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Depth Capture and Transparency of Regions Bounded by Illusory and Chromatic Contours

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Spillmann and Redies noted that when a transparent textured pattern is held above the Ehrenstein figure, the subjective surfaces appear to lie not in the plane of the figures but in the plane of the overlying texture. In Experiment 1, we tested this phenomenon with chromatic squares and found that the perceived depth of regions bounded by the chromatic contours was captured by overlying texture planes when the square was equiluminous with the background. We then tested this phenomenon with a variety of illusory contour stimuli and found that it only occurs with figures involving fine line terminators, and not, for example, with the solid Kanizsa triangle. These results suggest that chromatic contours and the illusory contours induced by line terminators provide only weak binocular disparity signals and that these signals are easily overwhelmed by the disparity signals from the overlying luminance texture.

Depth capture Binocular disparity Chromatic contours Illusory contours Transparency Texture

INTRODUCTION

When Spillmann and Redies (1981) held a piece of transparent texture above an Ehrenstein figure, they found that the illusory surfaces induced by the figure appeared to lie not in the plane of the figure but in the plane of overlying texture.

We first extended their observation of depth capture to figures defined by chromatic contours. That is, when a textured pattern consisting of random black dots was held over a colored square which was approximately equiluminous with the background, the colored square appeared to be pulled upward onto the plane of the texture. Ramachandran (1987) has reported a similar case of motion capture in which a static colored square was seen to move together with a superimposed texture that was moving back and forth.

Second, we tested the depth capture of illusory contours induced by two different kinds of inducing figures. Although Spillmann and Redies (1981) observed depth capture only with the Ehrenstein figures, illusory contours can be divided into two different types, depending on whether the inducing figures involve solid areas or fine lines (Fig. 1). In Fig. 1(a) and 1(c), the inducing figures produce illusory contours in directions parallel to the dark inner edges of the figures. On the other hand, Fig. 1(b) and 1(d) consists of thin lines and the illusory contours are perpendicular to the ends of the inducing thin lines. In our second experiment, we examined whether the depth of both types illusory contours are captured by texture.

EXPERIMENT 1: DEPTH CAPTURE OF CHROMATIC CONTOURS BY TEXTURE

Method

Observers. Two males participated as observers. They both had corrected-to-normal visual acuity and normal color vision.

Materials. The stimuli were presented on a color video display (23° × 17.25°, Apple M0401, 640 × 480 pixel resolution) at a 67 Hz frame rate controlled by a Macintosh IIcx and viewed at a distance of 57.3 cm from the observers' eyes. The test stimulus was composed of a textured square and a colored square. The textured square consisted of (50% density) fine black dots (2.15′ in radius) randomly scattered against the white background ($x = 0.33$, $y = 0.35$ in the CIE chromaticity coordinates; 50 cd/m^2) within a 5° square area. The 3° colored square was yellowish green ($x = 0.38$, $y = 0.50$). In the four disparity conditions shown in Fig. 2, the textured square was placed at one of three depth planes (4.3, 8.6 or 12.9′ of disparity in different sessions) either in front or behind the display screen and a colored square was either placed in the same depth plane as the texture (50% of the trials as catch trials) or in the plane of the display screen (50% of the trials as capture trials). In the capture trials, the texture and the colored square

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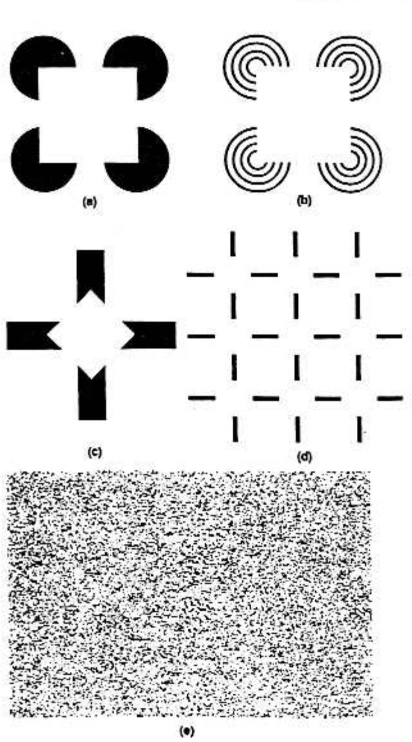

