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DOCTORAL AND POSTDOCTORAL DISSERTATIONS

A Cognitive Observer-Based Landmark-Preference Model

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1 Introduction

Landmarks, objects for orientation, are frequently used by humans (as well as many other species) for orientation and for navigation to known and unknown rural and urban environments. In 1960 Lynch [4] defined landmarks (in cities) as an important research topic. Ever since, landmarks have been within the research focus of architects, computer scientists, psychologists and many others. Sorrows and Hirtle [9] defined three relevant landmark aspects which are essential for using landmarks in navigation, called saliences. Raubal and Winter [5] as well as Klippel and Winter [3] presented a mathematical model in which they describe the relation between these three saliences and presented first empirical evidences for their assumptions. Additionally, the aspect of visibility was introduced (in its simplest form: how much of an object is visible to the observer). The model thus includes the three saliences, visual (e.g. color), semantic (meaning/typicality) and structural (location), and the visibility. It is formalized as:

$$s_t = v\,(w_v s_v + w_s s_s + w_u s_u),$$

with s_t = total salience, v = visibility, w = weighting factors, s = saliences and $_v$ = visual, $_s$ = semantic and $_u$ = structural.

However, a detailed empirical examination of this model is missing.

My thesis [6] and previous articles [7, 8] focused on the visibility, the visual and structural salience, their interaction, and the weights of these factors. The goal of my Thesis was, to evaluate this model empirical and to define the parameters based on wayfinding and recognition experiments in humans. The semantic salience will be ignored due to the fact that the meaning of an object strongly varies inter-individually (for a detailed explanation of the idiosyncratic meaning in semantic salience see Caduff and Timpf [1]). In order to evaluate the model, each of the relevant factors were examined alone and in combination with all other factors.

2 Experiments

The experimental setting is based on the virtual environment SQUARELAND, which basically consists of orthogonal intersections and squared blocks [2]. Participants saw a series of screenshots of intersections with four (different) landmarks. At each intersection they had to indicate which of these landmarks they would prefer to give route directions to someone who is unfamiliar with this environment/intersection (for an overview of all experimental environments see Fig. 1).

The first series of experiments showed that a landmark which has a color contrast to the surrounding landmarks (e.g. red object surrounded by yellow objects) pops out and will be preferred as a landmark. If each contrasting landmark is presented equally often at each position, the preference over all intersections should be equally distributed (see Table 1). The second experimental series revealed that if all objects have the same or different color(s), and the direction of turn is relevant (left or right), then the position of the landmark in relation to the observer determines the preference. In all these experiments landmarks located before the intersection and in the direction of the turn are the preferred ones (see Table 1). In series three the results

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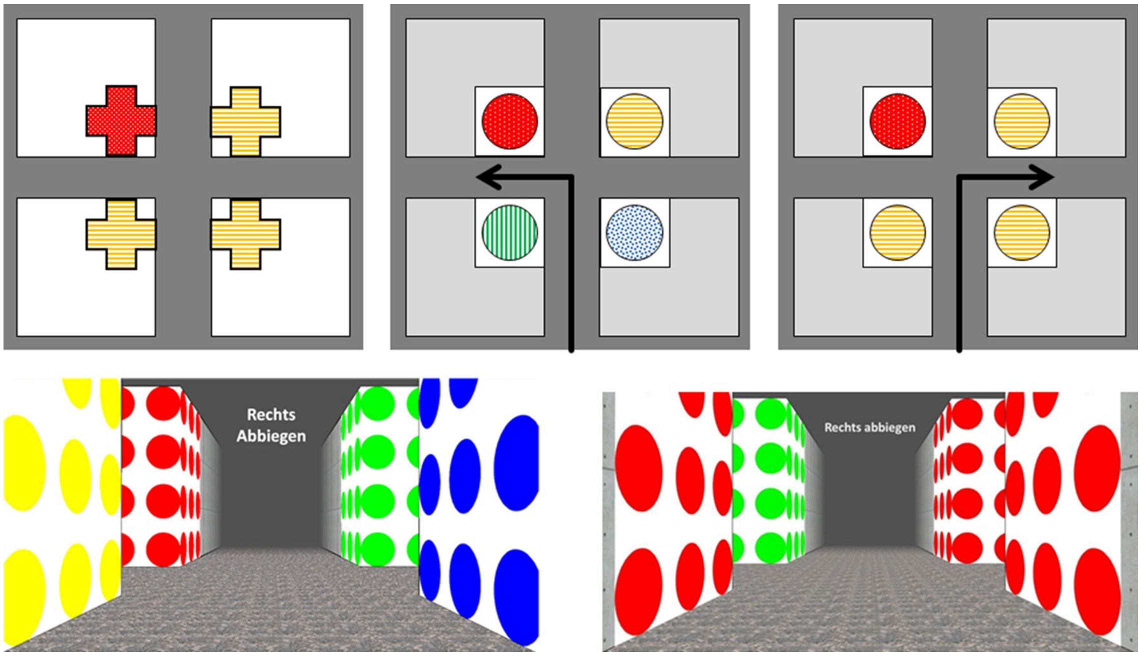

