Content Dependent Intra-Refresh Placement for Video Streaming

Ismail Ali, Martin Fleury, Sandro Moiron, and Mohammed Ghanbari
School of Computer Science and Electronic Engineering - University of Essex, Colchester, United Kingdom
fleury.martin55@gmail.com {iaali,smoiro,ghan}@essex.ac.uk

***Abstract*—Intra-refresh is an efficient error resiliency technique that protects against temporal error propagation resulting from transmission errors. Classic periodic intra-coded frames can add some protection and additionally facilitate random access, but within mobile networks with bandwidth constraints their disadvantages may outweigh their advantages. By analyzing the received video quality across a variety of video clips it becomes apparent that, for semi-active video sequences, cyclic intra-coded line placement results in superior video quality in the face of errors. For more active sequences, the quality gain is reduced but, for an equivalent constant bitrate, usually remains better than periodic intra-coded frames. This suggests a video streaming scheme which is content-dependent, turning on intra-refresh MB line when channel conditions and content type warrant it.**

I. Introduction

With the growth of video services for mobile networks [1] has come an increased need to protect compressed video bitstreams against the transmission errors, which are the defining feature of wireless networks. Unfortunately, as the basis of video compression [2] is mainly the exploitation of temporal redundancy, there are significant inter-picture data-dependencies amongst the packetized data sent to a mobile device. The increased coding efficiency of the H/264/AVC (Advanced Video Coding) standard [3] has made every bit count but this gain implies that the loss of even a single bit can result in degradation in quality, as the entropy decoder fails to synchronize. Though there are many forms of source-coded error resilience [4], this paper concentrates on the insertion of spatially-coded or intra-coded macroblocks (MBs) to halt temporal error propagation. In particular, the paper proposes that for semi-active video clips, ones without high motion coding complexity, it is unwise to employ intra-refresh through periodic intra-coded frames (I-frames), the drop in video quality at the receiver is then potentially large. Conversely, the paper proposes that insertion of a cyclic line of intra-refresh MBs [5] usually results in an improved error resiliency for sequences with moderate motion activity but also may preserve an advantage for more active or fully active sequences.

Quality-of-experience tests show [6] that semi-active sequences are more likely to be appreciated by viewers on mobile devices, as rapid motion is difficult to track on smaller screens, especially if their resolution is reduced and the viewing distance is also reduced. Consequently, service providers may select for mobile streaming content of the type favored by the proposed use of cyclic line insertion. If quality is important, as it might be at times for a video surveillance application, then variable bit-rate (VBR) streaming results in consistent quality. However, VBR streaming presents a problem to the constrained bandwidth of wireless networks, because of its varying bitrate, causing the maximum bandwidth required to be greater than the average bandwidth that would need to be reserved. Therefore, Constant Bit Rate (CBR) stream is more appropriate for Internet TV and IP protocol TV (IPTV) video streaming, the more so as it allows broadcasters to reserve storage and bandwidth resources in advance.

Gradual intra refresh can be implemented by randomly inserting intra coded MBs in order to introduce some resiliency. However, this arrangement does not guarantee full frame refresh in a fixed number of frames. For this purpose, cyclic intra refresh lines are a better alternative to provide Gradual Decoder Refresh (GDR). In GDR the stream is reset gradually to a clean state, from which future predictions can be made. If there are N lines per picture then the worst-case GDR should take place within 2*N-1 frames [5]. The refresh rate can be increased by cycling more than one line at a time. This will increase the data rate, as intra-coding is markedly less efficient than inter-coding. For example, in a comparison between the data rates for I-frames and P-frames an overhead of as much as ten times was found in [5] for coarsely quantized frames. Periodic intra-coded frames do permit more flexible random access, as might be used to support pseudo-video cassette recorder (VCR) functionality. However, for mobile viewing VCR functionality is not uppermost in the mind of the viewer. Besides, the end-to-end packet delay is also reduced by the dispersed insertion of intra-refresh MBs, as periodic intra-coded frames result in an influx of packets into transmission buffers, causing the waiting time to increase.