FIGURE 1. (a) and (c) The illusory contours are perceived in a direction parallel to the dark inner edges of the inducing figures. (b) and (d) The illusory contours are seen in a perpendicular direction to the ends of the inducing thin lines. (e) The readers may copy this texture onto a transparency and hold it about 1 cm over (a)–(d) in order to observe the differential capture effects.

always had different disparities. Since one of the two observers was not naive, we introduced the catch trials so that the observers were not biased by the knowledge that the texture and the colored square actually had different disparities. The luminance of the colored square was varied in seven steps so that the photometric Michelson contrast between the colored square and the background was −12, −8, −4, 0, 4, 8, or 12%. A phase haploscope was attached to the display and with polarized glasses the left and right eye images were projected into the two eyes alternately (33.5 Hz). The luminances and chromaticities shown above were measured through the haploscope and polarized glasses worn by the observers.

Procedure. In each trial, a fixation point was presented for 200 msec, followed by a blank (white) screen for 500 msec. The test stimulus was then presented for 200 msec. Two boxes with buttons were connected to the computer. The observer's task was to push the button on the right-hand box (with the right index finger) if the colored square appeared to be at the same depth plane as the texture and on the left-hand box (with the left index finger) if not. The next trial started 500 msec after the observer pushed one of the buttons. There was no feedback about the accuracy of the responses. In each experimental session, 700 trials (4 disparity conditions × 7 luminance conditions × 25 repetitions) were presented in a random order. The experiment consisted of three experimental sessions, one for each of three degrees of both crossed and uncrossed disparity (4.3′, 8.6′, and 12.9′) defining the depth of the textured squares.

Results

Figure 3 shows the percentage of capture trials in which the colored square appeared erroneously to be on the same plane as the texture (in these trials the colored square was always at zero disparity). In both observers, in both test conditions, the perceived depth of the colored square was captured by the texture most frequently when the luminance contrast of the colored square was nearly equiluminant to the background. Depth capture occurred more frequently for smaller disparities. The depth capture was stronger when the texture was placed behind the display plane than when it was in front. This may be because the fine texture elements, scattered on the colored square as well as on the background, always occluded the colored square providing a cue that it should lie behind the texture.

Figure 4 shows the percentage of catch trials for which observers correctly reported that the colored square appeared to lie on the same plane as the texture. For observer TW, for both crossed and uncrossed disparity, almost 100% of catch trials were reported correctly for all luminance contrasts. For observer GLZ, the percentage of correct responses for uncrossed disparity was lower than that for crossed disparity. It tended to be lower with increasing degrees of disparity, although it did not seem to be influenced by luminance contrast.

Discussion

One possible explanation for the depth capture of the equiluminous colored square by texture is that

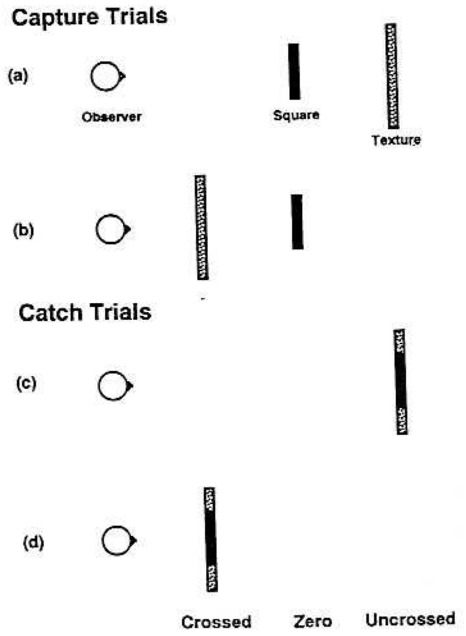

FIGURE 2. Schematic illustrations of disparities of texture and colored square in four conditions: capture trials (a) the square with zero disparity and texture with uncrossed disparity, and (b) the texture with crossed disparity and square with zero disparity; Catch trials (c) both the square and texture with uncrossed disparity, and (d) both the texture and square with crossed disparity.

