An approach to formalising relationships between speaker-relative and absolute spatial reference systems

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Abstract

There has been extensive empirical research in cognitive linguistics exploring different reference systems used to describe spatial situations across different cultures. It has been suggested that speaker relative and absolute spatial reference systems seem to be interchangeable. This report discusses speaker-relative and absolute spatial reference systems in terms of left-right systems and cardinal directions. An approach to formalising some of the relationships between both systems is proposed. We plan to provide an extension to this limited formalisation in a way which could enable automatic interchangeability between the systems of reference discussed within the (Human-Computer) interface of Geographic Information Systems. Natural language interfaces to navigation systems could be a very interesting application of such an extended formalisation.

Keywords: Spatial Reasoning, Cognitive Structure of Spatial Knowledge, Spatial Reference Systems

Introduction

There has been extensive empirical research in cognitive linguistics exploring different reference systems used to describe spatial situations across different cultures.

As for main stream European linguistics, the focus has clearly been on speaker-relative reference systems. One example is Landau and Jackendoff's (1993) egocentric axes model. Considering that most objects have a top and a bottom, a front and a back, and sides and/or ends, they differentiate three layers of axes, the generating axis, orienting axes and directed axes. The generating axis is the principal axis, which is vertical in case of a human. The orienting axes are orthogonal to the generating axis and to each other, they assemble the front-to-back and side-to-side directions. Finally, the directed axes indicate inherent regularities that distinguish one end from the other (i.e. top from bottom, front from back). Figure 1 illustrates the axes model.

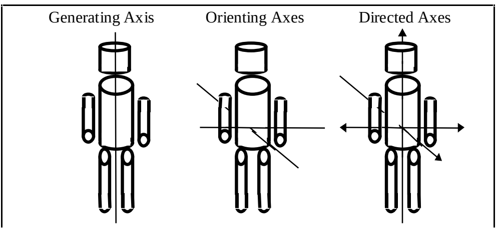

Fig. 1 Landau and Jackendoff's Axes (1993)

Similar to Landau and Jackendoff (1993), Vorweg and Rickert (1998) discussed the typicality effects in the categorisation of spatial relations. Based on psychological evidence, they identified LEFT, RIGHT, IN-FRONT, BEHIND, ABOVE and BELOW as preferred directions in perception. The LEFT-RIGHT, FRONT-BEHIND and ABOVE-BELOW axes and their origin establish a deictic frame of reference dependent on the point of view superimposed.

Psychological evidence suggests that there are natural spatial categories such as the relative orientation relations (i.e. speaker-relative reference system) mentioned above. However, some cultures use absolute orientation relations in everyday life

The example we will use in this report was taken from Pederson (1993). He discusses the linguistic and conceptual contrasts between speaker-relative and absolute spatial reference using the example of urban and rural Tamil speakers. He chose subjects from the same cultural area to avoid encountering differences in the linguistic reference systems caused by cultural differences. Urban Tamil speakers use the cardinal directions (i.e. NSEW) exclusively for describing large-scale (i.e. geographic) space and the left-right system for manipulable spaces (i.e. table-top or local spaces), while rural Tamil speakers use NSEW with both large-scale and table-top spaces. Many other rural cultures also use absolute reference systems, for example, many Australian languages are known for using cardinal directions to describe both geographic and local spaces [e.g. Levinson 1997].

This gives rise to the assumption that there could be natural spatial categories underlying both the absolute and the relative reference systems.

The previous assumption is supported by Pederson (1993) suggesting that speaker-relative and absolute spatial reference systems seem to be interchangeable. This report discusses an approach to formalising the relationships between speaker-relative and absolute reference system (from a main stream European linguistic perspective) based on existing models of qualitative spatial reasoning reviewed in the following section.

Previous Research

Some approaches to qualitative spatial reasoning have been based on methods developed for temporal reasoning purposes such as Allen's interval calculus. Allen (1983) introduced an interval calculus for dealing with qualitative temporal information by describing comparative relations between time intervals. This idea has frequently been extended to represent binary topological relations between spatial regions [e.g. Guesgen 1989, Egenhofer 1991].

Freksa (1992) generalised Allen's interval calculus to be applicable to semi-intervals (beginning or endings of events). He also introduced the notion of conceptual neighbourhood of qualitative relations, which is motivated by physical constraints on perception.