The insertion of a cyclic intra-refresh line on a per picture basis is a relatively simple scheme. However, more complex adaptive intra-refresh schemes also exist. For example in [7] such a scheme required the encoder to keep track of which parts of the image area were recently refreshed. The encoder would then refresh those MBs which had more of an impact on error propagation. Alternatively the authors of [8] proposed a scheme in which Flexible Macroblock Ordering (FMO) [9] is combined with adaptive MB grouping. Because such schemes are at an individual MB level, they significantly increase the computational complexity arising from the required video content analysis. Moreover, methods using 'explicit' FMO also increase the bitrate and the degree of inter-packet dependency due to the need to include additional packets with the updated

Fig. 1. Cyclic intra-refresh MB line technique for the *Paris* test sequence, showing successive MB lines in lighter shading, slice boundaries also shown.

MB maps for every picture. Other adaptive schemes such as [10] have relied on feedback from the receiver. Once the decoder detects an error, it informs the encoder, which transmits intra-coded MBs to halt any error propagation. However, this procedure is unsuitable for conversational video services such as videophone or mobile teleconferencing.

Still other schemes [5] [11] improve upon the deterministic application of the cyclic refresh line method by resolving a problem that exists at the boundary between a cleansed area and an area yet to be cleansed by intra-refresh. Suppose the direction of motion within the sequence is from a potentially corrupted region to a cleansed region. Then motion compensated prediction could predict a cleansed region from a suspect region. In that case, the cycle needs to revisit those predicted areas in order to undo the new corruption. It is possible to restrict the range of prediction [11] in these circumstances, but this might slightly reduce coding efficiency. Alternatively, the direction of motion can be estimated [5] by observation of motion vectors in the border regions between the clean and yet to be cleansed regions. Based on this a refresh pattern is found. However, this method does not lend itself easily to hardware implementation and depends on estimates. However, the main gain from this technique seems to be an improvement in data rate of about 1% rather than improved video quality. On the other hand, an adaptive strategy switching between cyclic intra-refresh line during poor channel conditions and periodic refresh when conditions improve may be a natural follow on from the results demonstrated in this paper. It should be noted that intra-coding requires significantly less computation time than inter-coding, because of the absence of motion estimation, which can take up to 70% of computation. Thus, intra-refresh line insertion will reduce the computation time across the whole sequence, which is an attractive proposition for a video conferencing application.

The following Section describes H.264/AVC's intra-refresh provision before Section III presents a comparison between periodic refresh and intra-refresh line insertion. Finally, Section IV draws some conclusions.

II. H.264 INTRA-REFRESH

Intra-coded frames are normally used to confine temporal error propagation [12]. Furthermore, the H.264 codec also supports intra-coded MBs (known as intra-refresh MBs) within inter-coded frames [13]. The insertion of intra-coded MBs into pictures normally encoded through motion-compensated prediction allows temporal error propagation to be arrested if matching MBs in a previous picture have been lost.

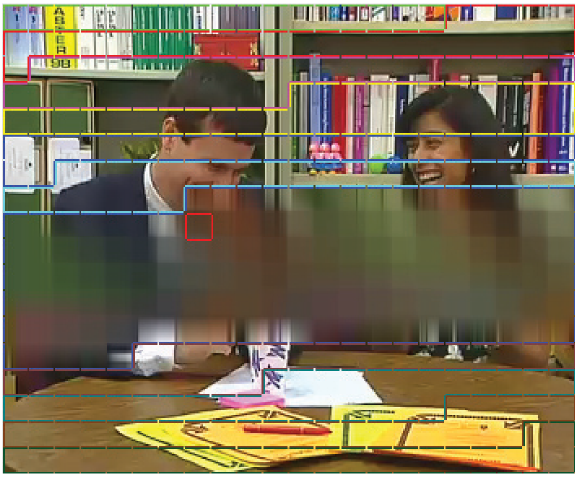

Fig. 2. A concealed slice in an I-frame.

Fig. 3. A concealed slice in a P-frame

The H.264/AVC bi-predictive B-frames add extra computational cost resulting from the identification of matching MBs in more than one frame. For applications intended for mobile devices with limited computational capabilities, predictively-coded P-frames are preferred. Therefore, in this work, the coding structure was either IPPP..., i.e. a potentially infinite sequence of P-frames after an initial intra-coded frame, or an IPP..I structure with a Group of Pictures (GoP) size of 18 when periodic I-frames were employed.

