

COMPUTATIONAL GRACEFUL DEGRADATION FOR VIDEO DECODING

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ABSTRACT

The implementation of software based video decoders is an advantageous solution over traditional dedicated hardware real-time systems. However, guaranteeing real-time performance, needed when processing video/audio bit-streams, by scheduling processing tasks of variable load and that might exceed the available resources, is an extremely difficult and in many cases an impossible challenge. In this paper we introduce the motivations and ideas of the Computational Graceful Degradation (CGD) approach for the implementation of video decoding. The goal is to provide results of possibly lower visual quality, but respecting the real-time constraints, when the required processing needs exceed the available processing resources. This approach is very attractive since it enables a more efficient usage of the hardware processing power without needing to implement resources for worst case complexity decoding. We show how such technique can be applied to the decoding of compressed video sequences. Simulation results for MPEG-4 and H.263 video compression standards showing some of the interesting achievements and potentialities of CGD approach are also reported. The presented approach can be virtually applied to any video compression standard and processor based platform, although the best performances are achieved when complexity prediction information provided as side information by the video standard is available. This option has been included in the new MPEG-4 standard.

1 INTRODUCTION

The complexity of video decoding is a fluctuating function of time [1]. By complexity we mean the processing time necessary to decode a compressed video bit-stream. Even considering a specific processor platform, a specific compression standard, with a relative level and profile, the complexity of video decoding is a variable quantity. Dedicated hardware platforms can guarantee worst case complexity decoding. In contrast, in the case of programmable platforms such a guarantee would imply the allocation of a processing power up to

two orders of magnitude higher than the one actually needed for an average decoding [1]. Conversely, a theoretical average value is not useful for an efficient scheduling of a decoding task. The average value for each considered sequence is not stationary, and its variation around the theoretical average one are so unpredictable that no useful scheduling policy can be realized. The first straightforward option is a sustained over-sizing of the processing resources. The second is to accept interruptions in the audio/video output streams when the needed decoding resources exceed the ones available in the system. Obviously both options are not desirable being respectively not economical, or providing a quality of the services which may easily result perceptually unacceptable. The main rationale of the Computational Graceful Degradation (CGD) approach is to provide results of poorer quality when the results of the desirable quality cannot be obtained in real time. When the complexity of the task exceeds the available processing power, real-time services, possibly of degraded quality, are nevertheless guaranteed respecting all real-time constraints. This approach enables the correct scheduling of real-time tasks even when the computational system load fluctuates above the system capabilities.

The concept of computational graceful system degradation using imprecise results has previously been introduced in the field of real-time computing with applications to control system and automation. In these contexts imprecise results are defined as intermediate results with the property that the more recent and intermediate result is the closer one that approximates the final result (i.e. the idea only works in monotonically improving computations) [2, 3, 4]. In these cases the problems to be solved are more concerned with fault tolerance, I/O overloads, stability and reactivity to unexpected inputs, and the corresponding techniques are not suitable for the purposes of video decoding. In our case, the goal is to guarantee real-time video decoding with possible degradations of the image quality, i.e. reductions of the peak signal to noise ratio (PSNR), without losing parts of the image content. Such al-

ternative is certainly much more desirable than other straightforward options such as cutting image portions or simply skipping frames. These latter options, as can be easily understood, can have catastrophic consequences on prediction based coding systems. In H.263 decoders, for instance, skipping the decoding of a single frame or a portion of it, implies the skipping of all future incoming frames (or portion of them) before the next incoming Intra frame. The time interval of such skipping operation might cover many seconds and the information content loss might be very relevant. Such abrupt interruptions, which are perceptually very annoying, might be caused not only by the simple fluctuation of the decoding complexity load, but also by the fluctuations of the load of other non-video processing tasks which reduce the available processing resources. Moreover, such events in general are out of the control of the video decoder system and cannot be easily forecasted. Considering these facts, it is evident the importance of techniques able to filter out complexity decoding peak loads or able to reduce the average decoding computation load without causing perceptually annoying consequences. Skipping B-VOP could be, in some cases, a viable option accepting the introduction of motion judder in the sequence reproduction. Unfortunately the presence of B-frames or B-VOP cannot be guaranteed in any bit-stream and just at the right time for which a reduction of the complexity is needed to respect the real time constraints.

In contrast with what could be commonly thought, also the classical multi-resolution coding features such as spatial or temporal scalabilities are not really useful for our goals. In general, they are used to optimize the transmission bandwidth usage enabling the compatibility of services at different titrates and spatial resolutions, but they must be embedded in the original bit-stream at the encoder side. If they are not embedded, the changes of resolution at the decoder size can results more computationally expansive than the simple decoding at the given resolution.

From these arguments the usefulness of CGD and its important features and applications are clear. The last key point that has left CGD as a good idea, but of difficult introduction in video coding, was that it was not clear how to implement it efficiently. Now that a technique able to predict with a good degree of approximation the required decoding time of each decoding process is demonstrated and available for MPEG-4 systems [5], we have the key for the useful and efficient implementation of CGD techniques.