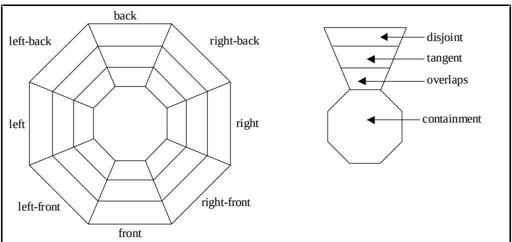

Fig. 2. Overview Model by Hernández

Hernández (1994) suggested a qualitative representation of positional information, which is called overview model in the following. The model divides spatial relations into two classes, called the orientation relation and the topological relation. For the orientation relation, the space around each object is divided into eight sub-spaces: back, right-back, right, right-front, front, left-front, left, left-back (see figure 2). The topological relation is added to each sub-space to describe how the boundaries of the direct neighbours relate (i.e. if they overlap, touch or do not touch each other).

The sub-spaces can be used to reason about the position of a reference object (e.g. a robot moving through space) with respect to other objects in the scene.

Of course, rotating the reference object in the horizontal space will effect the orientation of the reference object. Habel (1998) gives a detailed account on the effects on the human orientation while rotating around the principal axis using the example of the German word *drehen* (i.e. rotate). In order to formally describe rotation, he defines left and right rotation along an elementary curve c (as defined in Eschenbach and Kulik 1997).

We would like to propose a formalisation of the interchangeability between speaker-relative and absolute reference system also incorporating the effects of rotation.

Relative versus Absolute Reference System

As discussed before, linguistically encoded spatial reference can vary significantly across languages and cultures. There are two basic types of spatial reference: similar systems which are grounded on the same basic terms and contrasting types of systems which are organised with significantly different terms. The first "type of system determines reference by dividing the world into regions which are extensions from the body of the speaker. [...] These regions necessarily shift as the speaker shifts the alignment or location of his or her body. That is, they are *perspective dependent*." (Pederson 1993, pp. 294-295) We will call such systems speaker-relative or relative reference systems. One such relative reference system is as mentioned before the left-right system. The second type of reference system is "an absolute or *perspective-independent* system of spatial reference. [...] There are many different types[1] of absolute systems which all describe the relationship of two locations in such a way that the position of the speaker and hearer are irrelevant. The systems make reference to commonly agreed upon 'directions' which will always remain constant throughout the world commonly encountered by the speakers." (Pederson 1993, p. 295)

Hernández (1994) used a relative reference system to describe the orientations. Therefore his model had to consider the effects of change of perspective and reference frame. He gives a brief account on reference frames in terms of three different types: intrinsic, extrinsic and deictic reference frames. The orientation is given by some inherent property of the reference object when using intrinsic reference frames, e.g. the front of a chair is inherently determined by the chair's functionality. External factors impose an orientation on the reference object when the orientation is given with respect to an extrinsic reference frame. And lastly, "when the orientation is imposed by the point of view from which the reference object is seen ([... e.g.] from the speaker's point of view)"[2], we consider the reference frame deictic.

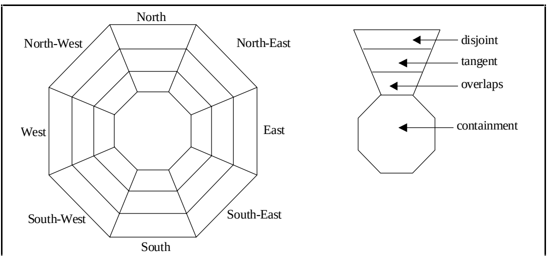

Fig. 3. Adapted Overview Model for absolute Orientation Relations

For the purpose of this report and also, because we base our illustration on Hernández's model which uses an intrinsic reference frame, we will use an intrinsic reference frame for describing relative spatial relations between objects in the later following illustration of our formalisation approach.

Hernández laid out the relative orientation relations as regions in his overview model.

The cardinal directions can be represented in a similar way (see figure 3). It needs to be added that the absolute system will not be rotated with the rotation of the inherent front of the reference object as it is the case for the relative orientations. In other words, the containment in the model can rotate (taking the relative orientations "with it") while the absolute regions remain constant with respect to the absolute reference (i.e. cardinal directions).