The scheme presented in this paper exploits the periodic insertion of intra-refresh MB lines in a cyclic pattern within successive temporally predicted video pictures. The objective of inserting intra-refresh MB lines is to mitigate error propagation at the cost of lower coding efficiency than purely predictive inter coding. Using a horizontal (or vertical) sliding intra-refresh line, Fig. 1, reduces the error drift arising from packet loss when periodic intra-coded frames are sent. Provided a cyclic pattern of lines are transmitted the sequence is completely refreshed after each cycle, as it is after the insertion of an I-frame at the start of each Group-of-Pictures.

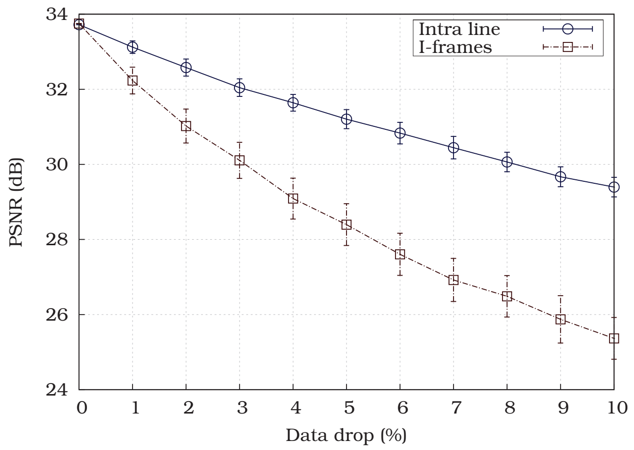

Fig. 4. PSNR versus video data loss rate for *Paris* CBR streaming.

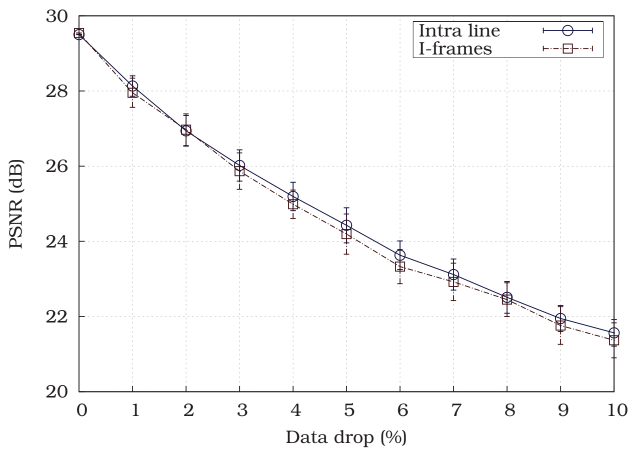

Fig. 5. PSNR versus video data loss rate for *Stefan* CBR streaming.

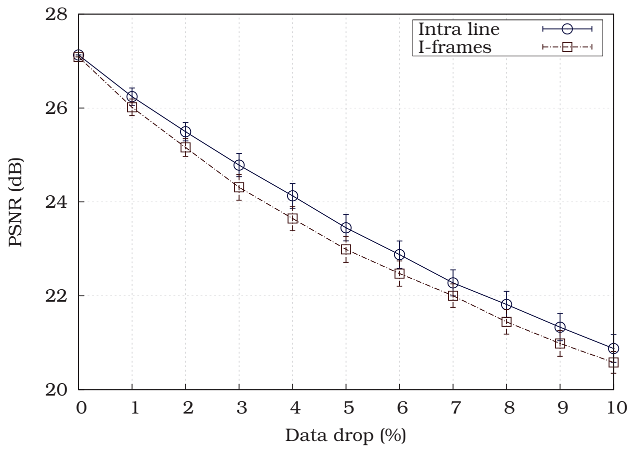

Fig. 6. PSNR versus video data loss rate for *Mobile* CBR streaming.

