# Empirical investigation on spatial templates for a diagonal spatial term

**Tokunaga, Takenobu (take@cl.cs.titech.ac.jp)**
**Watatani, Toshiaki (watatani.t.aa@m.titech.ac.jp)**
**Iida, Ryu (ryu-i@cl.cs.titech.ac.jp)**
Department of Computer Science, Tokyo Institute of Technology

**Terai, Asuka (asuka@nm.hum.titech.ac.jp)**
Department of Human System Science, Tokyo Institute of Technology

**Abstract**

The meaning of spatial relations have been intensively studied in cognitive science research. A *spatial template* is one of the typical representations of spatial relations, which maps a position of a located object to its acceptability for the corresponding spatial term. Spatial templates have been investigated for several orthogonal spatial relations. However, diagonal spatial relations have attracted less attention. The present study aims at empirically determining the spatial template for a Japanese diagonal spatial term, "*migiue* (upper right)". The data was collected with various geometrical conditions changing the size of objects and the aspect ratio of the background. The analysis of the data revealed that the reference axis for "*migiue* (upper right)" was the direction of 45°, and the acceptability of the diagonal relation could be affected by the acceptable regions of the adjacent orthogonal relations.

**Keywords:** spatial language; diagonal spatial term; spatial template;

## Introduction

There have been numerous studies on language and spatial relations in cognitive science (Talmy, 1983; Herskovits, 1985; Tversky & Lee, 1998; Levinson, 2003; Coventry & Garrod, 2004). Understanding a spatial relation involves reference objects (RO), located objects (LO), selection of an appropriate *reference frame* with respect to the context (Carlson-Radvansky, 1997; Carlson-Radvansky & Jiang, 1998), and the meaning of the spatial relation. As a representation of the meaning of spatial relations, Logan and Sadler (1996) proposed a *spatial template* that maps an LO position to the acceptability for the corresponding spatial term. They determined the spatial templates for six projective spatial terms ( "above", "below", "left of", "right of", "over" and "under") and four topological spatial terms ("next to", "away from", "near to", and "far from") through experiments. The LO positions were discretised by a $7 \times 7$ grid and each cell was assigned to an acceptability scale from 1 (bad) to 9 (good).

Surprisingly, diagonal spatial relations have attracted less attention than orthogonal spatial relations. One reason might be the fact that spatial terms expressing diagonal spatial relations tend to be lengthy in English, e.g. "the LO is *in front of and to the right of* the RO". In contrast, as Gapp (1995) noted, such combinations of spatial terms were very common in German and could be expressed in a simple form. This is also the case in Japanese, the target language of the present study. For instance, "*migi* (right)" and "*ue* (above)" can be directly combined to make a term "*migiue* (upper right)" for representing the upper right direction.

Another reason could be related to the so-called *oblique effect*, which claims humans show greater sensitivity to ratings with the orthogonal orientations, i.e. vertical and horizontal, than to other diagonal orientations (Appelle, 1972; Furmanski & Engel, 2000; Meng & Qian, 2005). The orthogonal spatial relations are more important for humans, thus these relations might have been intensively studied.

For investigating the acceptability of spatial relations, several researchers have used a radial grid layout (Huttenlocher, Hedges, & Duncan, 1991; Gapp, 1995; Hayward & Tarr, 1995; Crawford, Regier, & Huttenlocher, 2000; Huttenlocher, Hedges, Corrigan, & Crawford, 2004) instead of a square grid layout as Logan and Sadler (1996) did. They were interested in how angular deviation affected the acceptability of spatial terms. The spatial terms they were mainly concerned with were, however, still limited to orthogonal spatial terms[1]. They did not explicitly concern themselves with the acceptability of diagonal spatial terms such as "*migiue* (upper right)".

Against this background, the present study discusses the acceptability of a Japanese diagonal spatial term. More concretely, we aim at determining a spatial template for a Japanese term "*migiue* (upper right)"[2] with taking into account three geometrical factors: the size of RO and LO, and the aspect ratio of the background. The background aspect ratio has rarely been taken into account in past studies.

## Experiment 1

### Method

**Participants** Thirty four undergraduates and graduates (30 males and 4 females) from Tokyo Institute of Technology participated in the experiment. Each participant received 1,000 JPY for his/her participation. All participants were native Japanese speakers.

