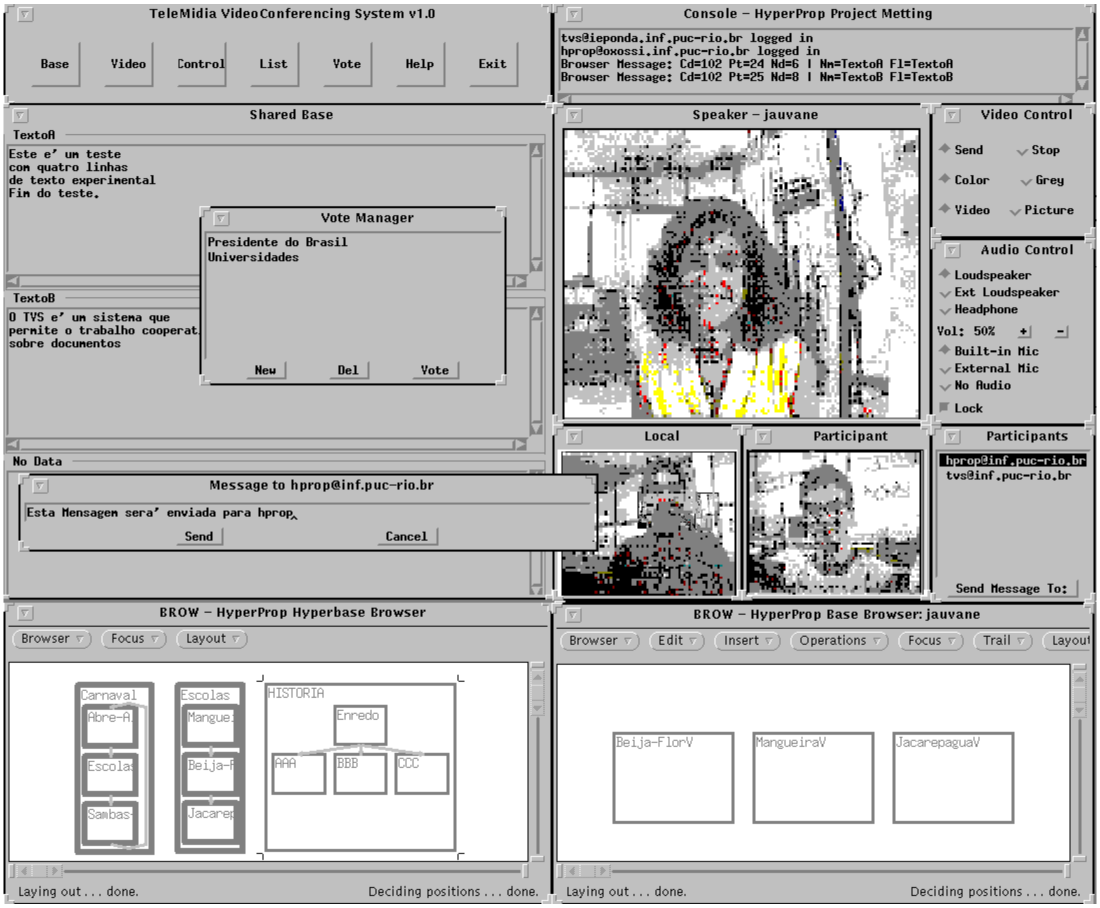


Figure 3.3: Interface PUC-Rio/TVS

3.2. H.263 x H.261

The H.263 structure is very similar to the H.261. Figure 3.4 shows the block diagram for the H.263 codec [H.263] and the Figure 3.5 shows the same block diagram, for the H.261 codec.

As can be seen, the main difference is the presence of a transmission coder/decoder in the H.261 recommendation, otherwise, the block diagram is the same.

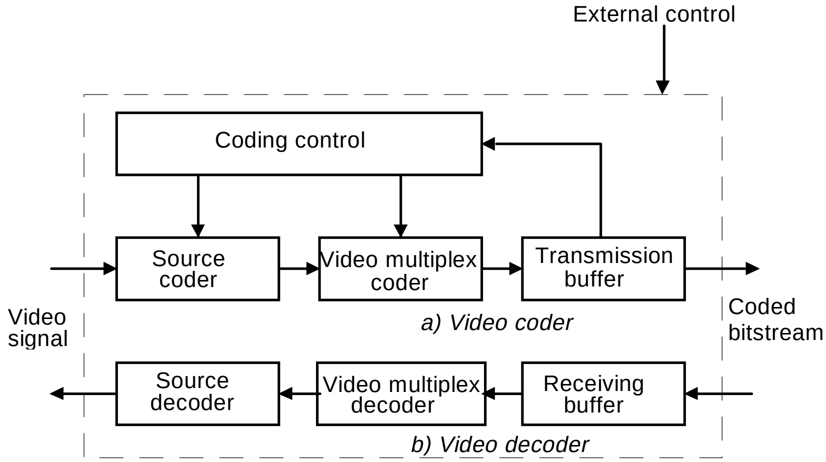


Figure 3.4: Block Diagram of the H.263 Video Codec

Concerning the picture format, anticipate in Figure 2.3, the original H.261 recommendation adopts just two picture formats, namely CIF and QCIF. The H.263 adopts three more picture formats, 4CIF (defined first in the IVS prototype, see the big image in Figure 3.2), 16CIF and SubQCIF (SQCIF), the aspect ratio is 4:3 as in a TV.

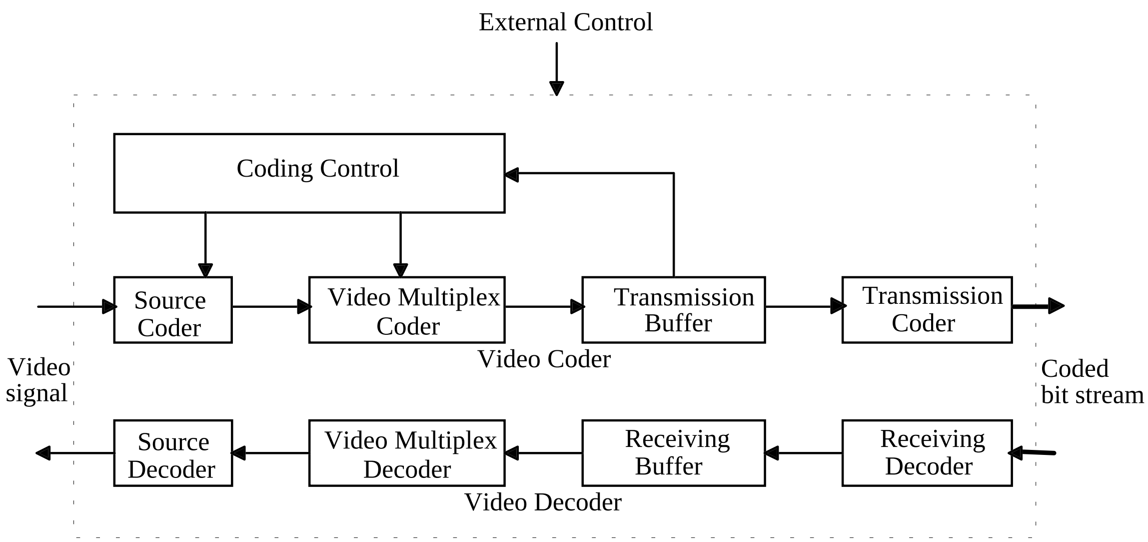


Figure 3.5: Block Diagram for H.261 Video Codec

Picture Format	number of pixels for luminance (dx)	number of lines for luminance (dy)	number of pixels for chrominance (dx/2)	number of lines for chrominance (dy/2)
sub-QCIF	128	96	64	48
QCIF	176	144	88	72
CIF	352	288	176	144
4CIF	704	576	352	288
16CIF	1408	1152	704	576

Figure 3.6: H.263 picture format resolutions

Some extensions proposed to the H.261 codec have included the SQCIF as an QCIF image, filling the remaining space with black, since the SQCIF is smaller than the QCIF.