TABLE I
MEAN PSNR GAIN (DECIBELS) WHEN USING INTRA-REFRESH MBS OVER USING PERIODIC I-FRAMES IN CBR STREAMING

Video data loss rate (%)	0	2	0	6	8	10
Akiyo	0.1	2.1	3.5	4.5	5.1	5.8
Bridge-close	0.3	1.7	2.7	3.3	4.1	4.9
Hall	0.0	1.5	2.6	3.2	4.0	4.6
News	-0.2	2.0	2.5	3.2	3.5	4.2
Paris	0.0	1.6	2.6	3.2	3.7	4.0
Highway	-0.1	0.6	1.6	1.9	2.3	3.0
Tempete	0.0	0.6	0.9	1.1	1.1	1.1
Tennis	-0.1	0.3	0.2	0.4	0.3	0.7
Mobile	0.0	0.3	0.5	0.4	0.4	0.3
Stefan	0.0	0.0	0.2	0.3	0.1	0.2
Football	-0.1	-0.1	-0.1	0.1	-0.1	0.1
Flower	-0.2	0.0	0.2	0.1	0.0	-0.2
Bus	-0.1	-0.1	-0.3	-0.1	-0.2	-0.3
Soccer	0.0	-0.8	-0.3	-0.9	-0.6	-0.7

The benefits of the proposed scheme arise from the fact that when using periodic I-frames and in the event of loss of any of the slices of those frames, spatial interpolation is used to conceal the lost pixels (Fig. 2) which is not as good as the motion copy error concealment method used to conceal lost slices from P-frames (Fig. 3). Motion copy error concealment is able to select from unaffected areas in a previous frame, whereas spatial error concealment copies from nearby areas without taking into account intervening motion between the current and previous frame. It also may result in blurring as a result of the interpolation process. It should be carefully noted that an intra-coded MB line within a temporally predicted frame represents a significant percentage of the bits devoted to compressing the whole frame. Nonetheless, a packet containing data from a line of intra-coded MBs represents a small portion of the image area. Therefore, only a small potential quality penalty arises from the loss of a packet containing intra-refresh MBs due to the small image area affected.

III. EVALUATION

This Section shows the relative advantage of intra refresh line over periodic insertion of I-frames in the context of broadcast CBR streaming, constant quality VBR streaming and also a lossy wireless environment.

A. CBR streaming

In evaluation tests, two versions of a CBR stream with Common Intermediate Format (CIF) format (352 $\times$ 288 pixels/frame) at 30 frame/s were coded using the JM 15.1[1] reference software for H.264/AVC. The first was coded with intra-refresh MB line and the other without, with the respective GoP structures described in Section II. Context Adaptive Binary Arithmetic Coding (CABAC) entropy coding from the Main profile of H.264/AVC was selected. To avoid network segmentation, packet sizes were limited at the encoder to 1 kB and packed using H.264/AVC's RTP packetization mode.

[1] Available at: http://iphome.hhi.de/suehring/tml/download/

Constrained intra prediction was set so that no inter-coded samples are used for intra-prediction. A single reference frames was used, as this limits the error introduced when using multiple reference frames in conjunction with intra-refresh MBs [14]. This setting of course has an impact on potential contamination from unclean areas to an already cleansed area of a picture sequence. By setting the periodic refresh rate to eighteen the quality for the two streams could be made close for the same target bitrate (as there are 18 MB lines in one CIF picture). That CBR data rate was 500 kbps.

Figure 4 shows the objective video quality for the semi-active video sequence *Paris*. The two studio presenters in this reference clip are seated and though they make some motions (see Fig. 1), the main coding complexity is spatial arising from the bookcase in the background. From Fig. 4, it can be seen that there is negligible difference in quality at zero error percentage, indicating that a periodic I-frame refresh at a rate of 18 is close in terms of compression to the use of a single cyclic line of IR of MBs. However, as the Uniformly-distributed data drop rate increases, there is a marked decrease in the mean PSNR for the periodically refreshed version.

Figures 5 and 6 show the effect on more active sequences, when it is immediately apparent that the gain is less. This is because motion (either object or camera motion) can disrupt the cleansing effect of the cyclic MB line. However, as remarked in Section I, it is the direction of motion in the border area between cleansed and about to be cleansed regions that is important. If predictions are made from a yet to be cleansed area of a previous picture to an already cleansed area, then cleansing must recover the newly corrupted area.

Table I summarizes CBR results in which for comparison purposes all sequences were limited up to 300 frames. The Table shows the PSNR gain [dB] from employing cycle intra-refresh line over the insertion of periodic I-frames. Gains for very static sequences such as *Akiyo* can be high while negative 'gains' do occur for sequences with adverse patterns of motion but the loss is usually less than 1 dB. Active sequences can be detected by inspection of non-zero motion vectors.

