Subjective contours can facilitate performance in a reaction-time task

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Subjective contours were compared with objective contours in their ability to facilitate performance in speeded tasks that required judging the position of a dot or the slope of a line segment relative to the contour. Subjective contours were found to reduce both reaction times and error rates for dot localization but not for the more difficult slope discrimination task. These results add to the growing body of evidence suggesting that subjective contours have functional properties similar to those of objective contours.

Subjective contours are illusory contours that are perceived in regions of the visual field not containing luminance gradients (Coren, 1972; Kanizsa, 1955, 1976; Schumann, 1904). Subjective contours can be a compelling illusion, and they are widely regarded as an important phenomenon for our understanding of contour, form, and depth perception. Most of the literature on subjective contours is aimed at explaining why they are perceived and at determining the necessary stimulus conditions and processing mechanisms for their emergence. The present study, however, focuses on the internal representations of subjective contours and on how their functional properties compare with those of objective contours.

The fact that a subjective contour may have a phenomenal appearance similar to that of an objective contour does not imply that their corresponding representations are identical or even similar; that must be determined empirically. However, the evidence collected to date does suggest a similarity. First, subjective contours act like objective contours in producing geometrical illusions such as the Poggendorf (Gregory, 1972; Meyer & Garges, 1979), the Zoellner (Pastore, 1971), and the Ponzo (Farne, 1968, as cited in Kanizsa, 1979). Second, sequentially presented subjective contours will go into apparent motion as objective contours do (von Grünau, 1979). In other words, as far as these two illusions are concerned, a subjective contour works about the same as an objective one, although the subjective contour may produce weaker effects. (For further examples, see Coren & Theodor, 1977; Smith & Over, 1975.)

The present study extends these comparisons of objective and subjective contours beyond the realm

of visual illusions by asking if subjective contours, like objective ones, can facilitate responses in a performance task. In a performance task, subjects are asked not to describe their percepts but to solve a well-defined problem as quickly and accurately as possible. Two tasks were chosen—dot localization and line slope discrimination—in which the presence of an objective contour facilitates the speed and accuracy of performance. In the dot localization task, the subject must decide whether a dot is located inside or outside a square; in the line slope task, the subject must decide whether the slope of a line segment is the same as or different from that of a comparison line. Both of these tasks can be performed with no reference lines physically present, since the subject can be asked to remember the position of a square and to judge the dot's location or the line's slope relative to the remembered or imagined square. But, as our data will show clearly, having the reference contours physically present helps enormously.

Our question is whether a square depicted via subjective contours will facilitate performance, too. Before this question can be asked, the proper comparison condition must be devised, since (1) subjective contours can be induced only through a properly arranged set of objective contours, and (2) these objective contours, rather than the subjective ones, might be responsible for any facilitation in performance that may be observed. The stimuli we selected are shown in Figure 1, which presents four ways of depicting a square. In Figure 1A, an objective square is shown; in Figure 1B, a blank field is presented, corresponding to the condition in which the subject must respond to a remembered or imagined square; in Figure 1C, a subjective square is presented, which most of our subjects reported little difficulty in perceiving; and in Figure 1D, a control stimulus is presented (adapted from Kanizsa, 1976, and from Meyer & Garges, 1979) that preserves the geometric properties of the subjective square but does not generate the perception of subjective

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Figure 1. Panels A, B, C, and D show the four context conditions used in Experiments 1 and 2: (A) square, (B) blank, (C) subjective square, and (D) control. Panel E shows the 12 possible positions of the target dot relative to the square.

contours. That is, subjects can imagine the square that is suggested by the figure, and they can mentally interpolate lines (called "virtual lines" by Kanizsa, 1976) or edges between the inducing contours, but they do not report seeing any subjective square or subjective contours, nor do they report seeing any of the usual concomitants to subjective contours, such as brightness or depth differences. It should be much easier to localize a flashed dot inside the square suggested in Figure 1D than in the purely imagined square of Figure 1B. But assuming that Figures 1C and 1D are comparable in the geometric cues they provide that might facilitate dot localization, any performance differences between these two figures will be assumed to be due to the perception of a subjective square in Figure 1C but not in Figure 1D.