2 PRINCIPLES OF DECODING USING THE CGD APPROACH

The decoding operations of a video compression algorithm can be divided into two main categories: 1) operations that cannot be simplified since they may prevent

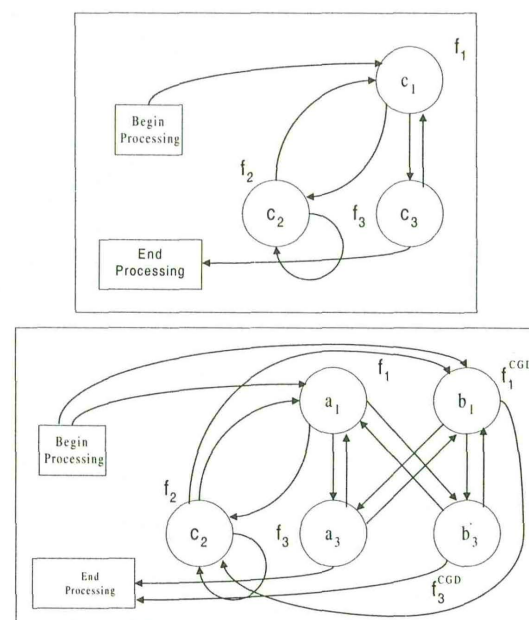


Figure 1: Upper diagram, example of a complexity model representing the data dependent execution of three algorithms. Lower diagram, example of the same complexity model of the upper diagram for which two algorithms (f_1 and f_3 are associated to new CGD algorithms (f_1^{CGD} and f_3^{CGD}).

the extraction and usage of relevant coding information, 2) operations that can be simplified, possibly leading to imprecise or degraded video results. To the first category typically belong all bit-stream parsing operations, entropy decoding (i.e. VLD and arithmetic coding), and all operations related to synchronization and to the syntax of the decoding process. For these operations no degradation mode definition is possible, otherwise it would imply skipping image portions or entire frames since either the data or the coding modes are lost. To the second category belong operations such as the IDCT, the prediction with and without motion compensation in its various forms (PB/B-frame prediction, overlapped block motion compensation (OBMC), half pixel interpolation, macroblock padding and so on). Simplifications of such operations applied to pixels or transform coefficients are always possible but at the expenses of imprecise results.

Two are the possible strategies for the implementation of CGD features. The first is to monitor the execution of the decoding process, to assume that the decoding time of each portion of the frame or VOP is proportional to the image area, and to execute CGD algorithms whenever the current monitored decoding time exceeds the current target decoding time suitable to respect the specified real-time constraints. Such simple strategy has several drawbacks. One is that there is no guaran-

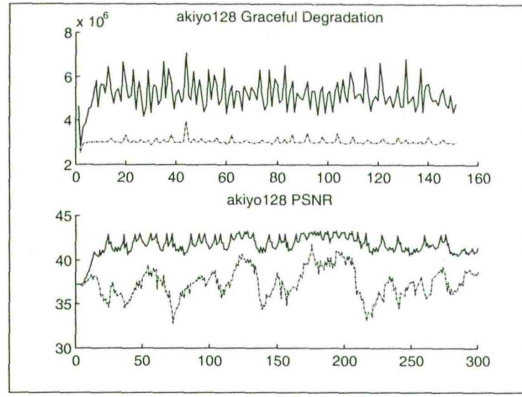


Figure 2: Example of CGD decoding of 300 frames of the sequence Akiyo at compressed at 128 kb/sec with H.263. The upper diagram reports the number of processor cycles for the original decoding (upper curve) and for the CGD decoding lower curve, versus the frame number. The lower diagram reports the two PSNR.

tee that the target decoding time is achieved. Another problem is due to execution of CGD algorithms that *a posteriori* could have not been necessary, thus introducing unnecessary image degradations. Moreover, such degradations are concentrated on critical image areas, and due to the drift given by the degraded reference for the prediction based algorithms, such degradations becomes visible and might seriously affect the resulting sequence PSNR. An example of such approach is reported in Fig. 2. The H.263 decoder has been modified by implementing computationally degraded IDCT and motion compensation algorithms. The interesting result achieved is that the decoding is obtained at a constant processing time for each frame. Unfortunately the PSNR degradations although limited to some dBs are nevertheless relevant from the perceptual point of view.

The second strategy is to exploit the complexity information carried by the frames or VOP headers, like it can be done for MPEG-4 systems [6], and use it in two stages. The first stage predicts the decoding time needed for the current frame or VOP, as described in [5]. The second, on the basis of the predicted decoding time and on the complexity information (i.e. statistics of the algorithms necessary to correctly decode the frame), executes only the CGD algorithms that are just necessary to not exceed the target decoding time.