B. VBR streaming

When testing VBR-encoded sequences, it is less easy to make a close comparison between sequences. Table II summarizes the test settings, showing the quantization parameter (QP) for both types of frames as well as data rates and video quality (PSNR). Bitrates in the Table are average values. Figs. 7 and 8 illustrate the equivalent results to Figs. 4 and 5. By careful construction of the comparison, it is apparent that the behaviour for CBR and VBR is similar.

C. Wireless Streaming

Using the well-known ns2 simulator, *Paris* was streamed with the same VBR-encoded configurations from Table II. To examine the behaviour in a wireless network, four IEEE 802.11b nodes were arranged in a linear topology, Fig. 9, each separated by 25 m. The middle two nodes act as repeaters. A shadowing channel model [15] was applied in an indoor setting, with standard parameters $\sigma = 6$, and characteristic distance 1 m. The path loss exponent was varied in Fig. 10. Again the cyclic intra-refresh line configuration is preferable, but the video quality response is dependent on the strength of the transmitted signal.

TABLE II
SIMULATION SETTINGS FOR VBR STREAMING

	Using intra-refresh line		Using periodic I-frames	
	Paris	Stefan	Paris	Stefan
QP (I and P)	31	37	31	37
Bitrate (kbps)	526	509	515	497
PSNR (dB)	34.20	29.18	34.26	29.22

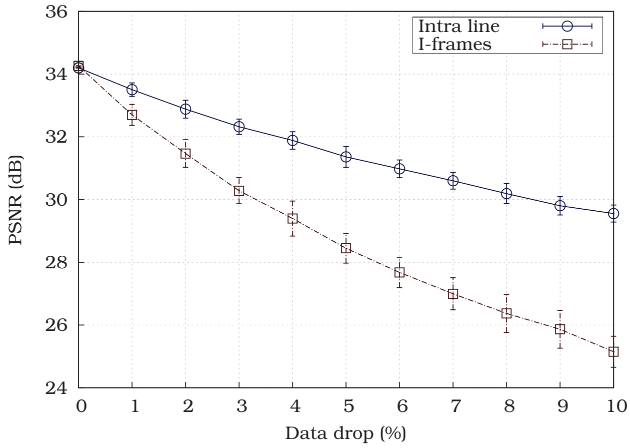

Fig. 7. PSNR versus video data loss rate for *Paris* VBR streaming.

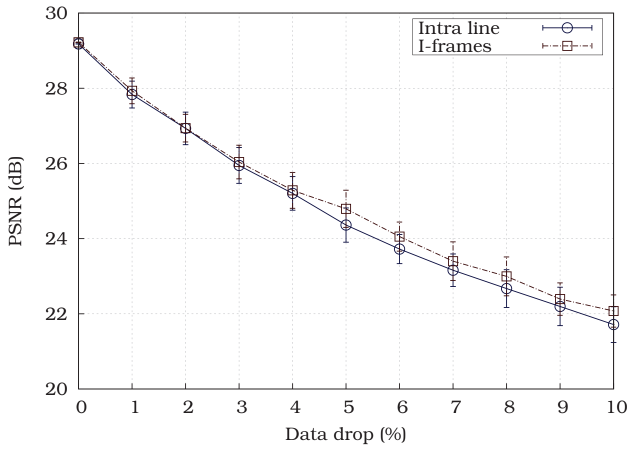

Fig. 8. PSNR versus video data loss rate for *Stefan* VBR streaming.

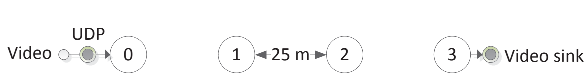

Fig. 9. Network topology for VBR streaming.

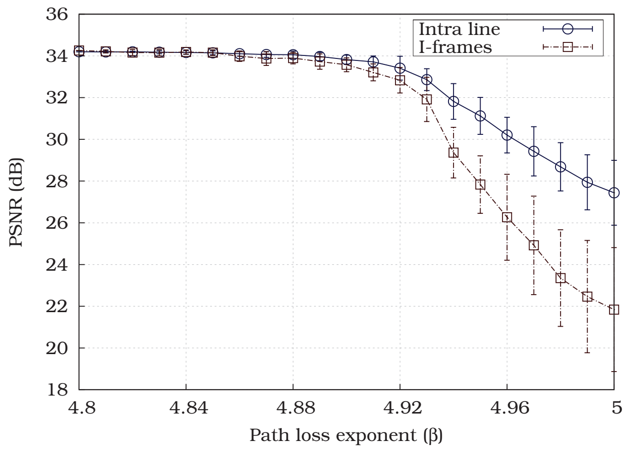

Fig. 10. Mean PSNR comparison of *Paris* VBR streaming with either cyclic intra-refresh line or periodic I-frame (with standard errors shown).