Landau and Jackendoff (1993) identified *back* to *front* as an inherent direction for humans, because this is the common direction in which we move. Similar to the previously described axes system, the absolute orientation could also be seen as having an inherent direction. The cardinal directions could be seen as some sort of landmarks defined by the sun's movement. As the sun moves from the East to the West, this movement direction approximately determines the cardinal directions.

As for this report, we will consider the horizontal axes only and topological information will be neglected for simplification's sake and because it can easily be added at a later point of time if necessary.

[1] e.g. cardinal directions, uphill-downhill systems

[2] Hernández 1994, p. 45

Illustration of the Formalisation Approach

As mentioned before, it has been suggested that the relative and the absolute reference systems seem to be interchangeable. We would like to formalise this interchangeability and formalise it in logic expressions. Those laying the foundations for possible applications to for example natural language interfaces to navigation systems and Geographic Information Systems. For the illustration of our formalisation approach, the following premise are defined.

The eight sub-spaces in the overview model can be seen as four main spaces (i.e. left, right, front, back for relative and North, South, West, East for absolute) and four secondary spaces[3] resulting from the overlap of two of the neighbouring main spaces.

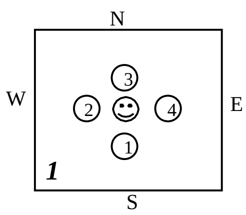

Fig. 6 Example Figure from Appendix I

For the purpose of our illustration, let's suppose that there are four objects, one in each main space. They are the objects to be localised (LO) and are labelled 1 to 4 in the illustration (see figure 6). The reference object (RO) will be a human being with an inherent front placed in different positions within the static object constellation. The RO will be positioned in the centre among all four objects and subsequently within each of all of the eight defined sub-spaces. For each position the RO will be rotated around its principal axis (i.e. the bottom-top-axis as defined by Landau and Jackendoff 1993) in 90° steps[4] resulting in what we will call different perspectives of the RO. For each of the positions the relation of the RO to each of the LOs is determined for the relative reference system (i.e. the relative relation R_r) in an intrinsic reference frame[5] and for the absolute reference system (i.e. the absolute relation R_a). The inherent front of the RO is irrelevant for the absolute reference system. For the relative reference system the four perspectives are taken into account for each position. This means that for each position four different relative relations between the RO and each LO can be determined.

Some of the relations are open to different interpretations, but for the purpose of our illustration, we will use the relations consistently in only one way. Also, the way the LOs are placed in the secondary spaces is open to interpretation, but consistently used only in one way throughout our illustration.

The nine different position possibilities following the outlined premise including the four perspectives of the RO are illustrated in figure 1 to 36 in appendix I.

The following notation has been used in the analysis tables in appendix II:

y	: reference object
x_i	: object i to be localised[6]

[3] i.e. left-back, left-front, right-back, right-front for relative and North-East, North-West, South-East, South-West for absolute

[4] This number is only a cognitive estimate and was chosen, because Pederson (1993) pointed out that, in general, reference systems are effectively equivalent in that they describe relative positions in terms of approximate right angles.

[5] i.e. considering the inherent front of the RO

[6] i is used according to the numbering of the LO in the illustration (appendix I)

$R_r y$: relative orientation relation that the RO y has with the LO x_i (i=1,..,4)
$R_a y$: absolute orientation relation that the RO y has to the LO x_i (i=1,..4).
l,r,b,f : left, right, back, front (respectively)
N,S,E,W : North, South, East, West (respectively)
Fig. k : figure k in appendix I.

Let's take the table for figures 1-4 (see table 1) from appendix II to further discuss the analysis.

$R_r y$	Fig. 1	Fig. 2	Fig. 3	Fig. 4	$R_a y$
x_1	f	l	b	r	S
x_2	r	f	l	b	W
x_3	b	r	f	l	N
x_4	l	b	r	f	E

Table 1. Example Table from Appendix II

As four perspectives (i.e. rotations in 90° steps) are considered for the relative reference system, the relation $R_r y$ can be found in the table within the relevant figure column. For example, in figure 1 appendix I, in which RO has the *Perspective(1)*, which is considered the starting point of the rotation and the rotation angle is therefore 0°, LO 1 (i.e. x_1) is in front of the RO (i.e. y). The four different perspectives incorporating a clockwise rotation can be defined as follows:

Perspective(1)=rotation(0°)
Perspective(j)=Perspective(j-1)+rotation(90°) with j=2,3,4.