More formally, let us consider a complexity model similar to the one illustrated in Fig. 1 composed by a set of I algorithms f_i , with $i = 1 \dots I$, and suppose to be able to design for all, or only for a subset S^{CGD} of the functions f_i composing the model, new functions f_i^{CGD} which have the following three properties: 1. the execu-

tion of a function f_i^{CGD} yields results that are an approximation of the ones produced by the original function f_i , 2. the execution of f_i^{CGD} does not prevent the execution of any subsequent decoding functions, 3. the weight w_i^{CGD} associated to f_i^{CGD} that represent the execution time of the f_i^{CGD} algorithm for the considered decoder implementation is lower than the corresponding w_i associated to f_i (i.e. $w_i^{CGD} < w_i$). A schematic representation of a complexity model which includes new degraded functions is reported in Fig. 1. The picture shows that new degraded algorithms can be executed at the place of the original algorithms. Obviously, the execution of any f_i^{CGD} may produce PSNR degradations in the reconstruction of some image parts, it does not prevent from correctly decoding the rest of the frame or VOP, but it reduces the necessary decoding time. Let us partition the functions constituting the complexity model into two disjoint sets: S^{Orig} and S^{CGD} respectively for the ones that do not admit a CGD version (f_2 for instance in Fig. 1) and for the ones for which it is possible to design a CGD version (f_1 and f_3). Let us consider for simplicity an image sequence composed by a sequence of single frames or VOPs and suppose that the execution time for the decoding of the frame or VOP is larger than the allocated decoding time:

$$T(t) > T_{Alloc}, \quad (1)$$

where $T(t)$ is the decoding time of the VOP at hand at the sampling time t . Since the decoding time can be approximated by its prediction [5] it can be expressed by:

$$T(t) \simeq T_{Pred}(t) = \sum_{i=1}^I c_i w_i, \quad (2)$$

where the c_i are the actual occurrences of algorithm f_i in the current frame or VOP [5], and the w_i are the corresponding complexity weights. The lower limit for the decoding time executing all CGD algorithms f_i^{CGD} at the place of f_i for all $i \in S^{CGD}$, is given by:

$$T_{CGD} = \sum_{i \in S^{CGD}} c_i w_i^{CGD} + \sum_{i \in S^{Orig}} c_i w_i. \quad (3)$$

If $T_{CGD} < T_{Alloc} < T_{Pred}$, is possible to guarantee the real-time constraints by executing the f_i^{CGD} algorithms and accepting approximate decoding results. It is also possible to find for each c_i with $i \in S^{CGD}$, a couple of coefficients a_i, b_i , for which $a_i + b_i = c_i$, and denoting as $T_{Process}$ any decoding time interval which respects the real time constraints, we can express the desired process decoding time as any decoding time value that satisfy the expression:

$$T_{process} = \sum_{i \in S^{CGD}} (a_i w_i^{CGD} + b_i w_i) + \sum_{i \in S^{Orig}} c_i w_i \leq T_{Alloc}. \quad (4)$$

Obviously for any Allocated Decoding Time the goal is to respect the real-time constraints with the lowest

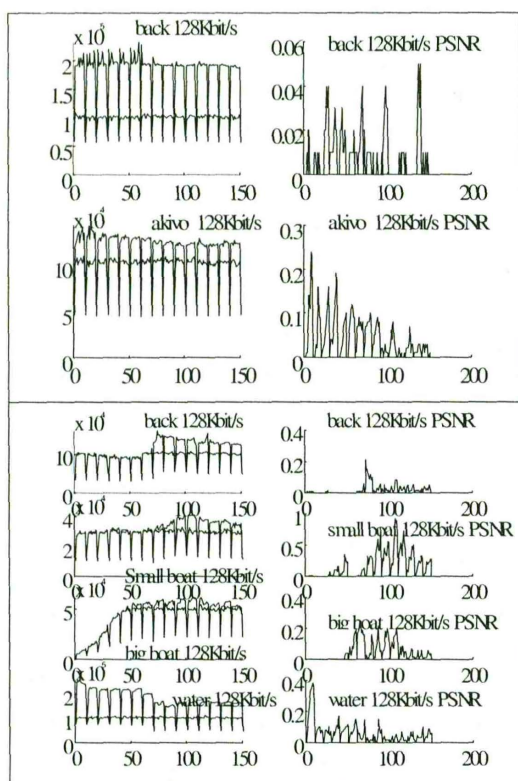


Figure 3: Left, decoding time results for the various VOP of sequences Akiyo and Coastguard, with and without imposing a bound. Right, the PSNR degradations versus the sequence VOP number.

degradation in the video/audio content. Associating a degradation measure to each w_i^{CGD} it is possible to minimize the degradation for any given T_{Alloc} . The challenge is to find the set $S_{a,b}$ of couple of coefficients a_i, b_i , with $i \in S_{CGD}$, that satisfy minimize the video degradations expressed as difference with the non degraded output:

$$S_{a,b} = \operatorname{argmin}(a,b)_{i \in S_{CGD}} : (\text{PSNR} - \text{PSNR}(a,b)). \quad (5)$$

The determination of the set $S_{a,b}$ can be done by means of many suitable optimization method or heuristics. The described techniques can be easily extended to the case of sequences containing multiple VOP at the same sampling time t .

