# Interactions of chromatic components on the perceptual quantization of the achromatic component

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## ABSTRACT

In the human color vision, it is well admitted that signals issued from the three types of receptors (L, M, S) are combined in two opponent color components and one achromatic component. In this paper, we are concerned by the cardinal directions A, Cr1 and Cr2 defined by Krauskopf[1]. We study in particular the interactions between luminance and chromatic components. These interactions should be taken into account in visual coding since they modify the visibility thresholds. We present here results that show the influence of the two chromatic components on the optimal perceptual quantizer of the achromatic component in particular subbands. On the subband called III-1 of luminance (radial selectivity 5.7 cy/d° to 14.1 cy/d°, angular selectivity -15 d° to 15 d°), we show influence of Cr1 and Cr2 sinusoidal maskers. Others results are also presented on the subband called II-1 (radial selectivity 1,5 cy/d° to 5,7 cy/d°, angular selectivity -22.5 d° to 22.5 d°) with Cr1 and Cr2 maskers.

Keywords:  color space, perceptual quantizer, visibility of quantization noise, subband coding.

## 1.  INTRODUCTION

Perceptual compression is performed by leaving out the information that would not be seen by the human visual system. This requires a good model of human perception in order to predict which information can be omitted. Several studies have shown the efficiency of coding schemes[2,3] where both analysis and quantization stages are based on the human visual properties. Extending such approaches to color images means to perform an opponent color coding with an appropriate color space since it is well known that the outputs of the three types of cone photoreceptors (L, M, S) are combined into an achromatic component and two chromatic component. Here we are concerned with Krauskopf's directions A, Cr1, Cr2. For each components, it can be identified both analysis and quantization stages like we have done in previous works[4,5] . Unfortunately, perceptual components are not independent and some interactions subsist between luminance and chrominance. In particularly, De Valois and al. have noted pedestal and masking effect on detection of sinusoidal gratings in cross channels situations[6]. It is all the more important to consider these interactions in visual coding schemes since they modify the visibility thresholds.

Section 2 presents various results (most of them induced by studies in our lab) about the human perception especially concerning the visibility of quantization noise and the chosen color space.  Section 3 describes the experimental conditions and procedure in order to characterize the interactions between pathways. Section 4 gives the results obtained for interactions of Cr1 and Cr2 among two sub-bands of luminance.

## 2.  HUMAN PERCEPTION MODEL

### 2.1. HUMAN LUMINANCE PERCEPTION : VISIBILITY OF QUANTIZATION NOISE

We present here our human vision model for perception of luminance since it is the one we are going to improve. This model contains two main functions, visual filtering and quantization, justified by the fact that our main goal is the design of a visual coding scheme.

### 2.1.1 VISUAL FILTERING MODELISATION

Like  in most approaches, we use a sub-band decomposition defined by analytic filters for luminance supposed to describe the different channels of the human vision system and so the visual filtering. Previous study have been conducted in our lab in order to characterize this decomposition, the experiments were based on the measurement of the masking effect between

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two complex narrow band limited signals. The obtained results led us to propose the spatial frequency patch shown in figure 1. For still images, we need to use four radial frequency channels, one low-pass called I with radial selectivity 0 cy/d° to 1.5 cy/d° and three bandpass called II, III, IV with radial selectivity respectively 1.5 cy/d° to 5.7 cy/d°, 5.7 cy/d° to 14.1 cy/d°, 14.1 cy/d° to 28.2 cy/d°. The three bandpass are decomposed into angular sectors associated with orientation selectivity. The angular selectivity is 45° for subband II and 30° for subbands III and IV.
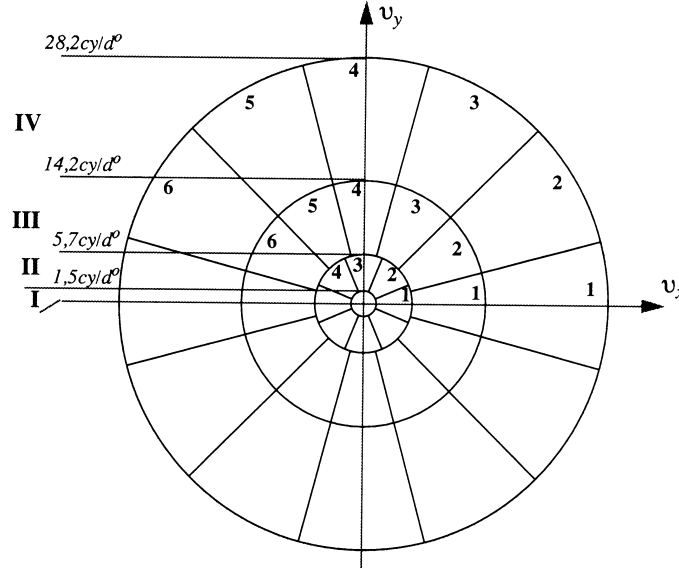