A priori, there are good reasons to predict either the success or failure of subjective contours in this task. On the plus side, there are the following: (1) Subjective contours can be quite powerful, so much so that some subjects are not easily convinced they are illusory; (2) subjective contours are adequate to produce certain visual illusions, as described above; and (3) it has now been amply demonstrated that other "subjective" percepts, such as images, produce effects qualitatively

similar to objective percepts in information processing tasks requiring mental rotation, scanning, and the like (Cooper & Shepard, 1973; Kosslyn & Pomerantz, 1977; Shepard & Metzler, 1971).

But, on the minus side, there are the following arguments: (1) Subjective contours are weaker than objective ones and tend to disappear when inspected closely or fixated directly (Kanizsa, 1976). Scrutinizing a subjective contour is like examining a faint shadow with a flashlight. An ephemeral subjective contour might not be of any help in a difficult task requiring focused attention at the region of the subjective contour. (2) Most experiments on subjective contours have asked subjects to attend to the contour and to judge it directly in some way; in the information processing task, attention is focused elsewhere (say, on localizing a dot), and the contour will play a role only if it still remains salient to the subject. (3) Most (if not all) experiments on subjective contours have allowed unlimited time to inspect the stimulus; in the present experiment, however, the subject is put under time pressure to respond, which might not leave sufficient time for the construction or maintenance of the subjective contour. (4) Although experiments have shown that images can be used in information processing tasks, they usually impede rather than facilitate performance relative to other strategies available to the subject (Kosslyn, 1980); thus, if subjects attempt to use the subjective contours they perceive, their performance might actually suffer. And, finally, (5) subjects are often unable to perform simple tasks on images they claim they experience clearly. For example, many subjects cannot tell if an image of the Star of David contains an embedded parallelogram, although they can spot the parallelogram easily when presented with the physical stimulus (e.g., Pylyshyn, 1978; Reed, 1974).

EXPERIMENT 1

Method

Subjects. The subjects were 20 students (15 males, 5 females) from SUNY at Buffalo who served either for pay or for credit in an introductory psychology course. All had normal or corrected-to-normal vision.

Stimuli and Apparatus. The stimuli consisted of single target dots presented in any of 12 positions against a background of one of four contexts, as shown in Figure 1. The four contexts will be called square, blank, subjective square, and control. The contexts and the dots were drawn separately on white cards and were presented in a three-field tachistoscope. The 12 dot positions were arranged along the left and right sides of the square, falling either just inside or outside, as shown in Figure 1E. They were drawn with a black, fine-tipped Pilot pen. At a viewing distance of 79 cm, the field of view visible within the tachistoscope measured 6.4×9.2 deg of visual angle. The square subtended a visual angle of 4.4 deg and the dots subtended .14 deg. The dots were centered .14 deg inside or outside the nearest edge of the square. (The stimuli in Figure 1 are drawn to scale.) When a single field was illuminated, the luminance of the black contours on the stimulus cards was

6.8 cd/m², while that of the white portions of the card was 43.1 cd/m². Subjects were shown all four contexts and all 12 possible target positions before the experiment commenced.

Procedure. Each subject served in 16 blocks of 12 trials, for a total of 192 trials. Within each block, the context remained constant, and all 12 dot positions were presented once, in a different random order for each context, counterbalanced over subjects. Over the 16 blocks, the four contexts were presented four times each in an order counterbalanced over subjects with a Latin square. Each block began with an exposure of the context stimulus for that block. In the blank context condition, the subject was told to recall the square's location in the field, since he would have to judge the dots' positions relative to the square from memory. The 12 trials then proceeded as follows. The context card was presented for 2.5 sec, after which the target card containing a single dot was also illuminated, superimposed upon the context card; this reduced the contrast of the stimuli and increased the luminances of the black and white portions of the cards to 49.9 and 86.2 cd/m², respectively (see Experiment 2). The target remained in view for 2.5 sec, during which time the subject was to respond. Subjects were permitted to scan the field freely during this interval. The task was to decide if the dot was located inside or outside the context square and to respond by speaking the word "in" or "out" into a microphone connected to a voice-operated relay. A response not occurring within the 2.5-sec interval was counted as an error. The target card was then extinguished, leaving the context card in view for another 2.5-sec intertrial interval, during which time the response and reaction time (RT, to the nearest msec) were recorded. Subjects were instructed to respond as quickly as possible while minimizing errors. No feedback was given, but subjects were usually aware when they had made an error.