**Material and design** We have four quadrants to consider for diagonal spatial terms: "upper right", "upper left", "lower right" and "lower left". Assuming symmetric acceptability

[1] Gapp (1995) investigated diagonal spatial terms as a combination of two orthogonal spatial terms. He did not, however, take into account the dominance of orthogonal relations over diagonal relations.

[2] Although we denote this target term as "upper right" in the rest of the paper, the actual term used in the experiments was the original Japanese term "*migiue*".

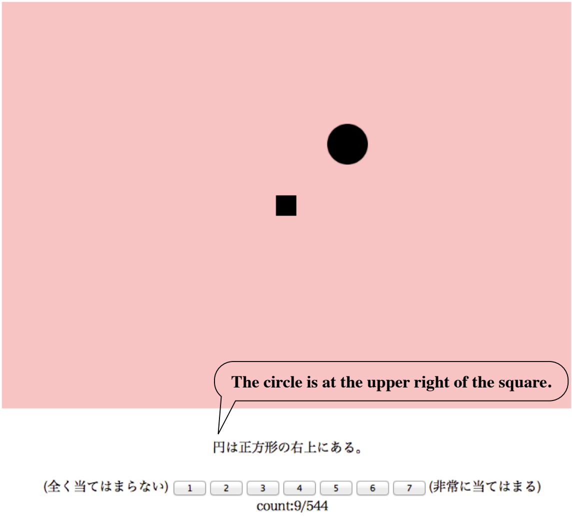


Figure 1: Example of stimulus

among these four quadrants, we investigated spatial templates for the upper right quadrant only. To obtain spatial templates for "upper right", we basically followed the goodness rating experiment described in (Logan & Sadler, 1996). Figure 1 shows the interface of a trial that was presented to the participants. Against the coloured background, a square (the reference object: RO) is placed in the center, and the circle (the located object: LO) is placed someplace within the upper right quadrant of the background. A sentence describing the spatial relation between the RO and LO is presented below the figure; "*En ha seihôkei no migiue ni aru.* (the circle is to the upper right of the square.)" in this example. The participants were instructed to rate the relevance of the sentence describing the spatial relation between two objects on the scale of 1 (bad) to 7 (good) by clicking one of seven buttons.

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|
| E | E1 | E2 | E3 | E4 | E5 | E6 | E7 | E8 | E9 |
| D | D1 | D2 | D3 | D4 | D5 | D6 | D7 | D8 | D9 |
| C | C1 | C2 | C3 | C4 | C5 | C6 | C7 | C8 | C9 |
| B | B1 | B2 | B3 | B4 | B5 | B6 | B7 | B8 | B9 |
| A | A1 | A2 | A3 | A4 | A5 | A6 | A7 | A8 | A9 |

Figure 2: Grid configuration for reference objects (Experiment 1)

The grid for the upper right quadrant with the origin at the RO position was configured as shown in Figure 2. The size of a cell was 50 × 50 pixels. The LO was placed one of these cells with its centroid at the center of the cell. The RO was placed with its centroid at the left bottom corner of the cell A1. The grid lines were invisible to the participants. We considered three geometrical factors: the RO size (R), the LO size (L) and the aspect ratio of the background (A). We had two variations for the object size: large (50 × 50 pixels) and small (25 × 25 pixels), and three variations for the background aspect ratio: 5:5, 5:7 and 5:9. Depending on the background aspect ratio, the cells from the first column to the fifth column (5:5), the cells from the first column to the seventh column (5:7) and the cells from the first column to the ninth column (5:9) were used for the LO position respectively. The total size of the background was 500 × 500 pixels for the 5:5 case, 500 × 700 for the 5:7 case, and 500 × 900 pixels for the 5:9 cases. The number of LO positions varied depending on the background aspect ratio: 24 for the 5:5 case, 34 for the 5:7 case and 44 for the 5:9 case[3]. The total number of trials for the acceptability rating became 408 ((#RO size) × (#LO size) × (#LO position for the three aspect ratios) = 2 × 2 × (24 + 34 + 44)). In addition to these trials, 136 fillers were added in which the LO was placed in other quadrants with the sentences being changed accordingly. The total number of the trials for a participant was 544 (408 + 136).