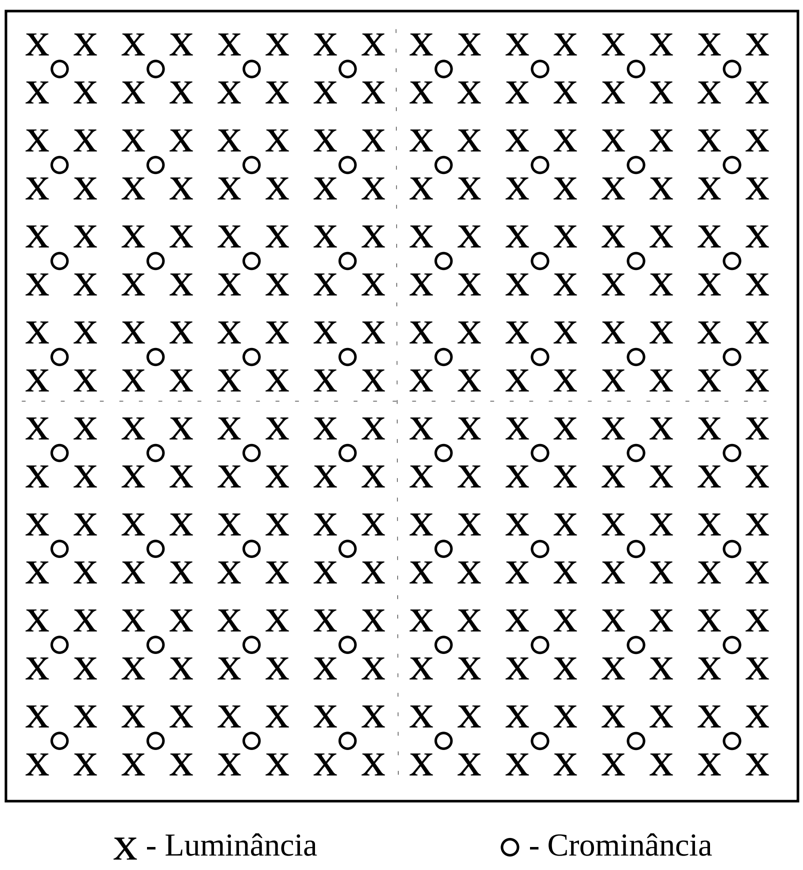


Figure 3.7: Luminance and Chrominance positions inside a Macroblock

Figure 3.6 presents a comparison among the five H.263 picture resolution standards, presenting the their three components: Y, C_B and C_R, respectively luminance and two different color components, whose values are in accordance with the ITU-R (previously CCIR) Recommendation 601. The source coder operates on non-interlaced pictures at a 30,000/1001 (≈29.97) rate. The position of the luminance and chrominance samples is presented in the Figure 3.7. The Chrominance components are sub sampled at the 4:1:1 rate, as shown in Figure 3.7, where for each four luminance components there is one chrominance component; however, there are two of them.

Both the H.261 and H.263 codecs have a four-layer hierarchical structure. The layers are Picture layer, Group of Blocks layer, Macroblock layer, and Block layer. Figure 3.9 shows the structure of each of these layers for the H.263 stream, Section 3.3 defines each of those components.

A block is an 8x8 matrix of coefficients while a macroblock is a set of 6 blocks, being 4 luminance blocks and two chrominance blocks, as shown in Figure 3.8. A Group of Blocks (GOB) is a Macroblock, and then comes the Picture when each picture is divided into groups of blocks (GOBs).

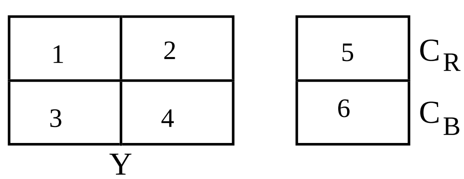


Figure 3.8: Arrangement of Blocks in a Macroblock

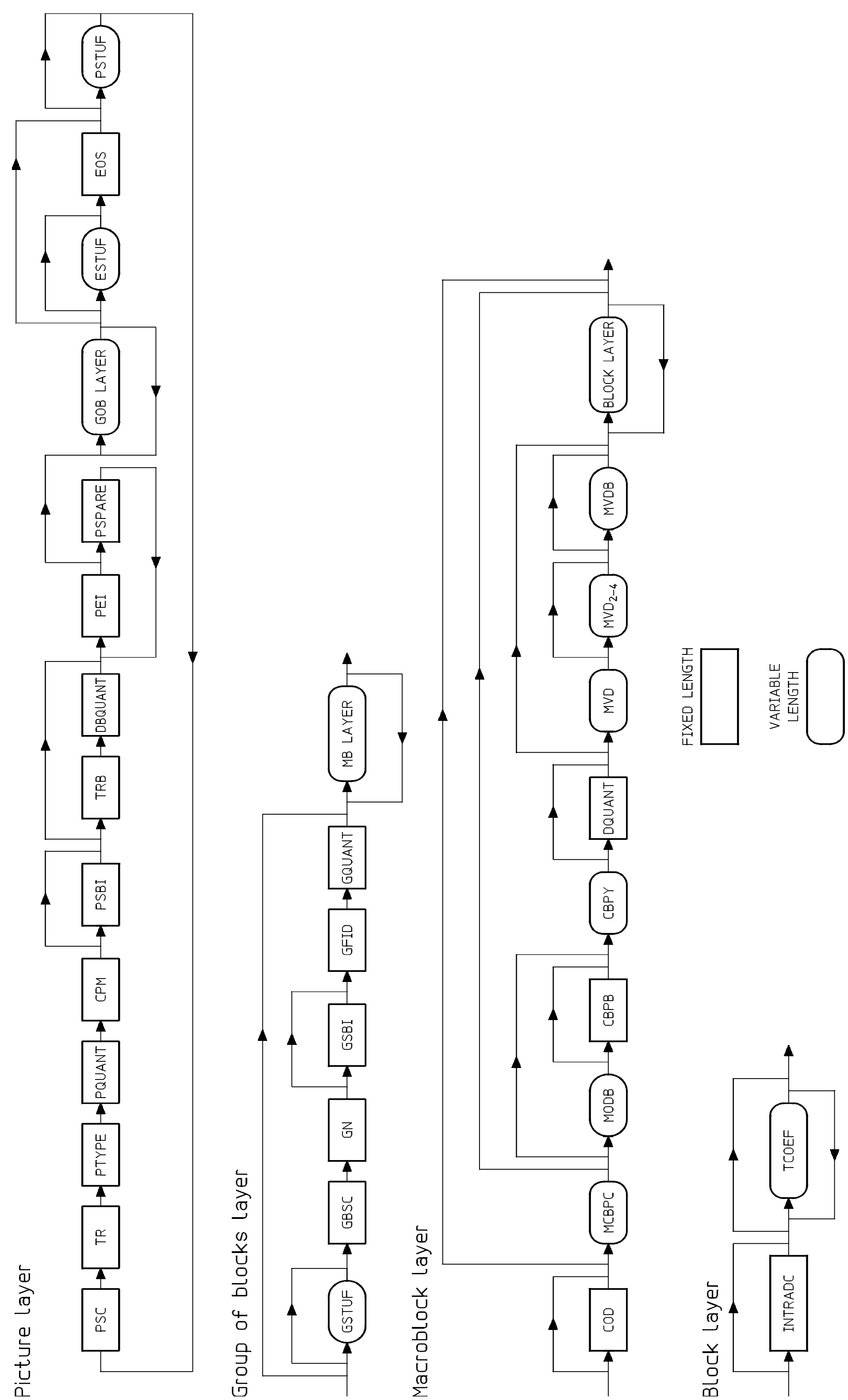
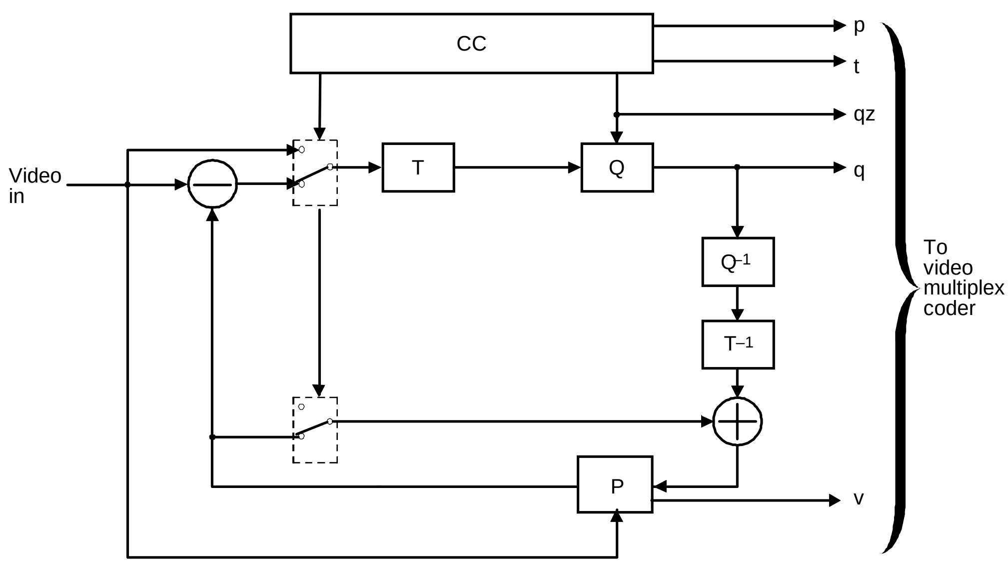