3 SIMULATION RESULTS

Simulation results demonstrate the possibility of successful implementations of CGD for MPEG-4 video decoding. A bound on the decoding complexity of each VOP is defined setting a maximum constant T_{Alloc} . Figure 3 report the results of MPEG-4 video decoding imposing such bounds on the decoding time of each video object

plane (VOP) for the test images Coastguard and Akiyo coded at 128 kb/s. On the left, the graphs report the decoding time in msec for the unbounded and bounded decoding (lower curve) versus the image sequence number. On the right the graphs reports the resulting PSNR degradation. The decoder is the Momusys CD on a Sun Ultrasparc station modified implementing degraded motion compensation algorithms. Obviously the actual results depend on the decoder, on the platform on the CGD algorithms implemented, but the good results demonstrate that bounded complexity decodings are possible with minimal image degradations much lower than the one obtained without complexity information and decoding time prediction.

4 CONCLUSION

We have introduced the motivations and concepts of the CGD approach for the implementation of video decoders on processor based platforms. Simulation results for MPEG-4 video decoding demonstrate the successful implementation of the CGD approach. Obviously, the implementation of CGD features are not proposed to be used at their maximum degradation rate but as tool able to guarantee real-time performance in presence of peaks of decoding complexity or as a way to ease the scheduling problems given by temporary fluctuations of the available processing power. Moreover, the presented approach may enable the successful implementation of video decoding for levels and profiles that would be forbidden if the complexity of *worst case decoding* has to be guaranteed.

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General Chairman's Message

IT IS MY PLEASURE TO WARMLY WELCOME YOU ALL TO EUSIPCO-98 IN THE BEAUTIFUL GREEK ISLAND OF RHODES. A place rich in history, culture, and natural beauties.

EUSIPCO-98 is to be held at the RODOS PALACE International Convention Center. It is located by the sea and it is an ideal place to combine stimulating scientific meetings with leisure.

I am very pleased that the response of the Signal and Image Processing Scientific Community confirmed the tradition of continued growth of the EUSIPCO conferences. This year we received more than 960 submissions from all over the world, 86 of which were allocated in 12 special sessions, 270 in 38 oral sessions, and 274 to 21 poster sessions. The program of the conference also includes 4 plenary talks on "hot" topics in the areas of Signal and Image Processing as well as in Communications.

I would like to express my deep appreciation to all organizing committee members and in particular N. Kalouptsidis, I. Pitas and A. Stouraitis, for their efforts and invaluable help in organizing EUSIPCO-98. I would like to thank the International Scientific Committee members for offering their time in reviewing the submitted papers. Their effort made it possible for the papers to be reviewed by three reviewers independently, which guaranteed a rigorous reviewing process, matching the prestige of the EUSIPCO conferences. Last but not least I want to thank the plenary speakers, the special session organizers, the session chairmen, and all the authors for their efforts towards a successful scientific event.

On behalf of the organizing committee, I wish you a pleasant stay in Rhodes, and I hope that all of you will enjoy an experience rich in science, culture and natural beauty.

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Figure 4: Actual and reconstructed frame from the "Miss America" test sequence

control points), and for 30 frames/sec the compressed video stream requires 47.7 Kbits/sec and 41.6 Kbits/sec respectively. Figure 4 shows an actual and a reconstructed frame of the "Miss America" video sequence¹. This face was synthesised by 19 control points and the 10 most important principal components, quantized at 12 bits, for each eye and the mouth. These were computed from a training set of 30 images extracted from the first 30 frames of the sequence.

5 DISCUSSION AND CONCLUSIONS

In this paper, we propose a simple encoding technique that can be used for the compression of face video data for low bit-rate videoconferencing applications. By using knowledge that the video data contains face images against a fairly uniform and stationary background, the proposed scheme encodes the face and background area in each frame as a linear combination of three basis views. Important facial features such as the eyes and mouth that change a lot during conversation or with

¹Grey-scale versions of the frame are shown here, although our experiments were performed with colour images

changes of expression, may be encoded using principal components analysis. As a subset of the control points used in the linear combination of views are used in the PCA, features reconstructed by PCA may easily be merged into the face reconstructed from the basis views.

The linear combination method can achieve very high compression ratios since for every new frame it does not transmit any textural information; only shape information needs to be transmitted. Also, it is computationally simple since only implicit 3D information derived from the three basis 2D face views is used. Furthermore, it preserves the temporal and spatial resolution of the video data. However, sparse correspondence between the basis and novel face views is needed, so as in other knowledge-based coding approaches, a robust and fast scheme for detecting faces and control points, along with elimination of control points outliers, is required. The quality of the reconstructed face images can be further improved by eliminating self-occlusion effects by hidden surface removal [10].