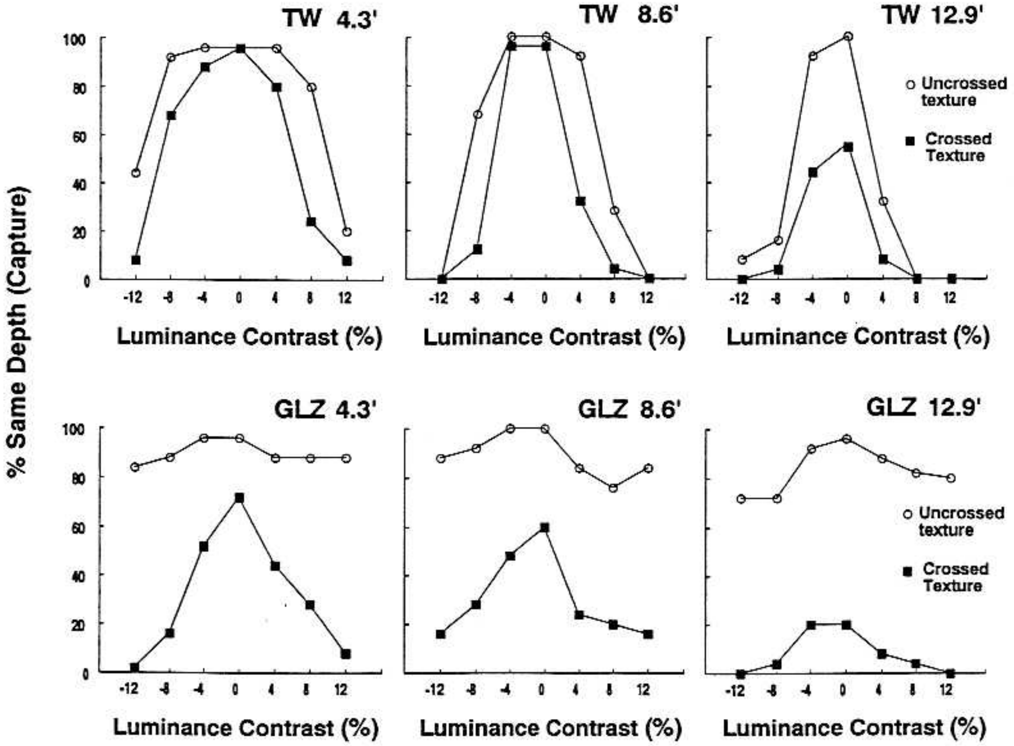

FIGURE 3. The percentage of trials in which the colored square was captured by the texture as a function of luminance contrast between the colored square and the background, with texture having crossed disparity and the colored square at zero disparity (open circles) and with texture having uncrossed disparity and the colored square at zero disparity (solid squares), for the two observers and three different degrees of disparity.

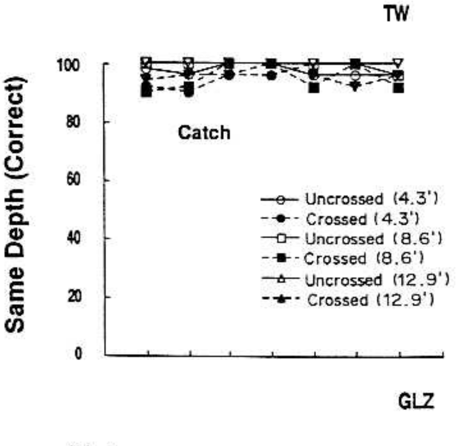

FIGURE 4. The percentage of trials in which the texture and the colored square appear at the same depth for the crossed and uncrossed catch trial conditions (both the texture and the colored square have the same disparity).

chromatic contours provide only a weak disparity signal. In particular, random dot stereograms produce little impression of depth when the dots are equiluminous red on green (de Weert & Sadza, 1983; Gregory, 1977; Lu & Fender, 1972). These weak signals from the chromatic contours in our experiment might be easily overridden by disparity from texture.

Is depth capture a specific consequence of using chromatic contours or a non-specific consequence of the weak depth signals they provide? To examine this distinction, we tested whether depth capture occurred for a low contrast achromatic square. For a contrast at which the observer (TW) could just notice a brightness difference, depth capture was observed. This suggests that depth capture is not a specific property of chromatic borders but common to any border that produces only weak disparity signals.