Figure 3.9: Syntax Diagram for Video Bitstream

H.263 defines that a group of blocks (GOB) comprises of k*16 lines, depending on the picture format (k = 1 for sub-QCIF, QCIF and CIF; k = 2 for 4CIF; k = 4 for 16CIF). The number of GOBs per picture is 6 for sub-QCIF, 9 for QCIF, and 18 for CIF, 4CIF and 16CIF. The GOB numbering is done by use of vertical scan of the GOBs, starting with the upper GOB (number 0) and ending with the lower GOB.

3.3. The H.263 Source Coder

The source coder is shown in generalized form in Figure 3.10. The main elements are prediction, block transformation and quantization.



T Transform
Q Quantizer
P Picture Memory with motion compensated variable delay

CC Coding control
p Flag for INTRA/INTER
t Flag for transmitted or not
qz Quantizer indication
q Quantizing index for transform coefficients
v Motion vector

Figure 3.10: Source Coder

3.3.1. Prediction

The prediction is inter-picture and may be augmented by motion compensation. The coding mode in which prediction is applied is called INTER; the coding mode is called INTRA if no prediction is applied. The INTRA coding mode can be signaled at the picture level (INTRA for I-pictures or INTER for P-pictures) or at the macroblock level in P-pictures. In the optional PB-frames mode B-pictures are always coded in INTER mode. The B-pictures are partly predicted bidirectionally. The Bidirectional Prediction is optional.

3.3.2. Motion compensation

The decoder will accept one vector per macroblock or if the optional Advanced Prediction mode is used one or four vectors per macroblock. If the PB-frames mode is used, one additional delta vector can be transmitted per macroblock for adaptation of the motion vectors for prediction of the B-macroblock.

Both horizontal and vertical components of the motion vectors have integer or half integer values. In the default prediction mode, these values are restricted to the range [-16,15.5] (this is also valid for the forward and backward motion vector components for B-pictures). In the Unrestricted Motion Vector mode however, the maximum range for vector components is [-31.5,31.5], with the restriction that only values that are within a range of [-16,15.5] around the predictor for each motion vector component can be reached if the predictor is in the range [-15.5,16]. If the predictor is outside [-15.5,16], all values within the range [-31.5,31.5] with the same sign as the predictor plus the zero value can be reached.

A positive value of the horizontal or vertical component of the motion vector signifies that the prediction is formed from pixels in the referenced picture which are spatially to the right or below the pixels being predicted.

3.3.3. Quantization

The number of quantizers is 1 for the first coefficient of INTRA blocks and 31 for all other coefficients. Within a macroblock the same quantizer is used for all coefficients except the first one of INTRA blocks. The decision levels are not defined. The first coefficient of INTRA blocks is nominally the transform DC value uniformly quantized with a step size of 8. Each of the other 31 quantizers use equally spaced reconstruction levels with a central dead-zone around zero and with a step size of an even value in the range 2 to 62.

3.3.4. Zig-Zag Scan

The coder takes advantage of the spatial redundancy through the use of DCT followed by a zig-zag scan given in Figure 3.11. The coefficient 1 is the DC coefficient.

1	2	6	7	15	16	28	29
3	5	8	14	17	27	30	43
4	9	13	18	26	31	42	44
10	12	19	25	32	41	45	54
11	20	24	33	40	46	53	55
21	23	34	39	47	52	56	61
22	35	38	48	51	57	60	62
36	37	49	50	58	59	63	64

Figure 3.11: Zig-Zag Scanning

3.4. Semantic and Syntax

3.4.1. Picture Layer

Data for each picture consists of a picture header followed by data for Group of Blocks, eventually followed by an end-of-sequence code and stuffing bits. The structure was shown in Figure 3.9 and is also presented in Figure 3.12. According to the recommendation, the PSBI is only present if indicated by CPM. TRB and DBQUANT are only present if PTYPE indicates ‘PB-frame’. Combinations of PSPARE and PEI may not be present. EOS may not be present, while ESTUF may be present only if EOS is present.

PSC	TR	PTYPE	PQUANT	CPM	PSBI	TRB	DBQUANT	PEI	PSPARE	PEI	Group of Blocks	ESTUF	EOS	PSTUF

Figure 3.12: Picture Layer Structure

- **Picture Start Code** (**PSC**) (22 bits): PSC is a word of 22 bits. Its value is 0000 0000 0000 0000 1 00000. All picture start codes must be byte aligned. This is achieved by inserting PSTUF before the start code such that the first bit of the start code is the first (most significant) bit of a byte.

- **Temporal Reference** (**TR**) (8 bits): An 8-bit number which can have 256 possible values. It is formed by incrementing its value in the previously transmitted picture header by one plus the number of non-transmitted pictures (at 29.97 Hz) since the previously transmitted one.

- **Type Information** (**PTYPE**) (13 bits): Information about the complete picture as shown in Figure 3.13.