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COMPUTATIONAL GRACEFUL DEGRADATION FOR VIDEO DECODING

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ABSTRACT

The implementation of software based video decoders is an advantageous solution over traditional dedicated hardware real-time systems. However, guaranteeing real-time performance, needed when processing video/audio bit-streams, by scheduling processing tasks of variable load and that might exceed the available resources, is an extremely difficult and in many cases an impossible challenge. In this paper we introduce the motivations and ideas of the Computational Graceful Degradation (CGD) approach for the implementation of video decoding. The goal is to provide results of possibly lower visual quality, but respecting the real-time constraints, when the required processing needs exceed the available processing resources. This approach is very attractive since it enables a more efficient usage of the hardware processing power without needing to implement resources for worst case complexity decoding. We show how such technique can be applied to the decoding of compressed video sequences. Simulation results for MPEG-4 and H.263 video compression standards showing some of the interesting achievements and potentialities of CGD approach are also reported. The presented approach can be virtually applied to any video compression standard and processor based platform, although the best performances are achieved when complexity prediction information provided as side information by the video standard is available. This option has been included in the new MPEG-4 standard.

1 INTRODUCTION

The complexity of video decoding is a fluctuating function of time [1]. By complexity we mean the processing time necessary to decode a compressed video bit-stream. Even considering a specific processor platform, a specific compression standard, with a relative level and profile, the complexity of video decoding is a variable quantity. Dedicated hardware platforms can guarantee worst case complexity decoding. In contrast, in the case of programmable platforms such a guarantee would imply the allocation of a processing power up to

two orders of magnitude higher than the one actually needed for an average decoding [1]. Conversely, a theoretical average value is not useful for an efficient scheduling of a decoding task. The average value for each considered sequence is not stationary, and its variation around the theoretical average one are so unpredictable that no useful scheduling policy can be realized. The first straightforward option is a sustained over-sizing of the processing resources. The second is to accept interruptions in the audio/video output streams when the needed decoding resources exceed the ones available in the system. Obviously both options are not desirable being respectively not economical, or providing a quality of the services which may easily result perceptually unacceptable. The main rationale of the Computational Graceful Degradation (CGD) approach is to provide results of poorer quality when the results of the desirable quality cannot be obtained in real time. When the complexity of the task exceeds the available processing power, real-time services, possibly of degraded quality, are nevertheless guaranteed respecting all real-time constraints. This approach enables the correct scheduling of real-time tasks even when the computational system load fluctuates above the system capabilities.

The concept of computational graceful system degradation using imprecise results has previously been introduced in the field of real-time computing with applications to control system and automation. In these contexts imprecise results are defined as intermediate results with the property that the more recent and intermediate result is the closer one that approximates the final result (i.e. the idea only works in monotonically improving computations) [2, 3, 4]. In these cases the problems to be solved are more concerned with fault tolerance, I/O overloads, stability and reactivity to unexpected inputs, and the corresponding techniques are not suitable for the purposes of video decoding. In our case, the goal is to guarantee real-time video decoding with possible degradations of the image quality, i.e. reductions of the peak signal to noise ratio (PSNR), without losing parts of the image content. Such al-

ternative is certainly much more desirable than other straightforward options such as cutting image portions or simply skipping frames. These latter options, as can be easily understood, can have catastrophic consequences on prediction based coding systems. In H.263 decoders, for instance, skipping the decoding of a single frame or a portion of it, implies the skipping of all future incoming frames (or portion of them) before the next incoming Intra frame. The time interval of such skipping operation might cover many seconds and the information content loss might be very relevant. Such abrupt interruptions, which are perceptually very annoying, might be caused not only by the simple fluctuation of the decoding complexity load, but also by the fluctuations of the load of other non-video processing tasks which reduce the available processing resources. Moreover, such events in general are out of the control of the video decoder system and cannot be easily forecasted. Considering these facts, it is evident the importance of techniques able to filter out complexity decoding peak loads or able to reduce the average decoding computation load without causing perceptually annoying consequences. Skipping B-VOP could be, in some cases, a viable option accepting the introduction of motion judder in the sequence reproduction. Unfortunately the presence of B-frames or B-VOP cannot be guaranteed in any bit-stream and just at the right time for which a reduction of the complexity is needed to respect the real time constraints.

In contrast with what could be commonly thought, also the classical multi-resolution coding features such as spatial or temporal scalabilities are not really useful for our goals. In general, they are used to optimize the transmission bandwidth usage enabling the compatibility of services at different bitrates and spatial resolutions, but they must be embedded in the original bit-stream at the encoder side. If they are not embedded, the changes of resolution at the decoder side can result more computationally expansive than the simple decoding at the given resolution.

From these arguments the usefulness of CGD and its important features and applications are clear. The last key point that has left CGD as a good idea, but of difficult introduction in video coding, was that it was not clear how to implement it efficiently. Now that a technique able to predict with a good degree of approximation the required decoding time of each decoding process is demonstrated and available for MPEG-4 systems [5], we have the key for the useful and efficient implementation of CGD techniques.