figure 1 : spatial frequency patch for visual filtering.

## 2.1.2 QUANTIZATION

Since we work in the context of image coding, we are particularly interested by the problems involved by quantization . It is more convenient here to study the visibility produced by quantization of the content of a particularly subband rather than the visibility of any increments or any white gaussian noises. Previously, we have shown[5] that perception of quantization noise on $L_{ij}$ at location (m,n) is directly dependent on the ratio between $L_{ij}$ and the average luminance at this location. This latter is computed from the subbands having a lower radial frequency. This ratio is therefore a local contrast $C_{ij}$ given by :

$$Cij(m,n) = \frac{Lij(m,n)}{\sum_{k=0}^{i-1}\sum_{l=0}^{Cardl} Lkl(m,n)}$$

Psychovisual tests performed on the different visual channels have shown that local contrasts must be always uniformly quantized in order to achieve a just noticeable quantization law, the quantization step being dependent of the visual subband considered. Inter-channels luminance masking effect is partially taken in account by this model, the model fails for masking effect along directional adjacency. So we have completed this model with further experiments and it has been successfully implemented in a visual coding scheme[4].

## 2.2. HUMAN COLOR PERCEPTION

To take into account perceptual properties some specific color spaces as L*a*b*, L*u*v* have been introduced. We are concerned here with psychophysically based color spaces. Perceptual color spaces are based on the fact that the peripheral parts of the human color vision include two different stages. In the first stage, the light information is transformed into neuro-electrical signals by the three types of cone receptors (L, M, S). The interactive nature of the second stage is generally admitted. It has been shown that the neuro-electrical signals are combined in an opponent manner. However there is no agreement on the receptor weightings needed to describe this opponent interaction. Several such color vision model have

been proposed in the literature, among this variety we validated in our lab from masking experiments the color space determined by Krauskopf[1]. In this space the achromatic Ach and chromatic Cr1 and Cr2 directions are defined as :

$$Ach = L + M$$

$$Cr1 = L - M$$

$$Cr2 = S - ( L + M ).$$

In previous study[7], experiments have been conducted to determine the frequency sensitivity of the components Cr1 and Cr2. Results show that for both Cr1 and Cr2, the overall shape has a low pass characteristic with a cut-off frequency around 4 cy/d° for the Cr1 component and 2 cy/d° for the Cr2 component.

Like in the luminance case, we have studied whether the human visual system analyses the chromatic components by a set of channels selectivity sensitive to a restricted range of spatial frequencies and orientations. So, for the orientation aspect, we have made several simultaneous masking experiments. For Cr2, we haven't found any selectivity in the frequency range lower than the cut-off frequency as it is observed for the luminance component in the same range. For Cr1, we have found a selectivity of about 45° in the range 3-4 cy/d° like the luminance component in the same frequency range, for frequency lower than 2 cy/d° we haven't observed any selectivity.

## 2.3. INTER-PATHWAY MASKING

Results of cross-masking between components[6] have shown that the linear transform from LMS responses to opponent-color space cannot efficiently decorrelate the cones responses. So, it subsists interaction that should modify perception on each components depending on the others. Therefore, we have to consider the inter-pathway masking effect between the luminance and chromatic components. Since it was shown that luminance masks have little effect on color contrast detection, while chromatic masks greatly affect the detectability of luminance contrast, we should particularly study the changes of the perception of the luminance component under the presence of Cr1 and Cr2 masks.