Since the observers' task in Experiment 1 was to answer if the colored square appeared to be at the same depth plane as the texture, one might say that it is possible that in the cases where they appeared to be at the same depth plane, the depth of that plane is somewhere between the disparity of the texture and the disparity of the colored square. We therefore examined the apparent depth of the texture when capture occurred. The same texture and colored square used in Experiment 1 were shown and a black rectangle (1.7 × 0.6°) was added as a depth probe at the lower part of the screen. The probe and the nearest corner of the texture were separated by 3.0°. At the optimal conditions for capture of Experiment 1 (colored square at 50 cd/m^2, texture disparity 4.3′, square at 0° disparity), the two observers confirmed that they saw the colored square at the same depth as the texture. They then adjusted the probe until it appeared to lie at the same depth as the texture. In all 20 trials (10 crossed, 10 uncrossed disparities), the observers adjusted the probe to the same depth as the texture, indicating that the depths of the square and the texture were not averaged; rather, the apparent depth of the colored square was captured by the texture.

Finally, Fig. 3 shows that for both observers, the curve relating capture to photometric luminance contrast is not centered at 0% contrast but appears to be offset slightly toward negative contrasts (colored square less luminous than the background). Assuming that the observer's equiluminance point lies at the center of the offset function, we find a slight deviation between individual equiluminance points and the CIE photometric equiluminance point, a result that has been reported frequently in previous studies (cf. Kaiser, 1988).

EXPERIMENT 2: DEPTH CAPTURE OF ILLUSORY CONTOURS BY TEXTURE

The depth capture reported by Spillmann and Redies (1981) for the Ehrenstein figure may also have been due to a weak disparity signal from the illusory contours. There are two general types of inducing figures for illusory contours—solid figures and fine line figures. Grossberg and Mingolla (1985) suggest that the illusory contours induced by the two types of the inducing figures are mediated by different mechanisms. On the other hand, other models assume that they are mediated by the same mechanism (Finkel & Edelmann, 1989; Von der Heydt & Peterhans, 1989). We examined whether similar depth capture is observed for both.

In this experiment, we measured the frequency of capture of illusory contours produced by either solid or fine line figures (Fig. 1) for several degrees of crossed and uncrossed disparity.

Method

Observers. The same two observers as in Experiment 1 were employed.

Materials. The solid Kanizsa square as shown in Fig. 1(a) and *the fine line Kanizsa square* as shown in Fig. 1(b) were used. The radius of solid circle in the solid Kanizsa square and the largest radius of circle in the fine line Kanizsa square were both 54′. The stroke width of the circles and gap size between the circles in the fine line Kanizsa square were 3′ and 6′. With both figures, clear illusory squares (3° × 3°) were perceived. There were four disparity conditions: (1) texture with crossed disparity and the illusory contour with zero disparity relative to the display plane, (2) texture with uncrossed disparity and the illusory contours with zero disparity, (3) both texture and the illusory contours with the same degree of the crossed disparity, and (4) both texture and the illusory contours with the same degree of the uncrossed disparity. The former two were capture conditions and the latter two were catch conditions. In the catch conditions, the same amount of disparity as the texture was introduced between the vertical edges of the cut sectors in the solid or fine line circles. As a result, the illusory contours were seen in front of or behind the display plane and at the same depth plane as the texture, but the inducing figures themselves were seen at the same plane as the background. The other aspects were similar to those in Experiment 1.

Procedure. One experimental session consisted of 200 trials. In each session, the order of the 200 trials (25 repetitions of the 8 combinations of two figure conditions and four disparity conditions) was random. The whole experiment consisted of three experimental sessions, one for each of the three degrees of disparity: 4.3′, 8.6′, or 12.9′.