2 PRINCIPLES OF DECODING USING THE CGD APPROACH

The decoding operations of a video compression algorithm can be divided into two main categories: 1) operations that cannot be simplified since they may prevent

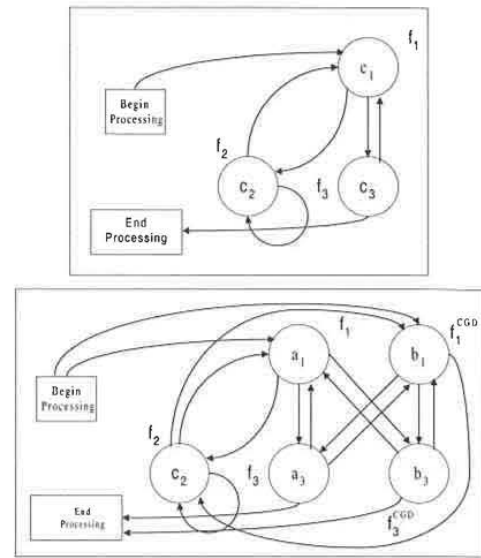


Figure 1: Upper diagram, example of a complexity model representing the data dependent execution of three algorithms. Lower diagram, example of the same complexity model of the upper diagram for which two algorithms (f_1 and f_3 are associated to new CGD algorithms (f_1^{CGD} and f_3^{CGD}).

the extraction and usage of relevant coding information, 2) operations that can be simplified, possibly leading to imprecise or degraded video results. To the first category typically belong all bit-stream parsing operations, entropy decoding (i.e. VLD and arithmetic coding), and all operations related to synchronization and to the syntax of the decoding process. For these operations no degradation mode definition is possible, otherwise it would imply skipping image portions or entire frames since either the data or the coding modes are lost. To the second category belong operations such as the IDCT, the prediction with and without motion compensation in its various forms (PB/B-frame prediction, overlapped block motion compensation (OBMC), half pixel interpolation, macroblock padding and so on). Simplifications of such operations applied to pixels or transform coefficients are always possible but at the expenses of imprecise results.

Two are the possible strategies for the implementation of CGD features. The first is to monitor the execution of the decoding process, to assume that the decoding time of each portion of the frame or VOP is proportional to the image area, and to execute CGD algorithms whenever the current monitored decoding time exceeds the current target decoding time suitable to respect the specified real-time constraints. Such simple strategy has several drawbacks. One is that there is no guaran-

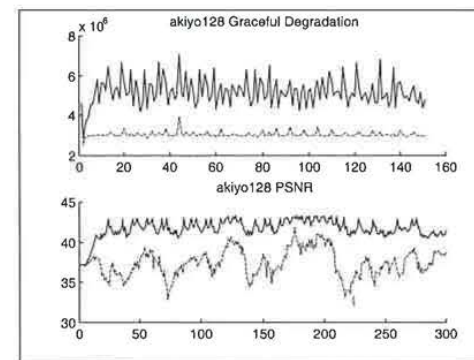


Figure 2: Example of CGD decoding of 300 frames of the sequence Akiyo at compressed at 128 kb/sec with H.263. The upper diagram reports the number of processor cycles for the original decoding (upper curve) and for the CGD decoding lower curve, versus the frame number. The lower diagram reports the two PSNR.

tee that the target decoding time is achieved. Another problem is due to execution of CGD algorithms that *a posteriori* could have not been necessary, thus introducing unnecessary image degradations. Moreover, such degradations are concentrated on critical image areas, and due to the drift given by the degraded reference for the prediction based algorithms, such degradations becomes visible and might seriously affect the resulting sequence PSNR. An example of such approach is reported in Fig. 2. The H.263 decoder has been modified by implementing computationally degraded IDCT and motion compensation algorithms. The interesting result achieved is that the decoding is obtained at a constant processing time for each frame. Unfortunately the PSNR degradations although limited to some dBs are nevertheless relevant from the perceptual point of view.

The second strategy is to exploit the complexity information carried by the frames or VOP headers, like it can be done for MPEG-4 systems [6], and use it in two stages. The first stage predicts the decoding time needed for the current frame or VOP, as described in [5]. The second, on the basis of the predicted decoding time and on the complexity information (i.e. statistics of the algorithms necessary to correctly decode the frame), executes only the CGD algorithms that are just necessary to not exceed the target decoding time.