**Procedure** The 544 trials were presented to each participant one by one on a 24 inch computer display of an iMac. The sequence of the trials were pseudo randomly generated with the occasional insertion of fillers for each participant. At one third and two thirds of the trial sequence, the participants were allowed to take a short break as long as he/she wanted. The participants finished their task within 20 to 40 minutes.

| | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| E | 3.18 | 4.97 | 5.79 | 6.44 | 6.53 |
| D | 3.32 | 5.06 | 6.12 | 6.62 | 6.15 |
| C | 3.85 | 6.09 | 6.59 | 6.12 | 5.76 |
| B | 4.26 | 6.59 | 5.53 | 5.03 | 5.12 |
| A | – | 3.74 | 3.53 | 3.09 | 2.65 |

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| E | 2.88 | 4.71 | 5.76 | 5.88 | 6.41 | 6.50 | 6.50 |
| D | 3.24 | 5.03 | 6.15 | 6.50 | 6.24 | 5.85 | 5.68 |
| C | 3.68 | 6.06 | 6.44 | 6.06 | 5.79 | 5.35 | 5.24 |
| B | 4.38 | 6.62 | 5.59 | 5.21 | 4.56 | 4.62 | 4.15 |
| A | – | 4.0 | 3.47 | 3.38 | 2.91 | 2.94 | 2.41 |

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|
| E | 3.06 | 4.79 | 5.24 | 5.88 | 6.29 | 6.12 | 6.15 | 6.00 | 6.06 |
| D | 3.44 | 5.15 | 6.12 | 6.32 | 6.26 | 6.09 | 5.82 | 5.88 | 5.44 |
| C | 3.59 | 5.59 | 6.47 | 6.21 | 5.85 | 5.50 | 5.44 | 5.18 | 4.91 |
| B | 4.03 | 6.44 | 6.09 | 5.29 | 4.82 | 4.59 | 4.62 | 4.21 | 4.11 |
| A | – | 3.71 | 3.44 | 3.26 | 3.32 | 2.91 | 2.85 | 2.32 | 2.29 |

Figure 3: Spatial template for "*migiue* (upper right)" (Experiment 1, R=large, L=large)

**Results** Figure 3 shows spatial templates for "upper right" with a large RO and LO. Each cell denotes the average rating across all participants. The mean standard error of the averages in Figure 3 is 0.217. This value is comparable to the result from (Logan & Sadler, 1996), which is 0.271. From

[3]Note that the RO is fixed at the A1 position.

these templates, we can see that the direction of a 45° angle is the most relevant as a reference axis for “upper right” (red coloured cells) regardless of the background aspect ratio. In addition to these three templates, we had nine more templates for a combination of three geometrical factors: the RO size, the LO size and the background aspect ratio. We omit the other templates due to space constraints. The tendency of the other templates is similar to Figure 3.

Table 1: Result of four-way (A, R, L, P) ANOVA (Experiment 1)

| Effect | DFn | DFd | F | $p$ |
|---|---|---|---|---|
| A | 2 | 66 | 1.864 | 0.163 |
| R | 1 | 33 | 19.35 | 0.000** |
| L | 1 | 33 | 0.459 | 0.503 |
| P | 23 | 759 | 132.0 | 0.000** |
| A-R | 2 | 66 | 0.348 | 0.707 |
| A-L | 2 | 66 | 2.233 | 0.115 |
| R-L | 1 | 33 | 16.04 | 0.000** |
| A-P | 46 | 1518 | 2.084 | 0.002** |
| R-P | 23 | 759 | 2.543 | 0.001** |
| L-P | 23 | 759 | 1.545 | 0.099 |
| A-R-L | 2 | 66 | 2.043 | 0.146 |
| A-R-P | 46 | 1518 | 1.561 | 0.042* |
| A-L-P | 46 | 1518 | 0.924 | 0.576 |
| R-L-P | 23 | 759 | 1.044 | 0.407 |
| A-R-L-P | 46 | 1518 | 0.708 | 0.806 |

($** : p < .01$, $* : p < .05$)

**Analysis** We conducted a four-way ANOVA with average ratings as the dependent variable, and the background aspect ratio (A: 5:5, 5:7 and 5:9), the RO size (R: large and small), the LO size (L: large and small), and the LO position (P: 24 positions) as the independent variables. Since the cells in the four right-most columns in Figure 2 were not included in the 5:5 aspect ratio configuration, we adopted only 24 cells in the column 1 to 5 for the analysis. Table 1 shows the result of the multivariate ANOVA indicating significant main effects of the LO position (P) and the RO size (R).