Most of the known studies in the literature used sinusoidal signals for both stimuli and masks. Here we are concerned with the visibility of quantization noise on complex signals, so we need to do specific experiments in order to appreciate the interactions.

# 3. EXPERIMENTS

## 3.1. SPECIFICATIONS

The design of psychovisual quantizers involves specifying thresholds and levels which minimize both entropy and some measure of distortion. For this approach we need to define several points :

*The choice of stimuli* : incremental (or decremental) patches and sinusoidal gratings have been generally used as stimuli. In order to be more realistic, texture images have served as tests signals. The choice of such images is justified by their stationary property and their spread frequency content.

*The choice of degradation* : as we explained it before, it is convenient for a coding scheme to consider the visibility of degradation produced by the quantization of the stimuli. Since we have shown that it was possible to apply an uniform quantization law on the band limited contrast of a specific subband without noticing degradations, we are going to quantize stimuli with an uniform quantizer and measure the threshold quantization step.

We need to use chromatic masks. As we want to characterize interactions, we need to control perfectly these masking signals, so we use sinusoids for Cr1 and Cr2 components. Finally, we construct stimuli filtering texture images in one subband of luminance, quantizing this filtering version then adding sinusoidal chromatic signals.

## 3.2. EXPERIMENTAL CONDITIONS

The tests were performed by a real time videosystem (TRYDIN) on a Mitsubishi monitor screen with P22 phosphor.

We fixed the mean luminance of the screen at $14.8$ cd/m$^2$. The gamma correction was derived from the luminance versus level for each channel of the screen (red, blue and green). The background luminance of the « vision room » was maintained at 8cd/m$^2$ and the observation distance was of the order of six times the height of the screen.

The stimuli were temporally weighted and spatially localized. The temporal weighting is used to avoid the flash phenomenon. The spatial localization limit the vision to the fovea field.

Six observers have participated to the experiments. They were between 24 to 30 years old. The tests have been conducted on each observer individually.

## 3.3. PROCEDURE

The two alternative forced choice procedure with one presentation was first used. For this procedure, in each trial we present the reference signal, a copy of this one and the quantized signal. The quantized signal was randomly present in one of the two positions A or B and the observer was required to identify the interval where it has occurred. We tracked the optimal step with a PEST procedure.
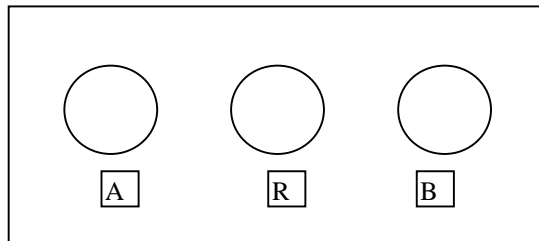


Figure 2 : stimuli configuration in the alternative forced choice procedure, R for the reference, the quantized signal can appear in one of the two positions A or B.

This kind of test is commonly used since it gives the best precision for the thresholds but in fact, is quite long and difficult for observers. So, we have decided to use the method of limits. Only two signals appeared, the reference one and the quantized one. The observer was required to detect where the quantized signal is. First, we started with a step where the observer clearly saw the difference then we progressively decreased the step until the observer could not seen the difference. Then we started with a step where the observer could not clearly seen the difference then we progressively increased the step until the observer saw the difference. Normally, this method do not give the right threshold but a threshold higher than the two alternative forced choice, in our case this is not annoying since we are interested by the relative elevation of the thresholds. We have verified this doing tests with the two procedures, results are shown on figure 4.
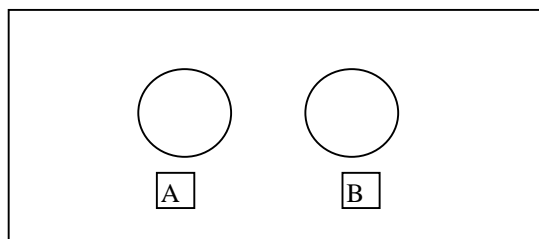