More formally, let us consider a complexity model similar to the one illustrated in Fig. 1 composed by a set of I algorithms f_i , with $i = 1 \dots I$, and suppose to be able to design for all, or only for a subset S^{CGD} of the functions f_i composing the model, new functions f_i^{CGD} which have the following three properties: 1. the execu-

tion of a function f_i^{CGD} yields results that are an approximation of the ones produced by the original function f_i , 2. the execution of f_i^{CGD} does not prevent the execution of any subsequent decoding functions, 3. the weight w_i^{CGD} associated to f_i^{CGD} that represent the execution time of the f_i^{CGD} algorithm for the considered decoder implementation is lower than the corresponding w_i associated to f_i (i.e. $w_i^{CGD} < w_i$). A schematic representation of a complexity model which includes new degraded functions is reported in Fig. 1. The picture shows that new degraded algorithms can be executed at the place of the original algorithms. Obviously, the execution of any f_i^{CGD} may produce PSNR degradations in the reconstruction of some image parts, it does not prevent from correctly decoding the rest of the frame or VOP, but it reduces the necessary decoding time. Let us partition the functions constituting the complexity model into two disjoint sets: S^{Orig} and S^{CGD} respectively for the ones that do not admit a CGD version (f_2 for instance in Fig. 1) and for the ones for which it is possible to design a CGD version (f_1 and f_3). Let us consider for simplicity an image sequence composed by a sequence of single frames or VOPs and suppose that the execution time for the decoding of the frame or VOP is larger than the allocated decoding time:

$$T(t) > T_{Alloc}, \quad (1)$$

where $T(t)$ is the decoding time of the VOP at hand at the sampling time t . Since the decoding time can be approximated by its prediction [5] it can be expressed by:

$$T(t) \simeq T_{Pred}(t) = \sum_{i=1}^I c_i w_i, \quad (2)$$

where the c_i are the actual occurrences of algorithm f_i in the current frame or VOP [5], and the w_i are the corresponding complexity weights. The lower limit for the decoding time executing all CGD algorithms f_i^{CGD} at the place of f_i for all $i \in S^{CGD}$, is given by:

$$T_{CGD} = \sum_{i \in S^{CGD}} c_i w_i^{CGD} + \sum_{i \in S^{Orig}} c_i w_i. \quad (3)$$

If $T_{CGD} < T_{Alloc} < T_{Pred}$, is possible to guarantee the real-time constraints by executing the f_i^{CGD} algorithms and accepting approximate decoding results. It is also possible to find for each c_i with $i \in S^{CGD}$, a couple of coefficients a_i, b_i , for which $a_i + b_i = c_i$, and denoting as $T_{Process}$ any decoding time interval which respects the real time constraints, we can express the desired process decoding time as any decoding time value that satisfy the expression:

$$T_{Process} = \sum_{i \in S^{CGD}} (a_i w_i^{CGD} + b_i w_i) + \sum_{i \in S^{Orig}} c_i w_i \leq T_{Alloc}. \quad (4)$$

Obviously for any Allocated Decoding Time the goal is to respect the real-time constraints with the lowest

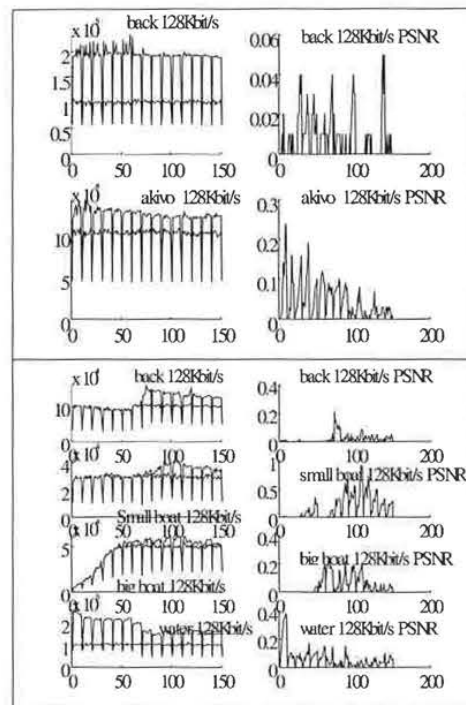


Figure 3: Left, decoding time results for the various VOP of sequences Akiyo and Coastguard, with and without imposing a bound. Right, the PSNR degradations versus the sequence VOP number.

degradation in the video/audio content. Associating a degradation measure to each w_i^{CGD} it is possible to minimize the degradation for any given T_{Alloc} . The challenge is to find the set $S_{a,b}$ of couple of coefficients a_i, b_i , with $i \in S_{CGD}$, that satisfy minimize the video degradations expressed as difference with the non degraded output:

$$S_{a,b} = \text{argmin}_{(a,b) \in S_{CGD}} : (\text{PSNR} - \text{PSNR}(a,b)). \quad (5)$$

The determination of the set $S_{a,b}$ can be done by means of many suitable optimization method or heuristics. The described techniques can be easily extended to the case of sequences containing multiple VOP at the same sampling time t .

3 SIMULATION RESULTS

Simulation results demonstrate the possibility of successful implementations of CGD for MPEG-4 video decoding. A bound on the decoding complexity of each VOP is defined setting a maximum constant T_{Alloc} . Figure 3 report the results of MPEG-4 video decoding imposing such bounds on the decoding time of each video object

plane (VOP) for the test images Coastguard and Akiyo coded at 128 kb/s. On the left, the graphs report the decoding time in msec for the unbounded and bounded decoding (lower curve) versus the image sequence number. On the right the graphs reports the resulting PSNR degradation. The decoder is the Momusys CD on a Sun Ultrasparc station modified implementing degraded motion compensation algorithms. Obviously the actual results depend on the decoder, on the platform on the CGD algorithms implemented, but the good results demonstrate that bounded complexity decodings are possible with minimal image degradations much lower than the one obtained without complexity information and decoding time prediction.