The absolute reference system is independent of the perspective of the RO and therefore, there is only one column per LO needed to describe $R_a y$. For example, in figures 1 to 4 appendix I, the LO 1 (i.e. x_1), is South of (i.e. S) the RO (i.e. y).

Based on the perspectives, we can now describe the relationship between the relative and absolute reference system. Similar to Herskovits (1986), we will use a logic description. Pj with j=1,..,4 represents Perspective(j).

The main spaces South, West, North and East and their equivalents using a relative reference system are defined in equation 1 to 4 respectively:

$$\forall x_i \forall y [R_r(x_i, y, f, P_1) \wedge R_r(x_i, y, l, P_2) \wedge R_r(x_i, y, b, P_3) \wedge R_r(x_i, y, r, P_4) \leftrightarrow R_a(x_i, y, S)] \quad \textbf{(1)}$$

$$\forall x_i \forall y [R_r(x_i, y, r, P_1) \wedge R_r(x_i, y, f, P_2) \wedge R_r(x_i, y, l, P_3) \wedge R_r(x_i, y, b, P_4) \leftrightarrow R_a(x_i, y, W)] \quad \textbf{(2)}$$

$$\forall x_i \forall y [R_r(x_i, y, b, P_1) \wedge R_r(x_i, y, r, P_2) \wedge R_r(x_i, y, f, P_3) \wedge R_r(x_i, y, l, P_4) \leftrightarrow R_a(x_i, y, N)] \quad \textbf{(3)}$$

$$\forall x_i \forall y [R_r(x_i, y, l, P_1) \wedge R_r(x_i, y, b, P_2) \wedge R_r(x_i, y, r, P_3) \wedge R_r(x_i, y, f, P_4) \leftrightarrow R_a(x_i y, E)] \quad \textbf{(4)}$$

The definitions for the secondary spaces are the combinations of the definitions of the main spaces considering the preferred directions (i.e. back to front for relative and East to West for absolute). In other words, the preferred direction will be specialised by the other two directions (i.e. left and right for relative or North and South for absolute). For example, the secondary space created by left and back space overlapping, would be called left-back[7] (lb) or North and West overlapping would be called North-West (NW). For the following logical description of secondary spaces, the operator $\oplus$ stands for overlap, RR_{jk} (k=1,2) stands for the relative relation k in perspective j (j=1,..,4) and C_k (k=1,2) stands for the cardinal direction k.

$$\mathop{R}_{j=1}^{4} {}_r(x_i, y, RR_{j1} \oplus RR_{j2}, P_j) \leftrightarrow R_a(x_i, y, C_1 \oplus C_2) \quad \textbf{(5)}$$

As an example for equation 5, we consider the overlap of South and East resulting in the secondary space South-East. We apply the main space definitions for South (i.e. equation 1) and for East (i.e. equation 4) to equation 5:

$$R_r(x_i, y, f \oplus l, P_1) \wedge R_r(x_i, y, l \oplus b, P_2) \wedge R_r(x_i, y, b \oplus r, P_3) \wedge R_r(x_i, y, r \oplus f, P_4) \leftrightarrow R_a(x_i, y, S \oplus E)$$

The resulting description is:

$$R_r(x_i, y, lf, P_1) \wedge R_r(x_i, y, lb, P_2) \wedge R_r(x_i, y, rb, P_3) \wedge R_r(x_i, y, rf, P_4) \leftrightarrow R_a(x_i, y, SE)$$

The final description can be verified in the analysis tables in appendix II.

Conclusion and Outlook

Our approach formalises the interchangeability between relative and absolute reference system for one particular constellation of objects, but we suggest that this approach could be adapted and used for any constellation as long as consistent interpretations of relationships are applied. The current approach is restricted by fixed positioning of objects and the necessity of having to consider four perspectives (i.e. in 90° rotations) in order to find the appropriate relationships.