Bit	Function
1	Always “1”, in order to avoid start code emulation.
2	Always “0”, for distinction with H.261,
3	Split screen indicator, “0” off, “1” on,
4	Document camera indicator, “0” off, “1” on,
5	Freeze Picture Release, “0” off, “1” on,
6-8	Source Format, “000” forbidden, “001” sub-QCIF, “010” QCIF, “011” CIF, “100” 4CIF, “101” 16CIF, “110” reserved, “111” reserved,
9	Picture Coding Type, “0” INTRA (I-picture), “1” INTER (P-picture),
10	Optional Unrestricted Motion Vector mode, “0” off, “1” on,
11	Optional Syntax-based Arithmetic Coding mode, “0” off, “1” on,
12	Optional Advanced Prediction mode, “0” off, “1” on,
13	Optional PB-frames mode, “0” normal I- or P-picture, “1” PB-frame.

Figure 3.13: PTYTE bits

Split screen indicator is a signal that indicates that the upper and lower half of the decoded picture could be displayed side by side. This bit has no direct effect on the encoding or decoding of the picture.

Freeze Picture Release is a signal from an encoder which responds to a request for packet retransmission or fast update request and allows a decoder to exit from its freeze picture mode and display decoded picture in the normal manner.

If bit 6-8 indicate a different source format than in the previous picture header, the current picture has to be an I-picture.

Bit 10-13 refer to optional modes that are only used after negotiation between encoder and decoder. If bit 9 is set to “0”, bit 13 has to be set to “0” as well.

- **Quantizer Information** (**PQUANT**) (5 bits): A fixed length codeword of 5 bits which indicates the quantizer QUANT to be used for the picture until updated by any subsequent GQUANT or DQUANT. The codewords are the natural binary representations of the values of QUANT which, being half the step sizes, range from 1 to 31.

- **Continuous Presence Multipoint** (**CPM**) (1 bit): A codeword of 1 bit that signals the use of the optional Continuous Presence Multipoint mode (CPM); “0” is off, “1” is on.

- **Picture Sub Bitstream Indicator** (**PSBI**) (2 bits): A fixed length codeword of 2 bits that is only present if Continuous Presence Multipoint mode is indicated by CPM. The codewords are the natural binary representation of the sub-bitstream number for the picture header and all following information until the next Picture or GOB start code.

- **Temporal Reference for B-pictures** (**TR_B**) (3 bits): TR_B is present if PTYPE indicates ‘PB-frame’ and indicates the number of non-transmitted pictures (at 29.97 Hz) since the last P- or I-picture and before the B-picture. The codeword is the natural binary representation of the number of non-transmitted pictures plus one. The maximum number of non-transmitted pictures is 6.

- **Quantization information for B-pictures** (**DBQUANT**) (2 bits): DBQUANT is present if PTYPE indicates ‘PB-frame’. In the decoding process a quantization parameter QUANT is obtained for each macroblock. With PB-frames QUANT is used for the P-block, while for the B-block a different quantization parameter BQUANT is used. QUANT ranges from 1 to 31. DBQUANT indicates the relation between QUANT and BQUANT as defined in Figure 3.14. In this table, “/” means division by truncation. BQUANT ranges from 1 to 31; if the value for BQUANT resulting from Figure 3.14 is greater than 31, it is clipped to 31.

DBQUANT	BQUANT
00	(5xQUANT)/4
01	(6xQUANT)/4
10	(7xQUANT)/4
11	(8xQUANT)/4

Figure 3.14: DBQUANT codes and relation between QUANT and BQUANT

- **Extra Insertion Information** (**PEI**) (1 bit): A bit which when set to "1" signals the presence of the following optional data field.

- **Spare Information** (**PSPARE**) (0/8/16 . . . bits): If PEI is set to "1", then 9 bits follow consisting of 8 bits of data (PSPARE) and then another PEI bit to indicate if a further 9 bits follow and so on. Encoders mustn't insert PSPARE until specified by the ITU. Decoders have to be designed to discard PSPARE if PEI is set to 1. This is defined to allow the ITU to specify future backward compatible additions in PSPARE. If PSPARE is followed by PEI=0, PSPARE=xx000000 is prohibited in order to avoid start code emulation (x=don't care, so 4 out of 256 values are prohibited).

- **Stuffing** (**ESTUF**) (Variable length): A codeword of variable length consisting of less than 8 zero-bits. Encoders may insert this codeword directly before an EOS codeword. If ESTUF is present, the last bit of ESTUF shall be the last (least significant) bit of a byte, so that the start of the EOS codeword is byte aligned. Decoders have to be designed to discard ESTUF.

- **End Of Sequence** (**EOS**) (22 bits): A codeword of 22 bits. Its value is 0000 0000 0000 0000 1 11111. It is up to the encoder to insert this codeword or not. EOS may be byte aligned. This can be achieved by inserting ESTUF before the start code such that the first bit of the start code is the first (most significant) bit of a byte.

- **Stuffing** (**PSTUF**) (Variable length): A codeword of variable length consisting of less than 8 zero-bits. Encoders have to insert this codeword for byte alignment of the next PSC. The last bit of PSTUF have to be the last (least significant) bit of a byte, so that the video bitstream including PSTUF is a multiple of 8 bits from the first bit in the H.263 bitstream. Decoders have to be designed to discard PSTUF.

3.4.2. Group of Block Layer

Data for each Group of Blocks (GOB) consists of a GOB header followed by data for macroblocks. The structure is shown in Figure 3.9 as well as Figure 3.15. Each GOB contains one or more rows of macroblocks. According to the H.263 recommendation, GSTUF may be present when GBSC is present. GN, GFID and GQUANT are present when GBSC is present. GSBI is present when Continuous Presence Multipoint mode is on, as indicated in the Picture header.

GSTUF	GBSC	GN	GSBI	GFID	GQUANT	Macroblock Data

Figure 3.15: Structure of GOB layer

- **Stuffing** (**GSTUF**) (Variable length): A codeword of variable length consisting of less than 8 zero-bits. Encoders may insert this codeword directly before an GBSC codeword. If GSTUF is present, the last bit of GSTUF has to be the last (least significant) bit of a byte, so that the start of the GBSC codeword is byte aligned. Decoders shall be designed to discard GSTUF.

- **Group of Block Start Code** (**GBSC**) (17 bits): A word of 17 bits. Its value is 0000 0000 0000 0000 1. GOB start codes may be byte aligned. This can be achieved by inserting GSTUF before the start code such that the first bit of the start code is the first (most significant) bit of a byte.

- **Group Number** (**GN**) (5 bits): A fixed length codeword of 5 bits. The bits are the binary representation of the number of the Group of Blocks. For the GOB with number 0, the GOB header including GSTUF, GBSC, GN, GSBI, GFID and GQUANT is empty; group number 0 is used in the PSC. Group number 31 is used in the EOS and the values from 18 to 30 are reserved for future use by the ITU.

- **GOB Sub Bitstream Indicator** (**GSBI**) (2 bits): A fixed length codeword of 2 bits that is only present if Continuous Presence Multipoint mode is indicated by CPM. The codewords are the natural binary representation of the sub-bitstream number for the GOB header and all following information until the next Picture or GOB start code.

- **GOB Frame ID** (**GFID**) (2 bits): A fixed length codeword of 2 bits. GFID has to have the same value in every GOB header of a given picture. Moreover, if PTYPE as indicated in a picture header is the same as for the previous transmitted picture, GFID has to have the same value as in that previous picture. However, if PTYPE in a certain picture header differs from the PTYPE in the previous transmitted picture header, the value for GFID in that picture shall differ from the value in the previous picture.