Results

Mean correct RTs and error rates for Experiment 1 are shown in Table 1. Analyses of variance showed significant effects of the four context conditions on both RT [$F(3,57) = 81.1$, $p < .001$] and error rates [$F(3,57) = 115.8$, $p < .001$]. By either measure, the square context produced the best performance and the blank the worst, with the subjective square superior to

the control context (800 vs. 842 msec; 5.4% vs. 8.1% errors). Subsequent *t* tests showed the superiority of the subjective square to the control to be significant both for RTs [$t(19) = 2.45$, $p < .05$] and for error rates [$t(19) = 2.28$, $p < .05$].

The effect of the 12 target positions was not significant for RTs [$F(11,209) = 1.61$, $p > .05$] but was significant for error rates [$F(11,209) = 4.16$, $p < .001$]. Most of this position effect was due to a bias toward saying "in," since "in" responses were both faster (851 vs. 877 msec) and more error-free (9.2% vs. 15.2% errors) than "out" responses. The reason for this bias is not clear. Finally, there was no significant Context by Position interaction for either RTs [$F(33,627) = 1.09$] or error rates [$F(33,627) = .56$]. More important, the superiority of the subjective square over the control context was observed at all 12 target positions for RT and at 9 of the 12 positions for error rates.

EXPERIMENT 2

In view of the small (but significant) superiority of the subjective contour over the control context in Experiment 1, we attempted to replicate the experiment with some changes in method, as described below. In particular, some of our subjects noted that the rapid luminance and contrast changes occurring at the moment the target appeared were distracting and temporarily destroyed their perception of a subjective square. We wished to see if eliminating this factor would improve performance in the subjective square condition.

Method

The method of Experiment 2 was identical to that of Experiment 1, with the following exceptions. A new set of 16

Table 1
Mean Correct Reaction Times (RT) in Milliseconds and Error Rates (ER) in Percentages
for the Four Contexts and 12 Dot Positions in Experiment 1

Position	Context									
	Square		Blank		Subjective Square		Control		Mean	
	RT	ER	RT	ER	RT	ER	RT	ER	RT	ER
1	787	11.0	1035	31.0	806	10.2	812	15.4	860	16.9
2	688	2.5	1128	27.5	740	2.5	783	1.2	835	8.4
3	804	8.2	1014	38.8	813	7.0	920	17.5	888	17.9
4	704	2.6	1030	13.4	815	4.3	836	5.4	846	6.4
5	750	8.2	1084	37.2	801	8.2	853	12.6	872	16.5
6	727	3.3	1051	33.2	804	10.2	850	4.6	858	12.8
7	692	7.2	1044	31.2	789	2.0	866	5.0	848	11.3
8	781	1.6	1125	28.0	783	2.4	786	1.0	869	8.3
9	746	10.4	1110	29.3	858	8.6	877	14.2	898	15.6
10	718	2.2	1033	29.8	826	3.5	829	4.6	852	10.0
11	766	9.1	1143	31.2	799	3.8	877	9.4	896	13.4
12	712	1.2	1101	28.0	767	2.4	809	6.2	847	9.5
Mean	740	5.6	1075	29.9	800	5.4	842	8.1	864	12.2

Note—Position numbers are from Figure 1e.

subjects (14 males, 2 females) was used. The tachistoscope programming was changed so that a third, blank field was illuminated whenever the target field was not; but, as in Experiment 1, the context field was always illuminated. Thus, all stimuli appeared under reduced contrast, but there was no change in total illumination at the onset and offset of the target.

Results

Table 2 shows the mean correct RTs and error rates for the four context conditions of Experiment 2. The rank ordering of RTs in the four conditions was the same as in Experiment 1, and the superiority of the subjective square over the control condition was replicated and amplified somewhat to 73 msec (vs. 42 msec in Experiment 1). Analysis of variance showed that the four context conditions differed significantly for both RTs [$F(3,45) = 85.8$, $p < .001$] and error rates [$F(3,45) = 81.41$, $p < .001$]. The RT difference between the subjective square and control conditions was significant by t test [$t(15) = 4.08$, $p < .001$] and was shown by 13 of the 16 subjects; the error rates for the subjective square and control contexts were identical, with half the subjects showing fewer errors on the subjective square and half on the control.