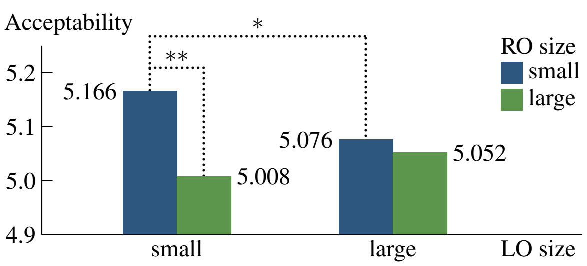


Figure 4: Interaction between object sizes

To investigate the effect of the aspect ratio (A) and the RO size (R) at each LO position (P), we conducted multiple comparisons for the interactions, P-A and P-R. The result of the multiple comparisons (Bonferroni’s method) is shown in Table 2. Table 2 reveals that the effect by the RO size (R) is

Table 2: Result of multiple comparisons (Experiment 1, Bonferroni’s method)

| P | A | R |
|---|---|---|
| A2 | 0.967 | 0.000** |
| A3 | 0.657 | 0.450 |
| A4 | 0.111 | 0.422 |
| A5 | 0.066 | 0.098 |
| B1 | 0.839 | 0.082 |
| B2 | 0.589 | 0.982 |
| B3 | 0.035* | 0.079 |
| B4 | 0.003** | 0.660 |
| B5 | 0.864 | 0.945 |
| C1 | 0.106 | 0.002** |
| C2 | 0.065 | 0.521 |
| C3 | 0.092 | 0.463 |
| C4 | 0.082 | 0.450 |
| C5 | 0.365 | 0.713 |
| D1 | 0.898 | 0.702 |
| D2 | 0.245 | 0.081 |
| D3 | 0.023* | 0.108 |
| D4 | 0.079 | 0.545 |
| D5 | 0.212 | 0.176 |
| E1 | 0.828 | 0.394 |
| E2 | 0.450 | 0.663 |
| E3 | 0.001** | 0.800 |
| E4 | 0.002** | 0.323 |
| E5 | 0.001** | 0.251 |

($** : p < .01$, $* : p < .05$)

particularly significant at the A2 and C1 positions, namely the positions close to the horizontal and vertical axes. Figure 4 shows the average ratings for the combinations of the RO and LO sizes, indicating that the smaller RO size tends to give higher ratings. In addition, the small LO with the small RO gives the highest ratings.

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|
| E | 3.18<br>2.88<br>3.06 | 4.97<br>4.71<br>4.79 | 5.79<br>5.76<br>5.24 | 6.44<br>5.88<br>5.88 | 6.53<br>6.41<br>6.29 | 6.50<br>6.12 | 6.50<br>6.15 | 6.00 | 6.06 |
| D | 3.32<br>3.24<br>3.44 | 5.06<br>5.03<br>5.15 | 6.12<br>6.15<br>6.12 | 6.62<br>6.50<br>6.32 | 6.15<br>6.24<br>6.26 | 5.85<br>6.09 | 5.68<br>5.82 | 5.88 | 5.44 |
| C | 3.85<br>3.68<br>3.59 | 6.09<br>6.06<br>5.59 | 6.59<br>6.44<br>6.47 | 6.12<br>6.06<br>6.21 | 5.76<br>5.79<br>5.85 | 5.35<br>5.50 | 5.24<br>5.44 | 5.18 | 4.91 |
| B | 2.26<br>4.38<br>4.03 | 6.59<br>6.62<br>6.44 | 5.53<br>5.59<br>6.09 | 5.03<br>5.21<br>5.29 | 5.12<br>4.56<br>4.82 | 4.62<br>4.59 | 4.15<br>4.62 | 4.21 | 4.11 |
| A | | 3.74<br>4.00<br>3.71 | 3.53<br>3.47<br>3.44 | 3.09<br>3.38<br>3.26 | 2.65<br>2.91<br>3.32 | 2.94<br>2.91 | 2.41<br>2.85 | 2.32 | 2.29 |