- **Quantizer Information** (**GQUANT**) (5 bits): A fixed length codeword of 5 bits which indicates the quantizer QUANT to be used for the remaining part of the picture until updated by any subsequent GQUANT or DQUANT. The codewords are the natural binary representations of the values of QUANT which, being half the step sizes, range from 1 to 31.

3.4.3. Macroblock Layer

Data for each macroblock consists of a macroblock header followed by data for blocks. The structure is shown in Figure 3.9 as well as Figure 3.16. According to the H.263 recommendation, COD is only present in pictures for which PTYPE indicates 'INTER', for each macroblock in these pictures. MCBPC is present when indicated by COD or when PTYPE indicates 'INTRA'. MODB is present for MB-type 0-4 if PTYPE indicates 'PB-frame'. CBPY, DQUANT, MVD and MVD$_{2\text{-}4}$ are present when indicated by MCBPC. CBPB and MVDB are only present if indicated by MODB. Block Data is present when indicated by MCBPC and CBPY. MVD$_{2\text{-}4}$ are only present in Advanced Prediction mode. MODB, CBPB and MVDB are only present in PB-frames mode.

COD	MCBPC	MODB	CBPB	CBPY	DQUANT	MVD	MVD$_2$	MVD$_3$	MVD$_4$	MVDB	Block Data

Figure 3.16: Structure of macroblock layer

- **Coded macroblock indication** (**COD**) (1 bit): A bit which when set to "0" signals that the macroblock is coded. If set to "1", no further information is transmitted for this macroblock; in that case the decoder shall treat the macroblock as an INTER macroblock with motion vector for the whole block equal to zero and with no coefficient data. COD is only present in pictures for which PTYPE indicates 'INTER', for each macroblock in these pictures.

- **Macroblock type & Coded block pattern for chrominance** (**MCBPC**) (Variable length): A variable length codeword giving information about the macroblock type and the coded block pattern for chrominance. MCBPC is always included in coded macroblocks.

- **Macroblock mode for B-blocks** (**MODB**) (Variable length): MODB is present for MB-type 0-4 if PTYPE indicates 'PB-frame' and is a variable length codeword indicating whether CBPB is present (indicates that B-coefficients are transmitted for this macroblock) and/or MVDB is present.

- **Coded block pattern for B-blocks** (**CBPB**) (6 bits): CBPB is only present in PB-frames mode if indicated by MODB. $CBPB_N$ = 1 if any coefficient is present for B-block N, else 0, for each bit $CBPB_N$ in the coded block pattern.

- **Coded block pattern for luminance** (**CBPY**) (Variable length): Variable length codeword giving a pattern number signifying those Y blocks in the macroblock for which at least one non-INTRADC transform coefficient is transmitted. $CBPY_N$ = 1 if any non-INTRADC coefficient is present for block N, else 0, for each bit $CBPY_N$ in the coded block pattern. Block numbering is given in FIGURE 5/H.263, the utmost left bit of CBPY corresponding with block number 1.

- **Quantizer Information** (**DQUANT**) (2 bits): A two bit code to define change in QUANT. QUANT ranges from 1 to 31; if the value for QUANT after adding the differential value is less than 1 or greater than 31, it is clipped to 1 and 31 respectively.

- **Motion vector data** (**MVD**) (Variable length): MVD is included for all INTER macroblocks (in PB-frames mode also for INTRA macroblocks) and consists of a variable length codeword for the horizontal component followed by a variable length codeword for the vertical component.

- **Motion vector data** (**MVD_{2-4}**) (Variable length): The three codewords MVD_{2-4} are included if indicated by PTYPE and by MCBPC, and consist each of a variable length codeword for the horizontal component followed by a variable length codeword for the vertical component of each vector. MVD_{2-4} are only present when in Advanced Prediction mode.

- **Motion vector data for B-macroblock** (**MVDB**) (Variable length): MVDB is only present in PB-frames mode if indicated by MODB and consists of a variable length codeword for the horizontal component followed by a variable length codeword for the vertical component of each vector.

3.4.4. Block Layer

If not in PB-frames mode, a macroblock comprises four luminance blocks and one of each of the two colour difference blocks as shown in Figure 3.7. The structure of the block layer is shown in Figure 3.17.

INTRADC	TCOEF

Figure 3.17: Structure of block layer

In PB-frames mode, a macroblock comprises twelve blocks. First the data for the six P-blocks is transmitted as in the default H.263 mode, then the data for the six B-blocks. INTRADC is present for every P-block of the macroblock if MCBPC indicates MB type 3 or 4. INTRADC is not present for B-blocks. TCOEF is present for P-blocks if indicated by MCBPC or CBPY; TCOEF is present for B-blocks if indicated by CBPB.

Index	FLC	Reconstruction level into inverse transform
0	0000 0001 (1)	8
1	0000 0010 (2)	16
2	0000 0011 (3)	24
.	. .	.
.	. .	.
126	0111 1111 (127)	1016
127	1111 1111 (255)	1024
128	1000 0001 (129)	1032
.	. .	.
.	. .	.
252	1111 1101 (253)	2024
253	1111 1110 (254)	2032

Figure 3.18: Reconstruction levels for INTRA-mode DC coefficient

- **DC coefficient for INTRA blocks** (**INTRADC**) (8 bits): A codeword of 8 bits. The code 0000 0000 and 1000 0000 are not used, the reconstruction level of 1024 being coded as 1111 1111 (see Figure 3.18).

- **Transform coefficient** (**TCOEF**) (Variable length): The most commonly occurring events are coded with the variable length codes given in Figure 3.19. The last bit "s" denotes the sign of the level, "0" for positive and "1" for negative. An EVENT is a combination of a last non-zero coefficient indication (LAST; "0": there are more nonzero coefficients in this block, "1": this is the last nonzero coefficient in this block), the number of successive zeros preceding the coded coefficient (RUN), and the non-zero value of the coded coefficient (LEVEL). The remaining combinations of (LAST, RUN, LEVEL) are coded with a 22 bit word consisting of 7 bits ESCAPE, 1 bit LAST, 6 bits RUN and 8 bits LEVEL. Use of this 22-bit word for encoding the combinations listed in Figure 3.19 is not prohibited. For the 8-bit word for LEVEL, the codes 0000 0000 and 1000 0000 are not used. The codes for RUN and for LEVEL are given in Figure 3.20.