There was a significant effect of target position on both RT [$F(11,165) = 2.85$, $p < .01$] and error rate [$F(11,165) = 2.28$, $p < .01$]. As in Experiment 1, this effect was due mainly to a bias toward the "in" response, which showed faster RTs (891 vs. 925 msec) and smaller error rates (9.1% vs. 12.0% errors) than the "out" responses. Finally, the Context by Position interaction was significant for RTs [$F(33,495) = 3.52$, $p < .001$] but not for error rates [$F(33,495) < 1$]. The RT interaction was due to various small effects, including (1) relatively faster responses for dots to the left of their adjacent contour in the square condition than in the others and (2) relatively slower responses in the middle dot positions (i.e., positions 3, 4, 9, and

10) as compared with the other positions in the subjective square and control contexts. The reason for the former effect is unclear. But the latter effect suggests that the geometric cues provided by the objective contours in these two displays were less effective for dots located farther away from the objective contours. Interestingly, the deterioration of performance in the middle positions compared with the top and bottom positions was greater in the control condition (98 msec) than in the subjective square condition (63 msec), which suggests that subjective contours may not fade away at greater distances from their objective, inducing contours.

Discussion

These two experiments have shown that a subjective contour may be used to advantage in an information processing task. They have shown that much of this advantage stems from geometrical properties of the objective, inducing contours, since the control as well as the subjective square context was superior to the blank context. However, a significant component stems from the perception of the subjective contour itself. Combining the data from Experiments 1 and 2, the superiority of the subjective square over the control context averaged 56 msec and was shown by 26 of 36 subjects ($p = .006$, one-tailed sign test).

This facilitation obtained in spite of two factors. First, the inducing field we used to create the subjective square was less complex than those used by Kanisza (1976) and others, so perhaps the subjective square was weaker than it might have been. Second, our subjects were given a difficult task requiring focal (and likely foveal) attention to the very region of the field containing the subjective contours (a factor that tends to suppress the appearance of subjective contours). In fact, a few of our subjects, when questioned informally after the experiment, told us they did not re-

Table 2
Mean Correct Reaction Times (RT) in Milliseconds and Error Rates (ER) in Percentages
for the Four Contexts and 12 Dot Positions in Experiment 2

Position	Context									
	Square		Blank		Subjective Square		Control		Mean	
	RT	ER	RT	ER	RT	ER	RT	ER	RT	ER
1	718	5.6	1127	25.2	841	10.9	926	2.1	903	11.0
2	759	.0	1291	29.8	750	.0	765	.0	891	7.4
3	710	.0	1150	29.6	875	11.4	993	9.8	932	12.7
4	755	1.6	1100	21.9	865	6.2	881	.0	900	7.4
5	735	.0	1193	19.9	818	1.2	905	5.3	913	6.6
6	801	6.8	1158	27.7	779	6.8	834	1.6	893	10.7
7	808	1.2	1188	25.1	761	1.6	864	1.2	905	7.3
8	698	.0	1117	34.3	810	1.6	841	1.6	867	9.4
9	920	13.0	1107	32.8	771	7.8	1055	16.3	963	17.5
10	706	1.2	1214	31.3	924	6.2	893	2.1	934	10.2
11	813	16.6	1184	31.0	813	3.8	930	15.9	935	16.8
12	715	1.6	1125	35.2	799	.0	793	1.6	858	9.6
Mean	761	4.0	1163	28.7	817	4.8	890	4.8	908	10.6

member noticing the subjective square during the experimental trials. Interestingly, those subjects' data did not appear to differ in any way from the data of the subjects who reported seeing a strong subjective square, but our debriefing was not done systematically enough to allow a formal analysis. Also, our informal questioning revealed that none of the subjects correctly guessed the hypothesis that was being tested. This makes it unlikely that our main finding was due to any demand characteristics operating; Experiment 3 will bolster this conclusion.

Given that our principal result in Experiments 1 and 2 was modest in magnitude (albeit respectable in statistical significance), we decided to try to generalize the result to a different task in Experiment 3—namely, line slope discrimination. Here, the subject must decide whether or not the slope of a target line segment is parallel to that of a reference contour that is depicted by an objective contour, a subjective contour, a virtual line contour, or a remembered (imaged) contour.