Figure 3 : stimuli configuration in the method of limit, the quantized signal can appear in one of the two positions A or B, in the other position there is the reference.
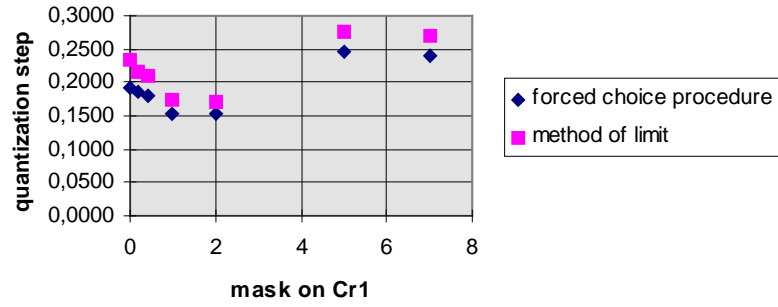
figure 4 : comparison of the method of limit and the alternative forced choice procedure for the measure of the optimal quantization step of subband III1 with a sinusoidal mask on Cr1 ; The measures with the method of limit are always higher than those done with the force choice procedure, but the relative elevation is the same for both methods.

## 4. RESULTS

### 4.1. SUBBAND III,1

The first experiments have been conducted with three observers on the subband called III-1 (radial selectivity 5.7 cy/d° to 14.1 cy/d°, angular selectivity -15 d° to 15 d°).

### 4.1.1. LUMINANCE MASKING WITH CR1

First we verified the symmetry of the influence at 0 cy/d° with positive and negative levels of Cr1, results appears in figure 5.a on the left. This property is interesting since it confirms the adequate choice for the color space. Then, we have compared the influence of Cr1 for three different frequencies (0 cy/d°, 2 cy/d°, 3 cy/d°), results are shown in figure 6. The choice of the mask's frequencies have been limited by the cut-off frequency of the Cr1 component. Since we found angular selectivity on Cr1, we have also measured the evolution of the optimal quantization step for two orientations of the mask (0 and 90°), results are shown in figure 5.b.

In all the cases, we observe both facilitation and masking effect depending on the mask level. Note that the amount of interactions is lower than in De Valois and al. Results[6]. This difference should be explained by the difference of the stimuli and by the different nature of the measure. De Valois and al measured detection thresholds of sinusoidal gratings when we have measured optimal quantization step in order to not see quantization noise.
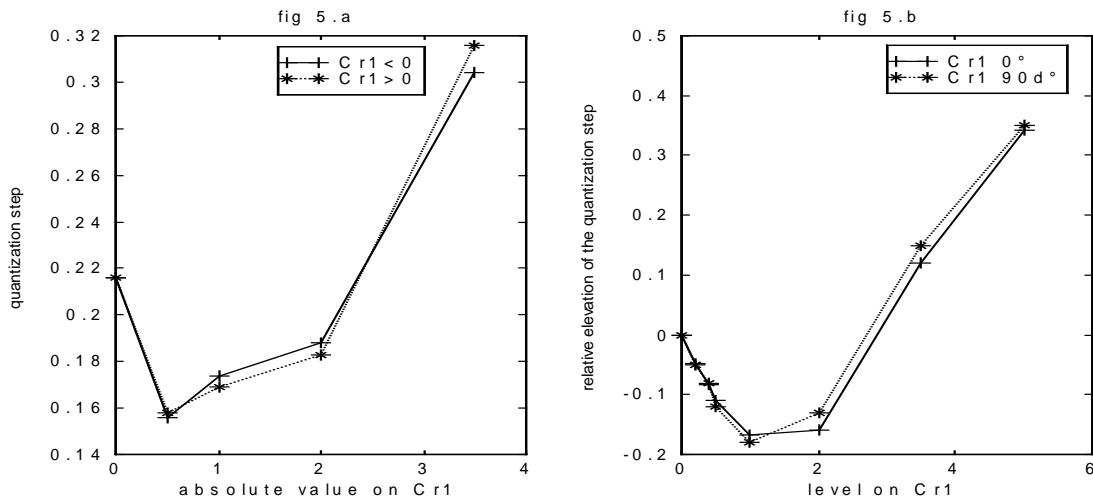