INDEX	LAST	RUN	LEVEL	BITS	VLC CODE
0	0	0	1	3	10s
1	0	0	2	5	1111 s
2	0	0	3	7	0101 01s
3	0	0	4	8	0010 111s
4	0	0	5	9	0001 1111 s
5	0	0	6	10	0001 0010 1s
6	0	0	7	10	0001 0010 0s
7	0	0	8	11	0000 1000 01s
8	0	0	9	11	0000 1000 00s
9	0	0	10	12	0000 0000 111s
10	0	0	11	12	0000 0000 110s

INDEX	LAST	RUN	LEVEL	BITS	VLC CODE
58	1	0	1	5	0111 s
59	1	0	2	10	0000 1100 1s
60	1	0	3	12	0000 0000 101s
61	1	1	1	7	0011 11s
62	1	1	2	12	0000 0000 100s
63	1	2	1	7	0011 10s
64	1	3	1	7	0011 01s
65	1	4	1	7	0011 00s
66	1	5	1	8	0010 011s
67	1	6	1	8	0010 010s
68	1	7	1	8	0010 001s

INDEX	LAST	RUN	LEVEL	BITS	VLC CODE
11	0	0	12	12	0000 0100 000s
12	0	1	1	4	110s
13	0	1	2	7	0101 00s
14	0	1	3	9	0001 1110 s
15	0	1	4	11	0000 0011 11s
16	0	1	5	12	0000 0100 001s
17	0	1	6	13	0000 0101 0000s
18	0	2	1	5	1110 s
19	0	2	2	9	0001 1101 s
20	0	2	3	11	0000 0011 10s
21	0	2	4	13	0000 0101 0001s
22	0	3	1	6	0110 1s
23	0	3	2	10	0001 0001 1s
24	0	3	3	11	0000 0011 01s
25	0	4	1	6	0110 0s
26	0	4	2	10	0001 0001 0s
27	0	4	3	13	0000 0101 0010s
28	0	5	1	6	0101 1s
29	0	5	2	11	0000 0011 00s
30	0	5	3	13	0000 0101 0011s
31	0	6	1	7	0100 11s
32	0	6	2	11	0000 0010 11s
33	0	6	3	13	0000 0101 0100s
34	0	7	1	7	0100 10s
35	0	7	2	11	0000 0010 10s
36	0	8	1	7	0100 01s
37	0	8	2	11	0000 0010 01s
38	0	9	1	7	0100 00s
39	0	9	2	11	0000 0010 00s
40	0	10	1	8	0010 110s
41	0	10	2	13	0000 0101 0101s
42	0	11	1	8	0010 101s
43	0	12	1	8	0010 100s
44	0	13	1	9	0001 1100 s
45	0	14	1	9	0001 1011 s
46	0	15	1	10	0001 0000 1s
47	0	16	1	10	0001 0000 0s
48	0	17	1	10	0000 1111 1s
49	0	18	1	10	0000 1111 0s
50	0	19	1	10	0000 1110 1s
51	0	20	1	10	0000 1110 0s
52	0	21	1	10	0000 1101 1s

INDEX	LAST	RUN	LEVEL	BITS	VLC CODE
69	1	8	1	8	0010 000s
70	1	9	1	9	0001 1010 s
71	1	10	1	9	0001 1001 s
72	1	11	1	9	0001 1000 s
73	1	12	1	9	0001 0111 s
74	1	13	1	9	0001 0110 s
75	1	14	1	9	0001 0101 s
76	1	15	1	9	0001 0100 s
77	1	16	1	9	0001 0011 s
78	1	17	1	10	0000 1100 0s
79	1	18	1	10	0000 1011 1s
80	1	19	1	10	0000 1011 0s
81	1	20	1	10	0000 1010 1s
82	1	21	1	10	0000 1010 0s
83	1	22	1	10	0000 1001 1s
84	1	23	1	10	0000 1001 0s
85	1	24	1	10	0000 1000 1s
86	1	25	1	11	0000 0001 11s
87	1	26	1	11	0000 0001 10s
88	1	27	1	11	0000 0001 01s
89	1	28	1	11	0000 0001 00s
90	1	29	1	12	0000 0100 100s
91	1	30	1	12	0000 0100 101s
92	1	31	1	12	0000 0100 110s
93	1	32	1	12	0000 0100 111s
94	1	33	1	13	0000 0101 1000s
95	1	34	1	13	0000 0101 1001s
96	1	35	1	13	0000 0101 1010s
97	1	36	1	13	0000 0101 1011s
98	1	37	1	13	0000 0101 1100s
99	1	38	1	13	0000 0101 1101s
100	1	39	1	13	0000 0101 1110s
101	1	40	1	13	0000 0101 1111s
102	ESCAPE			7	0000 011

INDEX	LAST	RUN	LEVEL	BITS	VLC CODE
53	0	22	1	10	0000 1101 0s
54	0	23	1	12	0000 0100 010s
55	0	24	1	12	0000 0100 011s
56	0	25	1	13	0000 0101 0110s
57	0	26	1	13	0000 0101 0111s

Figure 3.19: VLC table for TCOEF

Index	Run	Code
0	0	000 000
1	1	000 001
2	2	000 010
.	.	.
.	.	.
63	63	111 111

Index	Level	Code
-	-128	FORBIDDEN
0	-127	1000 0001
.	.	.
125	-2	1111 1110
126	-1	1111 1111
-	0	FORBIDDEN
127	1	0000 0001
128	2	0000 0010
.	.	.
253	127	0111 1111

Figure 3.20: FLC table for RUNS and LEVELS

Chapter IV

4. The Java Paradigm

In 1990, Sun Microsystems began studies on development of a platform independent object oriented language. Some few years ago, a first version of this language was available. The language was named Java. After this two released updates, versions 1.0.2 and the newest 1.1. are mostly widely used at this moment.

4.1. Java's Architecture

Java's Architecture, shown in Figure 4.1, consists of a two step procedure, to run a program: First, a programmer writes a Java source code and compiles it. The Java compiler (**javac**) creates an intermediate code, called Byte Code. The Byte Code is an intermediate code, not a specific code for a specific machine; it runs on an abstract machine called the Java Virtual Machine (**java**). That's why the code can run in any Java enabled machine. It is sufficient for a particular machine to have a Java Virtual Machine (JVM) implementation to run any Java code. In the second step, the user submits a previously compiled Java Byte Code to the JVM, in order to run the application. The JVM originally works as an interpreter. All this process is summarized in the Figure 4.2.

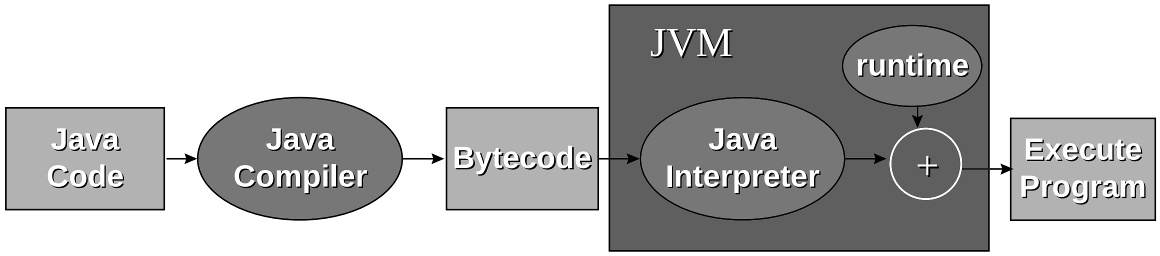


Figure 4.1: The Java Architecture

There are two different kinds of Java programs. The first is called a system, and works like a standard program such as a C code, the only difference is that the system runs over the JVM, through an interpretation procedure; the second Java program type is called Applet, which consist of a program that runs inside a Java Enabled Browser, such as Netscape, Microsoft Internet Explorer, or Sun's HotJava. A Java Enabled Browser contains an implementation of a JVM, which makes possible the execution of Java Byte Code. An Applet has a set of restrictions that were imposed for security reasons. For instance, an Applet is not allowed to handle any hardware device, e.g. as Hard Drive. So, it is not possible for somebody to write a harmful Applet which would delete all files on a Hard Disk.