Figure 5: Overlaid spatial template of three aspect ratios (Experiment 1, R=large and L=large)

**Discussion** Although there is no significant main effect of the background aspect ratio (A) in Table 1, several positions show a significant main effect of the aspect ratio in Table 2, i.e. B3, B4, D3, E3, E4 and E5. Among these positions, the ratings for the positions above the reference axis of “upper right”, i.e. the 45° line, (D3, E3, and E4) were the highest with the aspect ratio 5:5. In contrast, the ratings for the positions below the reference axis (B3 and B4) were the highest with the aspect ratio 5:9. This tendency was observed at other cells. Figure 5 shows an overlaid spatial template for “upper right” with different background aspect ratios (5:5, 5:7 and 5:9, i.e. three templates in Figure 3). The upper, middle and lower figures in a cell denote the acceptability ratings for the background aspect ratio 5:5, 5.7 and 5.9 respectively. The red coloured cells denote the reference axis for “upper right” and the dotted line denotes the diagonal line of the background with aspect ratios 5:7 and 5:9. This figure suggests that although the reference axis for “upper right” remains at the 45° direction regardless of the background aspect ratio, the acceptability for the positions below the reference axis is affected by the boundary of the background, i.e. the diagonal line of the background.

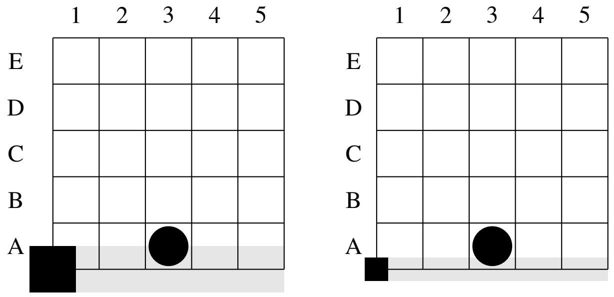


Figure 6: Effect by the RO size (Experiment 1)

Considering the earlier research results (Gapp, 1995; Regier & Carlson, 2001; Kobayashi, Terai & Tokunaga, 2008), given a fixed size of the background, a larger RO is expected to give a higher average rating, since the good region would enlarge according to the RO size. Figure 4, however, indicates the opposite result; the smaller RO gives the higher average rating. This would be explained by the effect of other spatial relations, “above” and “right” in this case. A larger RO enlarges the good region for “above” and “right” as well as that for “upper right”. Considering the oblique effect, the orthogonal (“above” and “right”) relations would be dominant over the diagonal (“upper right”) relation, thus the enlargement of the good region for the diagonal relation would be suppressed by those of the adjacent orthogonal relations. The main effect of the RO size at positions A2 and C1 in Table 2 also supports this hypothesis. Figure 6 illustrates this explanation. When the RO is large (the left figure), the centroid of the LO is at the edge of the good region for “right” (the gray area), while when the RO is small (the right figure), the LO centroid is out of the good region. Thus, the acceptability of “rightness” in the right figure could be lower than that in the left figure, and the good region for “right” interferes less with that of “upper right”. This hypothesis would explain the reason why the small RO gave a higher rating.

The interaction between the RO and LO sizes can be also explained in terms of the interference by the good region of the adjacent orthogonal spatial relations. As Figure 4 shows, when the RO is small, the average rating for the small LO is significantly higher than that for the large LO ($p < .05$), and