EXPERIMENT 3

Method

The method of Experiment 3 closely paralleled that of Experiment 2 with the following exceptions. A new group of 16 subjects (7 males, 9 females) was employed. A new set of stimuli was generated, as is shown in Figure 2. Again, there were four context fields, which were identical to those in Experiments 1 and 2 except for a 56-deg rotation, so that the context figure appeared more like a diamond than a square. The figures were shrunk slightly so the diamonds would fit on the tachistoscope cards in their new orientation. The 56-deg orientation was chosen, since the task required judging the slope of lines and we wished to avoid familiar and easily encoded slopes (e.g., 0, 45, 90 deg). We believed this would force the subject to compare the target lines with the context field rather than with the edges of the tachistoscope field or with some other representation of the reference angle. Target lines could occur in any of six positions about the context diamond, as shown in Figure 2. In each case of these six positions, there was one target whose slope was parallel to the nearest edge of the diamond, one whose slope was 5 deg greater, and one whose slope was 5 deg less than that of the diamond's edge (making their slopes 61 and 51 deg, respectively; note that these slopes have been exaggerated in Figure 2 for purposes

Figure 2. The "diamond" context used in Experiment 3. The 18 possible targets are shown in the six positions at which they could occur. Both the slopes and the lengths of these segments have been exaggerated in this figure for clarity.

of illustration). Thus, there were 18 target lines in all. The target line segments measured .44 deg in extent and were centered .36 deg from the nearest edge of the context diamond. The diamonds measured 3.99 deg on a side.

The subject's task was to decide as quickly as possible if the target line's slope was the same as or different from the slope of the diamond's nearest edge and to respond as quickly as possible by speaking the words "same" or "different" into a microphone. An experimental session again consisted of 16 blocks of 12 trials each, with the context stimulus constant throughout a block. Within a block of 12 trials, one "same" stimulus and one of the two possible "different" stimuli were presented at each of the six positions around the diamond, so the probabilities of "same" and "different" were equal. A mask consisting of a haphazard arrangement of randomly oriented line segments identical to the target lines was in view whenever a target line was not being presented; this was done in order to mask any persisting image of the target line from the preceding trial, so that its slope could not be used as a basis for judging the next target. The same mask was used on all trials; it consisted of 120 lines evenly spaced (not touching each other) across the field.

In all other respects, the design of this experiment corresponded to that of Experiment 2.

Results

The RT and error rate data for Experiment 3 are shown in Table 3. The rank ordering of the four context conditions was identical to that in Experiments 1 and 2. Analyses of variance showed that the four context conditions differed significantly from one another, both for RTs [$F(3,45) = 8.39$, $p < .01$] and error rates [$F(3,45) = 25.9$, $p < .001$]. Performance with the subjective diamond was slightly superior to the control context, both for RTs (15 msec) and for percent errors (2 percentage points), but neither of these approached significance, and, in fact, a majority of subjects showed superior performances with the control context for RTs (9 of 16 subjects), and only half of the subjects showed it for error rates. Thus, in contrast with Experiments 1 and 2, subjective contours seem to have been of little or no value in the slope discrimination task of Experiment 3.

Otherwise, the data show an RT bias in favor of the "different" response, which was faster (1,230 vs. 1,373 msec) but more error-prone (31% vs. 28% error) than the "same" response. The target line segments were quite short in this experiment, and several subjects remarked that almost all of the targets seemed different in slope from the reference slopes in the context stimulus; this probably accounts for the RT bias toward the different response. However, this bias was approximately equal for all four context conditions. No other effects proved significant.