4 CONCLUSION

We have introduced the motivations and concepts of the CGD approach for the implementation of video decoders on processor based platforms. Simulation results for MPEG-4 video decoding demonstrate the successful implementation of the CGD approach. Obviously, the implementation of CGD features are not proposed to be used at their maximum degradation rate but as tool able to guarantee real-time performance in presence of peaks of decoding complexity or as a way to ease the scheduling problems given by temporary fluctuations of the available processing power. Moreover, the presented approach may enable the successful implementation of video decoding for levels and profiles that would be forbidden if the complexity of *worst case decoding* has to be guaranteed.

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COST-BASED REGION GROWING FOR FRACTAL IMAGE COMPRESSION

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ABSTRACT

For application in fractal coding we investigate image partitionings that are derived by a merge process starting with a uniform partition. At each merging step one would like to opt for the rate-distortion optimal choice. Unfortunately, this is computationally infeasible when efficient coders for the partition information are employed. Therefore, one has to use a model for estimating the coding costs. We discuss merging criteria that depend on variance or collage error and on the Euclidean length of the partition boundaries. Preliminary tests indicate that improved coding costs estimators may be of crucial importance for the success of our approach.

1 INTRODUCTION

In fractal image compression the image to be coded is partitioned into image blocks called *ranges*. Each range is approximated by another image part, called *domain*, which is scaled geometrically and modified using an affine transformation for the grey values. The fractal code consists of the partitioning information and, for each range, the domain block indices and the transformation parameters. Under certain constraints this code represents a contractive transformation whose unique fixed point is an approximation to the original image.

One of the bit allocation problems of fractal coding is to decide how many bits should be spent for the partitioning information. The most widely used strategies to partition the image are hierarchical methods like quadtree or horizontal/vertical partitioning. Here the coding costs for the partition are relatively low. On the other hand, more complex partitionings could lead to lower approximation errors. A region-growing based approach was introduced to fractal compression in [1]. This approach was extended in [2, 3] leading to a fast fractal coder with coding results comparable to Fisher's HV-coder [4].

Image partitioning problems can be stated as optimization problems where a specific cost function has to be minimized [5]. In this paper we present a formulation of the partitioning problem in fractal coding along these lines and analyze two cost functions that include

the segmentation coding costs. The study was motivated by the question whether adding a segmentation cost constraint to the cost function will improve coding results, and by the need to determine properties of *good* partitionings.

This paper is organized as follows: In Section 2 we give basic definitions and state the partitioning problem as an optimization problem. We also comment on the inherent complexity of this problem. In Section 3 we outline the partition coding scheme used in this study. In Sections 4 and 5 algorithms for region-based fractal coding are presented. We report on coding results in Section 6 and give examples of decoded images.

2 OPTIMIZATION PROBLEM

Let $I : S = \{0, \dots, 2^n - 1\} \times \{0, \dots, 2^n - 1\} \rightarrow \{0, \dots, 255\}$ be an image, and let $\hat{I}$ be the image of size $2^{n-1} \times 2^{n-1}$ that is obtained from I via pixel averaging, i.e., $\hat{I}(i, j) = \sum_{0 \leq k, m \leq 1} I(2i + k, 2j + m)$.

A partition $\mathcal{P}$ for I is a set of subsets of S such that $\bigcup_{P \in \mathcal{P}} P = S$, $P \cap Q = \emptyset$ for $P, Q \in \mathcal{P}$, $P \neq Q$, and each $P \in \mathcal{P}$ is connected in the 4-neighbor sense. I restricted to a region $P \in \mathcal{P}$ is called a range of I .

Given a partition $\mathcal{P}$, the fractal code for image I is determined as follows. For each range R of this partition a block D_R of $\hat{I}$ (or of $\hat{I}$ under a square isometry) and real parameters s_R, o_R are sought such that

$$\|R - s_R D_R - o_R \mathbf{1}\|^2 = \min_D \min_{|s| < 1, o \in \mathbb{R}} \|R - s^q D - o^q \mathbf{1}\|^2.$$

Here, $\|\cdot\|$ stands for the Euclidean norm, $\mathbf{1}$ is a vector with a 1 in each component, and s^q, o^q stand for the quantized *luminance* parameters. If R corresponds to region P we set $E(P) := \|R - s_R D_R - o_R \mathbf{1}\|^2$, and the overall approximation error, called *collage error*, is defined by

$$E(\mathcal{P}) := \sum_{P \in \mathcal{P}} E(P).$$

The global optimization problem is to find in the space of all partitions the optimal one in the sense that the rate of the corresponding fractal code is lower than a given budget limitation while simultaneously the overall