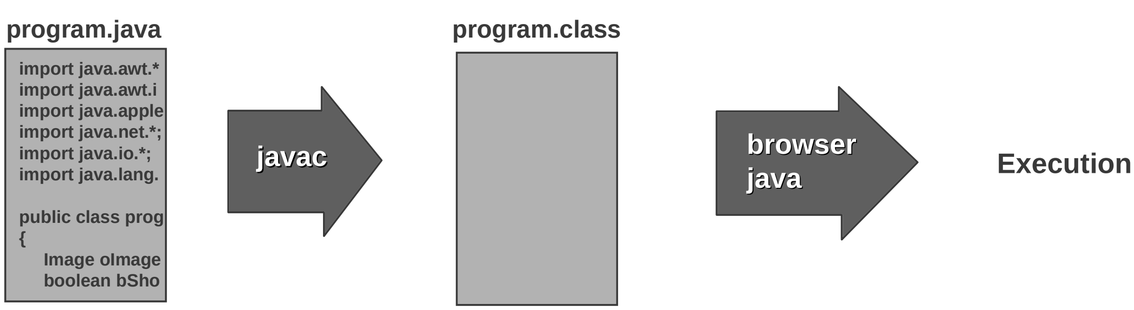


Figure 4.2: The steps required to run a program written in Java

The main feature of Java is the portability which makes easily possible the maintenance of a program that is supposed to run on several different machines.

4.2. Approaches for Applications for the Web

Until the creation of Java, when an application was available on the Internet, the user had to find the application, download the right version for his/her machine and operating system, if it is available, install the program, and finally, run it. Problem may occur if the program is not available for a determined machine, for instance, a version for OS2 is usually not available on the Internet. Now with Java, and particularly Applets, a user just has to find the application he/she needs, click in the application's link and the application will run. Automatically the application will be downloaded, installed, submitted to the JVM, and then executed. After the execution, the program will be automatically deleted. In the next time the user runs the program, the actual version will pass through the same process. Here we found another advantage in using Java Applets. If the programmer updates something in the Applet, for example including a new option in it, the user will run this new version without any necessary action from the user point of view in order to update his/her program, which is required for the conventional program paradigm.

4.3. Java Advantages and Disadvantages

As advantages, it is possible to quote the following:

- The program is platform independent. It can even run on non PC devices, such as Web-TV, Cellular phone PDA's, Network Devices.

- It is easy to update and to maintain a program as commented before.

- The Byte Code is extremely small, hence, is downloaded quickly. The code is small because it is not needed to link the code with libraries, since the JVM has a set of run time libraries with everything that is needed to run a program (see Figure 4.1).

- The language itself provides support for network communication through TCP/IP.

On the other hand, it is possible to enumerate the following disadvantages:

- It runs slower than a traditional program, due to the interpreting before running step; however, Just in Time compiling (JIT) can increase speed. That's why a Java Applet runs faster on Windows than on Solaris, for example, because the first uses the Just In Time compiling technique in its browsers, while the second doesn't do it.

- Security restrictions, such as no file manipulation, can make hard some implementations; however it is possible to write a Java system program to run as a server and exchange information with the Applet. The Java program is allowed to handle devices such as Hard Disk, etc. Due to the security restrictions an Applet can only exchange information with a server written for that Applet.

Chapter V

5. Java H.263 implementation

The goal of this project was to write an H.263 decoder in Java, in order to take advantage of the portability of the language. Now, the code can be converted into an Applet, since it does not access any device and can receive the video stream from a network connection. In this chapter, the implementation is presented as well as some limitations of Java in bit operations.

5.1. Codec Architecture

The Codec was planned with the architecture presented in the Figure 5.1 in mind. In some place, a user has a video camera that provides video to a video capture board, this video grabber provides the video stream to a small program, written in C due to performance matter, and this program receives the video stream and codes it into an H.263 video stream. Then, this video stream is provided to a Java Application, that works as a server as defined in the previous chapter. This Java Server, called Java Video Server just sends the H.263 video stream to an Applet that has required it through a network connection. On the other side of the network a user that is running the Java Decoder Applet (JDA), will see the video sent by the server in a window that the JDA opens to display the video.

Java was not developed for efficient bit handling. The performance of this decoder is heavily damaged because of it; however, the new versions of Java will introduce some new features that should improve the performance.

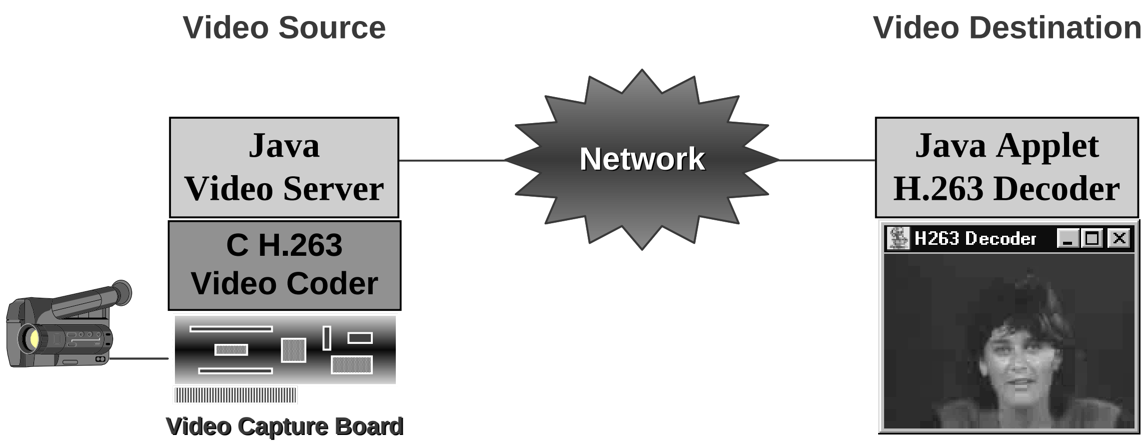


Figure 5.1: Java Video Codec Architecture

In the actual decoder, a method to convert from a Byte into an Integer and from an Integer back to Byte was required (Byte = 8 bits signaled integer; Integer 32 bits signaled integer). The problem shown bellow, required the implementation of the following methods:

From Byte to Integer:

- 11001100 = -52 ⇒ 11...111001100 = -52 instead of expected 00…011001100.

From Integer to Byte:

00…0010000000 = 128 ⇒ 00000000 = 0 instead of the expected 10000000.

```
int Byte2Int(byte bValue)
{
	int iReturn = bValue;

	return iReturn&0xff;
}

byte Int2Byte(int iValue)
{
	byte bReturn=0;

	iValue &= 0xff;

	if(iValue==128)
	{
		bReturn = -128;
		return bReturn;
	}
	return (byte) iValue;
}
```