figure 5 : fig. 5.a. symmetry of the influence of Cr1 among the quantization step. Fig. 5.b. relative elevation of the quantization step of subband III,1 with Cr1 mask at 3 cy/d° and two orientations 0° and 90°.
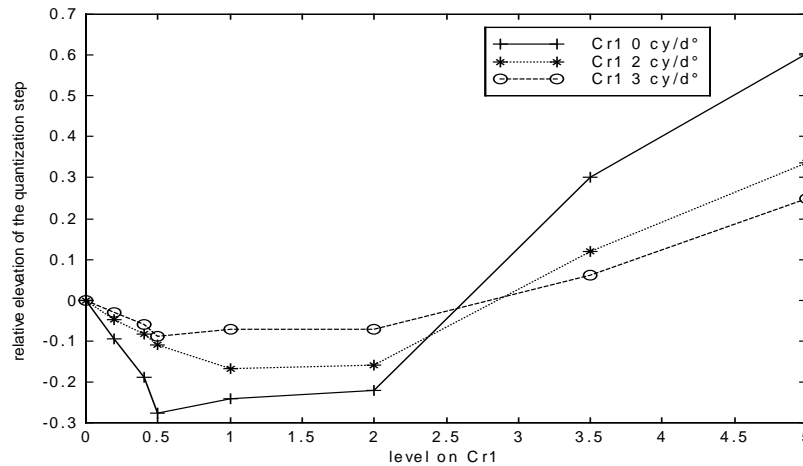
figure 6 : relative elevation of the quantization step in the subband III,1 with three different frequencies for the mask on Cr1.

The results show that the local mean value of Cr1 pondered by its frequency response rules the interaction among the subband III-1 of luminance. This conclusion is consistent with the results of luminance-luminance interactions : if the frequency of the mask is lower than the frequency domain of the masked subband, the mask acts as a local mean that can be take into account with a band limited contrast and its associated quantization law.

### 4.1.2. LUMINANCE MASKING WITH CR2

Then, we have measured the influence of the Cr2 upon the subband III-1 of luminance with two observers at 0 cy/d°. We don't use other frequencies since the Cr2 cut frequency is low  (2 cy/d°) and there is no angular selectivity. The results in figure 7 show little interactions (less than 5 %). We conclude that Cr2 doesn't affect the perception of this subband so we haven't tested the composite interaction of Cr1 and Cr2.
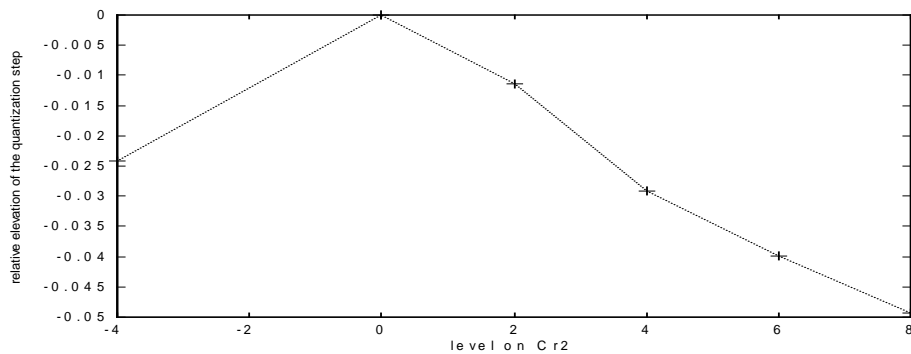


figure 7 : relative elevation of the quantization step of subband III,1 for a mask on Cr2 at 0 cy/d°.

### 4.2. SUBBAND II,1

Other experiments have been conducted with two observers on the subband called II,1 (radial selectivity 1,5 cy/d° to 5,7 cy/d°, angular selectivity -22.5 d° to 22.5 d°).