IV. Conclusion

By means of a comprehensive set of tests, this paper has demonstrated the advantage of the cyclic intra-refresh approach over periodic refresh, except when a video sequence displays adverse motion characteristics. For semi-active sequences, the gain in video quality can be very significant. It is not difficult to identify active video sequences through inspection of the MB motion vectors. In fact, it is also possible to identify adverse motion directions which are against the direction of intra-refresh cleansing. This allows real-time identification of content that is suitable for either of the two forms of intra refresh and may well permit an adaptive scheme, which also employs channel condition estimation. These observations will guide the direction of future investigations.

References

[1] D.R. Bull, C.N. Canagarajah, and A.R. Nix, *Insights into mobile multimedia communications*, Academic Press, Inc., Orlando, FL, USA, 1999.

[2] M. Ghanbari, *Video Coding: An Introduction to Standard Codecs*, Inst. of Elec. Engineers, Stevenage, UK, UK, 1999.

[3] T. Stockhammer, M.M. Hannuksela, and T. Wiegand, "H.264/AVC in wireless environments," *IEEE Trans. on Circ. Syst. Video Technol.*, vol. 13, no. 7, pp. 657 – 673, 2003.

[4] T. Stockhammer and W. Zia, "Error-resilient coding and decoding strategies for video communication," in *Multimedia over IP and wireless networks*, M. van der Schaar and P.A. Chou, Eds., pp. 13 – 58. Academic Press, Inc., Amsterdam, Netherlands, 2007.

[5] R.M. Schreier and A. Rothermel, "Motion adaptive intra refresh for low-delay video coding," in *Int. Conf. on Consumer Electronics, ICCE '06.*, 2006, pp. 453 – 454.

[6] F. Agboma and A. Liotta, "Addressing user expectations in mobile content delivery," *Mobile Information Systems*, vol. 3, no. 3, pp. 153–164, 2007.

[7] J. Jiang, B. Guo, and W. Mo, "Efficient intra refresh using motion affected region tracking for surveillance video over error prone networks," in *Eighth Int. Conf. on Intelligent Sys. Design and Applications*. IEEE, 2008, pp. 242–246.

[8] K. Tan and A. Pearmain, "An FMO based error resilience method in H.264/AVC and its UEP application in DVB-H link layer," in *IEEE Int. Conf. on Multimedia and Expo, ICME*, 2010, pp. 214 –219.

[9] P. Lambert, W. De Neve, Y. Dhondt, and R. Van de Walle, "Flexible macroblock ordering in H.264/AVC," *J. Visual Commun. and Image Representation*, vol. 17, no. 2, pp. 358 – 375, 2006.

[10] J.T. Wang and P.C. Chang, "Error-propagation prevention technique for real-time video transmission over ATM networks," *IEEE Trans. Circ. Syst. Video Technol.*, vol. 9, no. 3, pp. 513–523, 1999.

[11] E. Krause et al., "Method and apparatus for refreshing motion compensated sequential video images," 1991, US Patent 5,057,916.

[12] J. Ostermann, J. Bormans, P. List, D. Marpe, M. Narroschke, F. Pereira, T. Stockhammer, and T. Wedi, "Video coding with H.264/AVC: Tools, performance, and complexity," *IEEE Circ. Syst. Mag.*, vol. 4, no. 1, pp. 7 – 28, 2004.

[13] S. Wenger, "H.264/AVC over IP," *IEEE Trans. Circ. Syst. Video Technol.*, vol. 13, no. 7, pp. 645 – 656, 2003.

[14] S. Moiron, I. Ali, M. Ghanbari, and M. Fleury, "Limitations of multiple reference frames with cyclic intra-refresh line for H.264/AVC," *Electronics Letters*, vol. 47, no. 2, pp. 103 –104, 2011.

[15] T.S. Rappaport, *Wireless communications: Principles and practice*, Prentice Hall, New Jersey, 1996.