We plan to provide an extension to this limited formalisation in a way which could enable automatic interchangeability between the systems of reference discussed within the (Human-Computer) interface of Geographic Information Systems. Natural language interfaces to navigation systems could be a very interesting application of an extended formalisation.

[7] as already defined in Hernández (1994)

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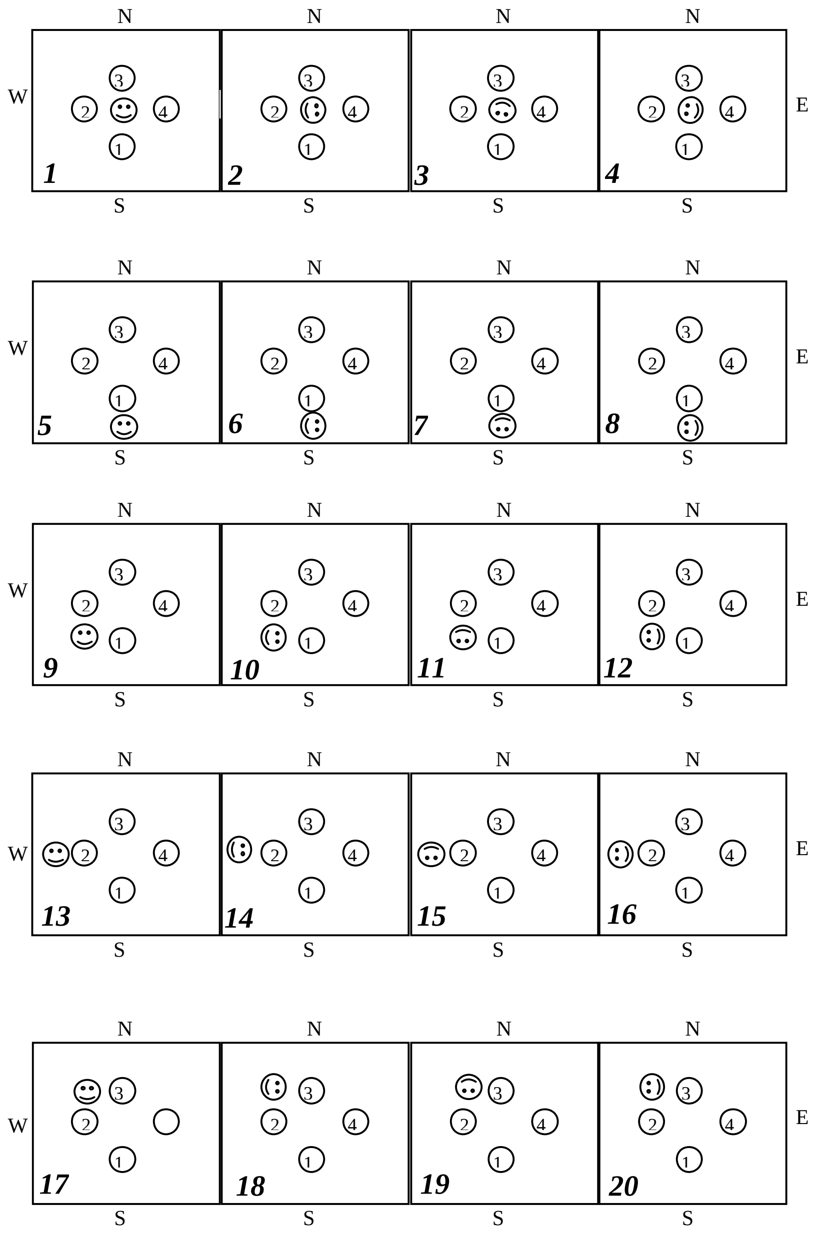
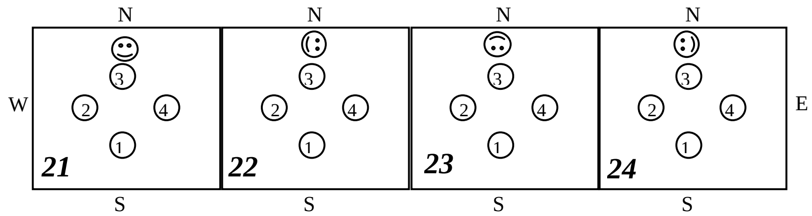
Appendix I