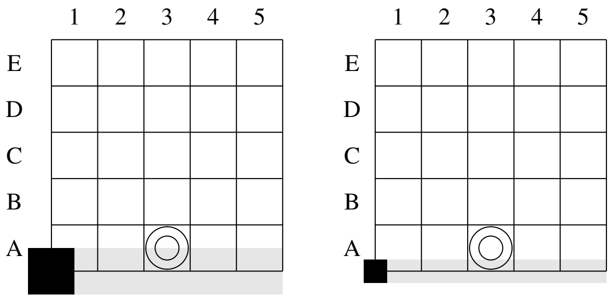


Figure 7: Interaction between the RO and LO sizes

when the LO is small, the average rating for the small RO is significantly higher than that for the large RO ($p < .01$). Figure 7 illustrates the explanation for this observation. Two LOs are depicted as white circles in the same cell for comparison. The centroid of the LOs moves relative to the good region for “right” according to the combination of object sizes. When the RO is small (the right figure), the centroid of the LOs is out of the good region for “right”, and the overlapping area between the LO and the good region drastically decreases as the LO becomes small (the inner circle). Actually, there is no overlap in this case. When the RO is large (the left figure), the centroid of the LOs is at the edge of the good region, and the difference of overlapping areas is less than that of the small RO case. The ratios of the overlap against the LO are the same; both overlapping areas are half of the object sizes. Thus, the good region for “right” has less effect on the good region for “upper right”. That leads to the higher average rating for the small RO and LO. Table 2 shows a significant difference by the RO size (R) at the lowest horizontal cell (A2), which falls into the good region for “to the right of the RO”. The difference is also significant at the leftmost vertical cell (C1), which falls into the good region for “above the RO”. These significant interactions support the above explanation. In summary, we have drawn a hypothesis that since orthogonal relations are dominant over diagonal relations, the good region of the former would interfere with that of the latter. We conducted a follow up experiment in order to verify this hypothesis, which is described in the next section.

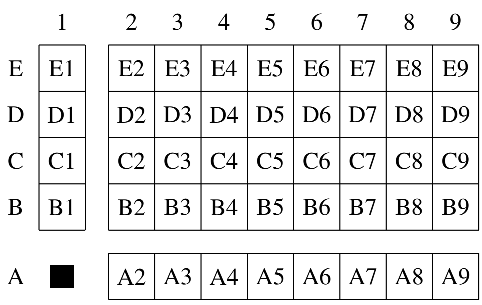


Figure 8: Grid configuration for reference objects (Experiment 2)

## Experiment 2

### Method

**Participants** Thirty three graduates and undergraduates (28 males and 8 females) from Tokyo Institute of Technology participated in the follow up experiment. There was no overlap in participants between the two experiments. Each participant received 1,000 JPY for his/her participation. All participants were native Japanese speakers.

**Material and design** The experimental setup is the same as Experiment 1 except for the grid configuration. In Experiment 2, the position of the RO was shifted by 50 pixels both downward and leftward as shown in Figure 8. The column 1 and row A were also shifted accordingly. This configuration is more similar to that of Logan and Sadler (1996) than the configuration of Experiment 1. The procedure of the experiment is the same as that of Experiment 1.

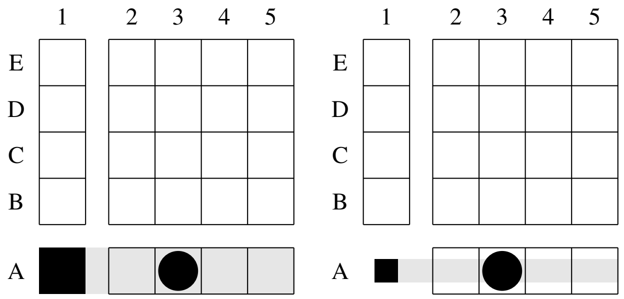


Figure 9: Effect by the RO size (Experiment 2)

| | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| E | 1.54 | 4.84 | 5.91 | 6.36 | 6.73 |
| D | 1.30 | 5.39 | 6.15 | 6.76 | 6.30 |
| C | 1.42 | 6.15 | 6.79 | 6.18 | 5.82 |
| B | 1.33 | 6.90 | 6.03 | 5.24 | 5.09 |
| A | – | 1.57 | 1.24 | 1.39 | 1.30 |

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| E | 1.30 | 4.94 | 5.70 | 6.36 | 6.61 | 6.64 | 6.70 |
| D | 1.30 | 5.24 | 6.15 | 6.55 | 6.64 | 6.42 | 5.97 |
| C | 1.24 | 5.70 | 6.76 | 6.45 | 6.21 | 5.73 | 5.55 |
| B | 1.42 | 6.85 | 6.06 | 5.55 | 5.00 | 4.42 | 4.76 |
| A | – | 1.42 | 1.33 | 1.33 | 1.39 | 1.33 | 1.67 |