Results

Figure 5 shows the percentage of responses in the capture trials in which the illusory square appeared to be on the same depth plane as the texture. For both observers, whether texture had crossed or uncrossed disparity, depth capture was weak for the solid Kanizsa square. On the other hand, for the fine line Kanizsa square, for both observers, strong depth capture was found especially when texture had uncrossed disparity. To a lesser extent, depth capture was also found when texture had crossed disparity. As in Experiment 1, this

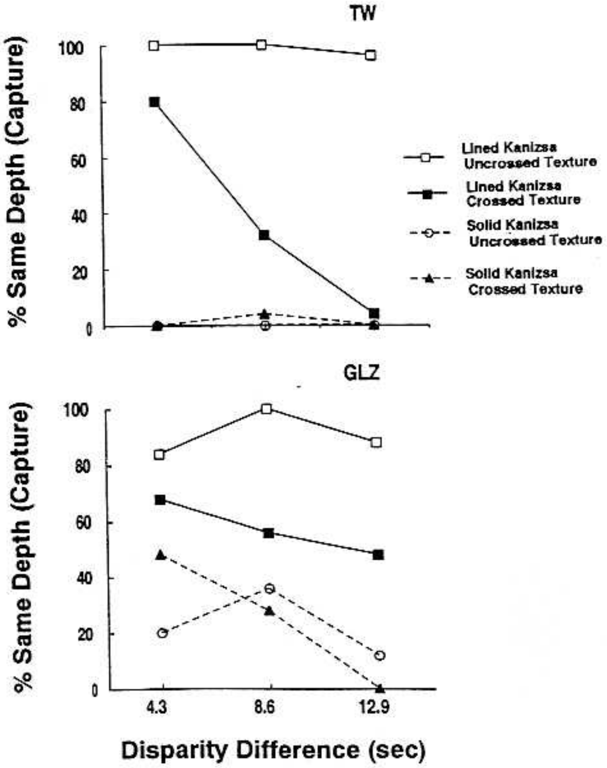

FIGURE 5. The percentage of trials in which the illusory square was captured by the textured square as a function of direction of the texture disparity for the solid Kanizsa and the fine line Kanizsa square, for the two test conditions.

asymmetry may arise because the fine texture elements are visible in the area of the illusory square, therefore appearing to occlude it.

Figure 6 shows the percentage of the catch trials for which the depth of illusory figures was seen correctly (at the same depth as the texture). The percentage is high for both observers and both inducing figures and for crossed and uncrossed disparity.

GENERAL DISCUSSION

We found that chromatic contours and the illusory contours induced by the fine line version of the Kanizsa square were captured in depth by the luminance texture, but the illusory contours induced by the solid Kanizsa square were not.

Why are the illusory contours induced by the solid inducing figures not captured by the texture? We examined several other illusory contours holding a transparent texture over them, and found that in general, illusory contours induced by line ends were captured but those induced by edges of solid figures were not. One possible explanation is that the difference is due to a simple stimulus property of the inducing figures. As was shown in the catch trials of Experiment 2, the disparity between the vertical edges of the cut sectors in the solid or fine line circles can determine the apparent depth of the illusory figures (Blomfield, 1973; Gregory & Harris, 1974). The vertical edges of the cut sectors in the solid circles would provide strong disparity signals (Rogers & Graham, 1983). On the other hand, fine line figures have only the fine end points of the horizontal lines to provide disparity signals. We assume that the differential capture effects for the two illusory contours are not so much due to the differences in quality of these illusory contours as to difference in disparity signals provided by the inducing figures. Consequently, we conclude that our results do not support the notion of qualitative differences between the two types of illusory contours [Fig. 1(a) vs Fig. 1(b)].

Why are the weak disparity signals overridden and replaced by the stronger disparity signals from the texture and why only for smaller disparity values? One factor may be the mutual facilitation between adjacent cells that respond to the same disparity (e.g. Marr & Poggio, 1976). The effect of such facilitation is to favor the characterization of a stimulus as a uniform surface over which disparity changes smoothly. In Marr and Poggio's (1976) original model, this process was intended to suppress the noisy scatter of disparity values due to potential false matches and even to fill in disparity values at locations where there were no image features. In our stimuli, this process would simply suppress the weaker disparity signals from the illusory contours or chromatic contours and attribute one disparity value—one depth plane—to both texture elements and the chromatic or illusory square. However, the goal of the smoothing process is only to smooth over noisy measurement, not to render the entire image as one depth plane. There must therefore be limits on the variability that will be reduced by smoothing: a large enough change must be interpreted as a real change in depth in the scene. Thus when the disparity signal from the contour of the square is sufficiently strong (solid Kanizsa square) or sufficiently different from the disparity of the surrounding texture, a second surface becomes visible with one transparent surface overlying the other (see Akerstrom & Todd, 1988). In Experiment 1, capture occurred less frequently when the luminance contrast of the colored square against the background was high or when the disparity difference between the texture and the colored square was large (12.9′).