DISCUSSION AND CONCLUSIONS

The results of Experiment 3 stand in contrast with those from Experiments 1 and 2 in that the subjective contour was of little or no help in judging the slope of a target line segment. The small apparent facilitation was statistically insignificant and was shown by a minor-

Table 3
Mean Correct Reaction Times (RT) in Milliseconds and Error Rates (ER) in Percentages for Target Lines With the Same and Different Slopes at the Six Positions Around the Four Different Diamond-Shaped Contexts in Experiment 3

Position	Response	Context									
		Square		Blank		Subjective Diamond		Control		Mean	
		RT	ER	RT	ER	RT	ER	RT	ER	RT	ER
1	Same	1340	16	1436	63	1465	27	1496	23	1434	32
	Different	1146	16	1304	36	1195	22	1275	16	1230	22
2	Same	1290	14	1294	47	1292	14	1411	23	1322	25
	Different	1179	16	1264	44	1224	19	1168	23	1209	25
3	Same	1338	27	1367	31	1404	31	1421	42	1383	33
	Different	1186	14	1295	47	1220	23	1154	20	1214	26
4	Same	1240	16	1498	34	1347	19	1348	36	1358	26
	Different	1124	28	1413	50	1228	44	1168	44	1233	41
5	Same	1273	17	1334	45	1313	27	1495	17	1354	27
	Different	1171	28	1352	38	1221	36	1194	42	1235	36
6	Same	1330	17	1460	41	1328	31	1419	16	1384	26
	Different	1158	25	1325	44	1352	36	1212	47	1262	38
Mean		1231	19	1362	43	1299	27	1314	29	1301	30

Note—Position numbers are from Figure 2.

ity of subjects. Performance on the control context again shows that the objective contours of the inducing stimuli were beneficial in this task, but the presence of a subjective contour was of no added help. We interpret the lack of an effect in this experiment to indicate that the positive effect found in Experiments 1 and 2 was unlikely to have resulted from demand characteristics, since whatever demand characteristics may have existed should have been equal in all three experiments.

There are at least three reasons why subjective contours were of no help in Experiment 3. The first is that having a masking field present interfered with the perception of the subjective contour. (Note that no masks were used in Experiments 1 and 2.) This seems unlikely, since (1) most observers still see the subjective diamond despite the mask's presence, and, more importantly, (2) the same result obtained in an otherwise similar pilot experiment in which no masking field was used. In fact, we used the mask in Experiment 3 expressly for the purpose of amplifying any effect of the subjective contours. The second possibility is that there is something peculiar to the line slope discrimination task that makes subjective contours useless as a reference stimulus. Perhaps the internal representations of subjective contours do not make slope information as readily available as position information, so that dot localization is possible but slope discrimination is not. The third possibility, which is more testable, is that the slope discrimination task was more difficult than the dot localization task, even when an objective square or diamond was present; both RTs and error rates were substantially higher in the slope task. Perhaps the subjective diamonds in Experiment 3 simply did not have the perceptual resolution required to compare their slope with that of

the target segments. If so, then making the slope task easier by widening the angular disparity between the target and reference slopes should restore the effectiveness of subjective contours that was found in dot localization.

In conclusion, this study has shown that, in at least one task, subjective contours are sufficiently well represented in the visual system to be of use in reducing reaction times and error rates in an information processing task. They are not merely epiphenomena that perceivers experience; they are "really there" in a functional sense and may be accessed under time pressure to assist in performing difficult discriminations. To be sure, they differ from objective contours in both quantitative and qualitative ways, since subjective contours are fainter in the first place and since they become fainter still when attended to or fixated directly (unlike objective contours, which behave oppositely). The fact that the dot localization task would seem to have required both focused and foveal attention makes the effectiveness of subjective contours all the more impressive. It remains for future experiments to define the available properties of subjective contours more precisely by attempting to generalize their usefulness to other perceptual tasks.

Had our study produced the opposite result, that is, that subjective contours are of no value in a performance task, our conclusion would have been that subjective contours, although phenomenally real, are in functional terms either absent from the processing system or are so weakly represented that the effort required to use them exceeds any utility they might have. We now know that subjective contours are not as fragile as they seem, and so it may prove useful to try to localize more precisely where they originate in the visual system. The fact that subjective contours are useful in a time-

pressured task, coupled with the fact that subjective contours enter into basic sensory processes such as brightness, motion, and depth perception, suggests an early locus. But at the same time there is evidence that later, more cognitive processes also determine whether subjective contours will be perceived (Bradley & Petry, 1976; Kanizsa, 1976; Ullman, 1976). For example, a given stimulus field may give rise to two distinct and multistable perceived organizations; under these conditions, the type of subjective contours perceived, or even whether any are perceived, depends on which organization is imposed on the stimulus. This suggests that subjective contours emerge from an interaction of early and later processes, which would make the task of localizing their exact origin formidable indeed.

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