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|
| E | 1.36 | 4.88 | 5.48 | 6.21 | 6.58 | 6.48 | 6.39 | 6.42 | 6.30 |
| D | 1.45 | 5.33 | 6.24 | 6.61 | 6.70 | 6.24 | 6.15 | 5.55 | 5.76 |
| C | 1.36 | 6.06 | 6.64 | 6.48 | 6.12 | 5.73 | 5.61 | 5.39 | 5.00 |
| B | 1.30 | 6.73 | 6.52 | 5.52 | 5.06 | 4.97 | 4.94 | 4.70 | 3.97 |
| A | – | 1.36 | 1.33 | 1.39 | 1.42 | 1.36 | 1.42 | 1.33 | 1.30 |

Figure 10: Spatial template for "*migiue* (upper right)" (Experiment 2, R=large, L=large)

If our hypothesis is correct, the effect of the RO size and the interaction between the RO and LO sizes would disappear because the relative position of the LO centroid does not vary even though the RO size changes as shown in Figure 9.

Table 3: Result of four-way (A, R, L, P) ANOVA (Experiment 2)

| Effect | DFn | DFd | F | $p$ |
|---|---|---|---|---|
| A | 2 | 64 | 0.690 | 0.505 |
| R | 1 | 32 | 0.019 | 0.891 |
| L | 1 | 32 | 0.846 | 0.365 |
| P | 23 | 736 | 551.9 | 0.000** |
| A-R | 2 | 64 | 2.948 | 0.060 |
| A-L | 2 | 64 | 0.064 | 0.938 |
| R-L | 1 | 32 | 3.518 | 0.070 |
| A-P | 46 | 1472 | 2.954 | 0.000** |
| R-P | 23 | 736 | 1.242 | 0.228 |
| L-P | 23 | 736 | 1.890 | 0.026* |
| A-R-L | 2 | 64 | 1.618 | 0.206 |
| A-R-P | 46 | 1472 | 1.300 | 0.129 |
| A-L-P | 46 | 1472 | 1.107 | 0.323 |
| R-L-P | 23 | 736 | 0.619 | 0.855 |
| A-R-L-P | 46 | 1472 | 0.530 | 0.973 |

($** : p < .01$, $* : p < .05$)

**Result** Figure 10 shows the spatial templates for "upper right" with three different aspect ratios. The other conditions are the same as Figure 3. In this configuration, the participants tend to give very low ratings in the horizontal and vertical aligned cells, i.e. column 1 and row A. This is obviously because these cells are completely located within the good region for "above" and "right".

**Analysis and discussion** We conducted a four-way ANOVA in the same manner as Experiment 1. Table 3 shows the result of the multivariate ANOVA. As we expected, the main effect of the RO size (R) and the interaction between the RO and LO size disappeared. This supports our hypothesis described in the previous section.

## General discussion

The present study discussed the acceptability of the LO positions for a Japanese diagonal spatial term "*migiue* (upper right)" based on the empirical data. The data was collected through the experiments taking into account three geometrical factors: the size of RO and LO, and the background aspect ratio. Our findings through the data analysis can be summarised as follows.

- The reference axis of "*migiue* (upper right)" stays at the direction of 45° even though the aspect ratio of the background varies. This seems robust as far as the aspect ratios used in the experiments (5:5, 5:7 and 5:9). However, according to the horizontal extension of the background, the acceptability of the area below the reference axis tends to be higher, and that of the area above the reference axis tends to be lower. This would be the effect by the diagonal line of the background. This tendency is particularly remarkable in the distant area.

Interestingly, this observation is contrary to the finding by Gapp (1995), which claimed that the acceptability was not affected by the distance, although it became slightly higher when the LO was close to the RO within the area where the angular deviation from the reference axis is less than 45°. In our data, the angular deviation is less than 45° in all positions, but the distant positions tend to show higher acceptability. For instance, the pairs of cells A2 and B5, and B1 and E2 have the same angular deviation from the reference axis, about ±26.5°. As Figure 3 shows, the ratings of the distant positions (B5 and E2) are consistently higher than that of the close positions (A2 and B1) in all aspect ratios. An ANOVA on the average ratings at these four positions showed a main effect of the distance ($F(1,33) = 20.2,\ p < .01$).

- The acceptability of the diagonal spatial relation is affected by the adjacent orthogonal spatial relations. In our case, the acceptable regions of "above" and "right" interfere with the acceptability of "upper right". This hypothesis was confirmed by the main effect of the RO size, and the interaction between the RO and LO size.