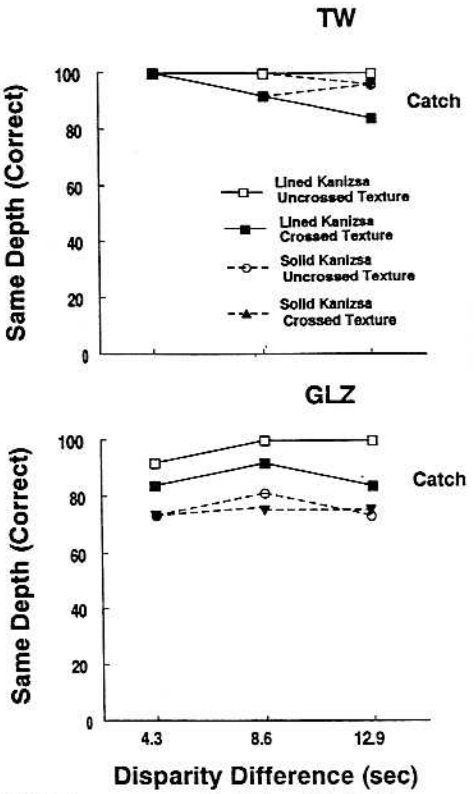

FIGURE 6. The percentage of trials in which depth was seen correctly for three degrees of disparity, for the crossed and uncrossed catch trial conditions (both the texture and the illusory figures have the same disparity).

To summarize the present study, the depth capture occurs with equiluminous chromatic contours and the illusory contours induced by the fine line Kanizsa square, but does not occur with those induced by the solid Kanizsa square. It is suggested that chromatic contours and the illusory contours induced by the fine line Kanizsa square provide only weak disparity signals and that these signals are overridden by the stronger disparity signals spreading cooperatively from the adjacent luminance texture.

REFERENCES

Akerstrom, R. B. & Todd, J. T. (1988). The perception of stereoscopic transparency. *Perception and Psychophysics*, *44*, 421–432.

Blomfield, S. (1973). Implicit features and stereoscopy. *Nature: New Biology*, *245*, 147.

Finkel, L. H. & Edelman G. M. (1989). Integration of distributed systems by reentry: A computer simulation of interactive functionally segregated visual areas. *Journal of Neuroscience*, *9*, 3188–3208.

Gregory, R. L. (1977). Vision with isoluminant colour contrast: 1. A projection technique and observations. *Perception*, *6*, 113–119.

Gregory, R. L. & Harris, J. (1974). Illusory contours and stereo depth. *Perception and Psychophysics*, *14*, 411–416.

Grossberg, S. & Mingolla, E. (1985). Neural dynamics of form perception: Boundary completion, illusory figures and neon color spreading. *Psychological Review*, *92*, 173–211.

Kaiser, P. K. (1988). Sensation luminance. A new name to distinguish CIE luminance from luminance dependent on an individual's spectral sensitivity. *Vision Research*, *28*, 455–456.

Lu, C. & Fender, D. H. (1972). The interaction of colour and luminance in stereoscopic vision. *Investigative Ophthalmology*, *11*, 482–489.

Marr, D. & Poggio, T. (1976). Cooperative computation of stereo disparity. *Science*, *194*, 283–287.

Ramachandran, V. S. (1987). Interaction between color and motion in human vision. *Nature*, *328*, 645–647.

Rogers, J. B. & Graham, M. E. (1983). Anisotropies in the perception of three-dimensional surfaces. *Nature*, 1409–1411.

Spillmann, L. & Redies, C. (1981). Random-dot motion displaces Ehrenstein illusion. *Perception*, *10*, 411–415.

Von der Heydt, R., Peterhans, E. & Baumgartner, G. (1984). Illusory contours and cortical neuron responses. *Science*, *224*, 1260–1262.

de Weert, C. M. M. & Sadza, K. J. (1983). New data concerning the contribution of color differences to stereopsis. In Mollon, J. D. & Sharpe, L. T. (Eds), *Colour vision: Physiology and psychophysics* (pp. 553–562). London: Academic Press.

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