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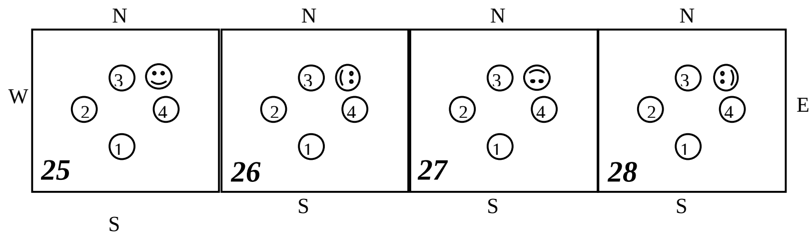
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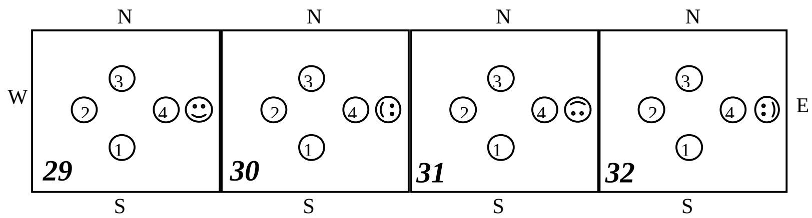
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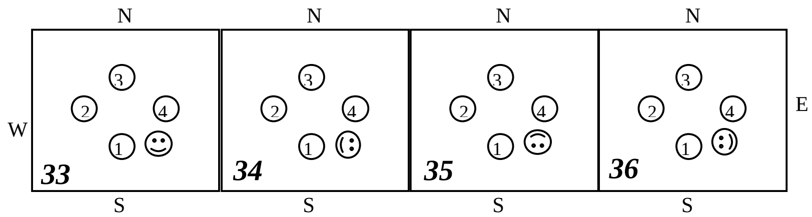
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Appendix II

$R_r y$	Fig. 1	Fig. 2	Fig. 3	Fig. 4	$R_a y$
x_1	f	l	b	r	S
x_2	r	f	l	b	W
x_3	b	r	f	l	N
x_4	l	b	r	f	E

$R_r y$	Fig. 5	Fig. 6	Fig. 7	Fig. 8	$R_a y$
x_1	b	r	f	l	N
x_2	rb	rf	lf	lb	NW
x_3	b	r	f	l	N
x_4	lb	rb	rf	lf	NE

$R_r y$	Fig. 9	Fig.10	Fig. 11	Fig. 12	$R_a y$
x_1	l	b	r	f	E
x_2	b	r	f	l	N
x_3	lb	rb	rf	lf	NE
x_4	lb	rb	rf	lf	NE

$R_r y$	Fig. 13	Fig. 14	Fig. 15	Fig. 16	$R_a y$
x_1	rb	lb	lf	rf	SE
x_2	l	b	r	f	E
x_3	lb	rb	rf	lf	NE
x_4	l	b	r	f	E

$R_r y$	Fig. 17	Fig. 18	Fig. 19	Fig. 20	$R_a y$
x_1	lf	lb	rb	rf	SE
x_2	f	l	b	r	S
x_3	l	b	r	f	E
x_4	lf	lb	rb	rf	SE

$R_r y$	Fig. 21	Fig. 22	Fig. 23	Fig. 24	$R_a y$
x_1	f	l	b	r	S
x_2	rf	lf	lb	rb	SW
x_3	f	l	b	r	S
x_4	lf	lb	rb	rf	SE

$R_r y$	Fig. 25	Fig. 26	Fig. 27	Fig. 28	$R_a y$
x_1	rf	lf	lb	rb	SW
x_2	rf	lf	lb	rb	SW
x_3	r	f	l	b	W
x_4	f	l	b	r	S

$R_r y$	Fig. 29	Fig. 30	Fig. 31	Fig. 32	$R_a y$
x_1	rf	lf	lb	rb	SW
x_2	r	f	l	b	W
x_3	rb	rf	lf	lb	NW
x_4	r	f	l	b	W

$R_r y$	Fig. 33	Fig. 34	Fig. 35	Fig. 36	$R_a y$
x_1	r	f	l	b	W
x_2	rb	rf	lf	lb	NW
x_3	rb	rf	lf	lb	NW
x_4	b	r	f	l	N