  The above-mentioned contradiction between the results of ours and Gapp (1995)'s would be also explained by the interference by the orthogonal relations. The closer the LO is to the RO, the closer the LO is to the reference axis of the adjacent orthogonal relations ("above" and "right") as well, thus the acceptability would be affected more by the orthogonal relations.

Considering these findings together, we would say that the acceptability of diagonal spatial terms is determined by the interaction among four axes, namely, the horizontal axis, the virtical axis, the diagonal axis at 45° and the diaglonal axis of the background. Among these axes, the two orthogonal axes are most dominant as past studies suggested. The diagonal axis of the background seems most recessive but still affects the diagonal axis at 45°.

Future research directions include the evaluation of existing computational models for spatial relations against the diagonal spatial relations. According to our preliminary experiments in which the Proximal and Centre-of-mass model and Attention Vector Sum model (Regier & Carlson, 2001) were applied to our data for "upper right" with setting its reference axis at 45°, these models fit quite well to the data. We found, however, the deviation from the data enlarged as the deviation of the diagonal axis of the background from the reference axis at 45° increased. As described above, these two diagonal axes should be taken into account in these computational models for diagonal spatial terms. We need further investigation to determine the quantitative effect of the interaction of these axes on the acceptability of the diagonal relations for building a computational model.

## References


Appelle, S. (1972). Perception and discrimination as a function of stimulus orientation – oblique effect in man and animals. *Psychological Bulletin*, *78*(4), 266-278.

Carlson-Radvansky, L. A. (1997). The influence of reference frame selection on spatial template construction. *Journal of Memory and Language*, *37*(3), 411-437.

Carlson-Radvansky, L. A., & Jiang, Y. (1998). Inhibition accompanies reference-frame selection. *Psychological Science*, *9*(5), 386-391.

Coventry, K. R., & Garrod, S. C. (2004). *Saying, seeing, and acting*. Psychology Press.

Crawford, L., Regier, T., & Huttenlocher, J. (2000). Linguistic and non-linguistic spatial categorization. *Cognition*, *75*(3), 209-235.

Furmanski, C. S., & Engel, S. A. (2000). An oblique effect in human primary visual cortex. *Nature Neuroscience*, *3*(6), 535-536.

Gapp, K.-P. (1995). Angle, distance, shape, and their relationship to projective relations. In *Proceedings of the 17th annual conference of the cognitive science society* (p. 112-117).

Hayward, W. G., & Tarr, M. J. (1995). Spatial language and spatial representation. *Cognition*, *55*, 39-84.

Herskovits, A. (1985). Semantics and pragmtics of locative expressions. *Cognitive Science*, *9*(3), 341-378.

Huttenlocher, J., Hedges, L. V., Corrigan, B., & Crawford, L. E. (2004). Spatial categories and the estimation of location. *Cognition*, *93*(2), 75-97.

Huttenlocher, J., Hedges, L. V., & Duncan, S. (1991). Categories and particulars: Prototype effects in estimating spatial location. *Psychological Review*, *98*(3), 352-376.

Kobayashi, T., Terai, A., & Tokunaga, T. (2008). The role of attention in understanding spatial expressions under distractor condition. In *Proceedings of the 5th international workshop on natural language processing and cognitive science (NLPCS 2008)* (p. 74-83).

Levinson, S. C. (2003). *Space in language and cognition*. Cambridge University Press.

Logan, G. D., & Sadler, D. D. (1996). A computational analysis of the apprehension of spatial relations. In P. Bloom, M. A. Peterson, L. Nadel, & M. F. Garrett (Eds.), *Language and space (language speech and communication)* (p. 493-529). The MIT Press.

Meng, X., & Qian, N. (2005). The oblique effect depends on perceived, rather than physical, orientation and direction. *Vision Research*, *45*(27), 3402-3413.

Regier, T., & Carlson, L. A. (2001). Grounding spatial language in perception. *Journal of Experimental Psychology: General*, *130*(2), 273-298.

Talmy, L. (1983). How language structures space. In J. Herbert L. Pick & L. P. Acredolo (Eds.), *Spatial orientation – theory, research, and application* (p. 225-282). Plenum Press.

Tversky, B., & Lee, P. U. (1998). How space structures language. In *Spatial cognition* (Vol. LNCS 1404, p. 157-175). Springer.