Bellow, the dither method that convert the Y, Cr, Cb components used by the ITU-T H.263 recommendation into the RGB components required to create a Java Image is presented. Note that for each component, the above Byte2Int and Int2Byte methods have to be performed several times, which degrades the performance substantially.

```
void Color32DitherImage(byte src[][], int out[])
{
	byte lum[]  = src[0];
	byte cb[]   = src[1];
	byte cr[]   = src[2];
	int cols, iCR=0, iCB=0, iLUM=0;
	int rows;

	int L, CR, CB;
	int row1, row2;
	int lum2;
	int x, y;
	int cr_r;
	int cr_g;
	int cb_g;
	int cb_b;
	int cols_2;

	cols  = coded_picture_width;
	rows  = coded_picture_height;
	cols_2= cols/2;
	row1  = 0;
	row2  = cols_2 + cols_2;
	lum2  = cols_2 + cols_2;

	for(y=0; y<rows; y+=2)
	{
		for(x=0; x<cols_2; x++)
		{
			int R, G, B;
```

```
                  CR    = Byte2Int(cr[iCR++]);
                  CB    = Byte2Int(cb[iCB++]);
                  cr_r  = Cr_r_tab[CR];
                  cr_g  = Cr_g_tab[CR];
                  cb_g  = Cb_g_tab[CB];
                  cb_b  = Cb_b_tab[CB];

                  L = L_tab[Byte2Int(lum[iLUM++])];

                  R = (L + cr_r);
                  G = (L + cr_g + cb_g);
                  B = (L + cb_b);

                  out[row1++] = (0xff<<24 | R<<16 | G<<8 | B );

                  L = L_tab[Byte2Int(lum[iLUM++])];

                  R = (L + cr_r);
                  G = (L + cr_g + cb_g);
                  B = (L + cb_b);

                  out[row1++] = (0xff<<24 | R<<16 | G<<8 | B );

                  L = L_tab [Byte2Int(lum[lum2++])];
                  R = (L + cr_r);
                  G = (L + cr_g + cb_g);
                  B = (L + cb_b);

                  out[row2++] = (0xff<<24 | R<<16 | G<<8 | B);

                  L = L_tab [Byte2Int(lum[lum2++])];
                  R = (L + cr_r);
                  G = (L + cr_g + cb_g);
                  B = (L + cb_b);

                  out[row2++] = (0xff<<24 | R<<16 | G<<8 | B);
            }
            iLUM += cols_2 + cols_2;
            lum2 += cols_2 + cols_2;
            row1 += cols_2 + cols_2;
            row2 += cols_2 + cols_2;
      }
}
```

Both methods Int2Byte and Byte2Int are also largely used during the decoding of the video stream, where each byte has to be converted into an integer, that works as a buffer with 32 bits inside.

```
// return next n bits (right adjusted) without advancing
int ShowBits(int piNumber)
{
      int iValue;
      int iByte=0;
      int iCalc;

      if(iInputCounter<piNumber)
            FillBuffer();
```

```
      iValue = (96 - iInputCounter)>>>3;

      iByte=(Byte2Int(viInputBuffer[iValue])<<24)|(Byte2Int(viInputBuffe
r[iValue+1])<<16)|(Byte2Int(viInputBuffer[iValue+2])<<8)|Byte2Int(viInpu
tBuffer[iValue+3]);

      iCalc = ((iInputCounter-1) & 7) + 25;

      return (iByte>>>(iCalc-piNumber)) & viMask[piNumber];
}
```

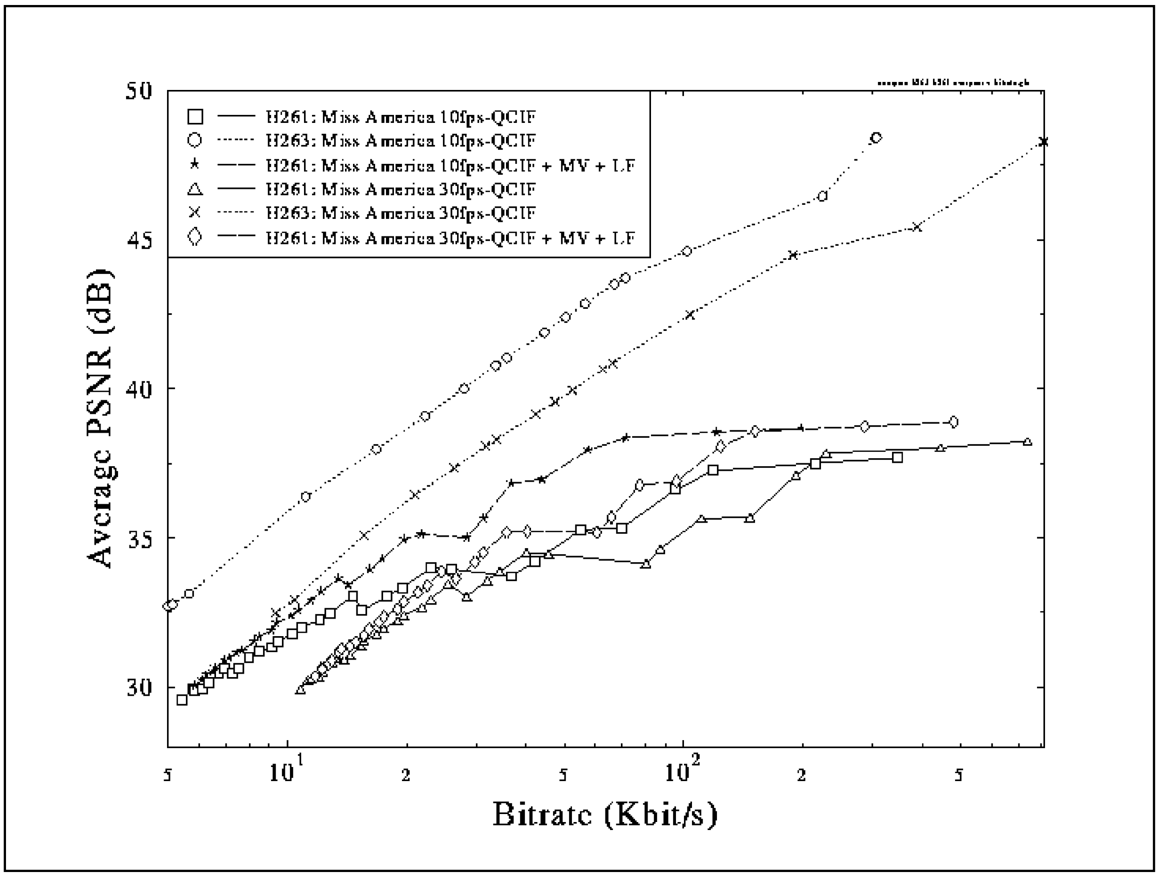


Figure 5.2: H.263 × H.261

The H.263 Codec has a better performance than the H.261 Codec discussed in Chapter 2 and 3. Figure 5.2 shows a comparison between them. The performance of the decoder written in Java is very fair, since the frame rate of just 2 frames/sec was reached. The frame rate should be improved when the next release of Java becomes available. In future a new structure called Multimedia Framework will be included which should improve the bit operation capabilities.

The decoder has a little bit more than 3860 lines, just for comparison, this document up to this point has 1930 lines, exactly one half of the decoder source code.

Chapter VI

6. Conclusion

The implementation of an H.263 Java Decoder as well as an architecture for exchange of video transmission through a network was presented in this document. Due to the fact that the decoder was written in Java, it is possible to receive the video on any machine, such as Windows95, MacOS or Unix stations. This decoder is going to be used in the JETS project (Java Enabled TeleColaboration System) at Multimedia Communications Research Laboratory to create a videoconferencing environment over Java Enabled Browsers, such as Netscape, Microsoft Internet Explorer, Sun's HotJava, etc.

The Decoder has shown to be robust; however the frame rate needs a substantial improvement.

6.1. Further Recommendation and Future Work

- Rewrite some parts of the Decoder Applet in order to improve the performance on not so powerful CPU's.

- Include the Coder/Decoder architecture in the JETS project, in order to improve the telelearning environment (http://www.mcrlab.uottawa.ca/jets).

- Adapt the Coder to be used as video source, the video capture board itself, as well as complete the communication between Coder/Decoder.

- Include some of the H.263 optional features that were not implemented in this first prototype.

- To adapt the Java Video Server to use the RTP[11] [IETF 97]for efficient multicast transmission.

[11] Real Time Protocol

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