### 4.2.1.LUMINANCE MASKING WITH CR1

For three frequencies (0 cy/d°, 1,5 cy/d°, 3 cy/d°) and two orientations (0 and 90 d°) of the mask on Cr1, we have measured the relative elevation of the quantization step in subband II,1.The results shown in figure 8, confirm our approach of a band limited contrast extended for color found with the subband III-1. Lower frequency of Cr1 than the range of the studied subband doesn't influence the quantization step as Cr1 frequency is included in the range of the subband. In the same range of frequency of the subband,, mask angle is a sensible factor to explain the variation of the quantization step. Considering a visual filtering decomposition for the cr1 component such as for the luminance component should be useful to explain the various interactions and to extend the band limited contrast model.
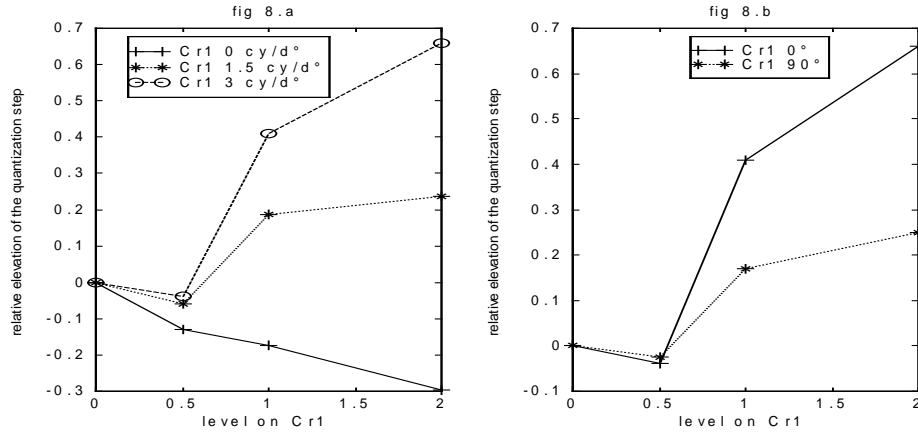


figure 8 : on fig 8.a. relative elevation of the quantization step of subband II,1 for three different frequencies of the mask on cr1. On fig. 8.b. relative elevation of the quantization step of subband II,1 for a Cr1 mask at 3 cy/d° and two orientations.

### 4.2.2. LUMINANCE MASKING WITH CR2

We have measured the influence of the Cr2 upon the subband II-1 of luminance with two observers at 0 cy/d°. The results (on figure 9) showed more interactions than with the subband III-1. So, we have tested the composite interaction of Cr1 and Cr2 : the results show an additive contribution.
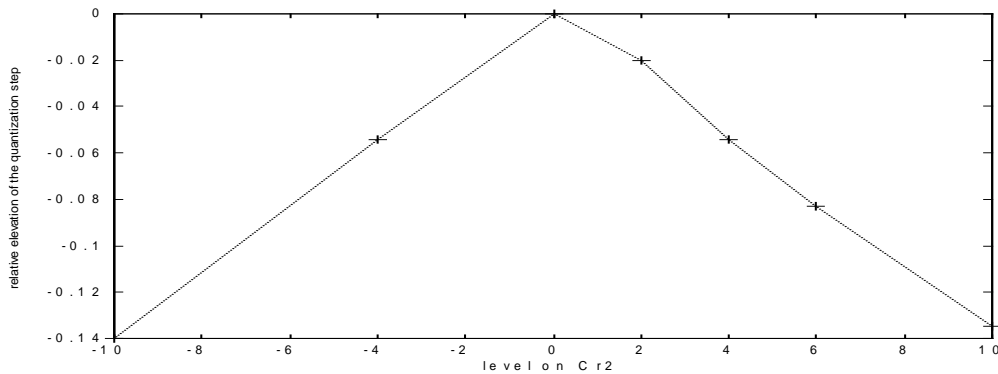


figure 9 : relative elevation of the quantization step of subband II,1 mask on cr2 at 0 cy/d°.

## 5. CONCLUSION AND PERSPECTIVES

Several experiments have been conducted in order to characterize the interactions of chromatic components upon perceptual quantization of the achromatic components. Results show that interactions exist but in a different way than in the one of sinusoidal gratings. Some properties of these results seem to be consistent with the extension of the band limited contrast definition with color.

From these results completed with the study of the other subband (I and IV), we will get a model of the perception of luminance modified by color. This model will be soon implemented in a visual subband image coding. We have already made subjective quality evaluation on still images degraded only in subband III-1 of luminance. The evaluations were first made on the images restricted to their luminance component (monochrome images), then on the same color images (completed with their chromatic components). The differences of quality between these two situations seem to be consistent with the interactions measures.  Results would be used to parametrize others human vision models.

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