Fig. 1 *Top row, left* exemplary screenshot of a series 1 experiment (visual salience). Allocentric perspective of a Squareland intersection with three identical objects and one that differs. *Center* exemplary screenshot of series 2 experiment (structural salience). Allocentric perspective, four different objects and the direction of turn is shown by an *arrow*. *Right* exemplary screenshot of a series 3 experiment (visual and structural salience). Allocentric perspective, three identical and one different object and an *arrow* showing the direction of turn. *Bottom row, left* exemplary screenshot of a series 4 experiment (structural salience and visibility). Egocentric perspective, four different objects and the verbal instruction (rechts abbiegen = turn right) for the direction of turn. *Right* exemplary screenshot of the final experiment (visual and structural salience and visibility). Egocentric perspective, three identical and one different object, and the verbal instruction (rechts abbiegen = turn right) for the direction of turn

Table 1 Results of the experiments

	Preferred landmark positions in %				
	Series 1: visual salience[a]	Series 2: structural salience[b]	Series 3: visual and structural salience[c]	Series 4: structural salience and visibility[d]	Visual, structural salience and visibility[e]
Behind the intersection, opposite the direction of turn	25	04.64	13.75	06.66	12.28
Behind the intersection, in the direction of turn	25	19.13	20.31	36.25	30.69
Before the intersection, opposite the direction of turn	25	04.21	15.63	04.89	12.50
Before the intersection, in the direction of turn	25	72.02	50.31	52.45	44.53

[a]Derived distribution; each contrast object was presented equally often at each position

[b]Accumulated over all experiments of these series

[c]Results of one prototypical experiment

[d]Results of one prototypical experiment

[e]Results of the last experiment

showed that if one object differs from the surrounding and the direction of turn is relevant, the participants combine both saliences (visual and structural). So, the preferred landmarks (over all intersections) differ from the preference of the pure visual salience as well as from the pure structural salience. However, how the participants weighted the two saliences may not be answered.

Until now all intersections were presented in an allocentric (bird-eye) perspective in which the view-position of the observer does not influence the participant's preference. In the following series of experiments an egocentric (first-person) perspective was used and the direction of turn was relevant. In the fourth series the position of view determines what was visible of the individual landmarks. The preference in this perspective differs from the preferences in the allocentric perspective and the view-position (difference to the middle of the intersection and view angle in relation to the middle of the intersection) also influences the preference. This is the influence of the visibility. In the last experiment the influence of the visual and structural salience in combination with the visibility was tested. Here the results showed again that all three aspects are considered and combined.

3 Mathematical Model and Conclusion

In all these experiments the preferences of the participants varied depending on the visual and structural salience of the objects as well as the view-position. In conclusion, the empirical findings showed that a revision of the mathematical model is necessary. First, the weighting factors must be defined and second, the visibility needs a definition based on the empirical findings. To adapt the model an iterative method (Newton's method) was used to define the weighting factors. Theoretical assumptions based on the literature, empirical findings and the participants' reports led to the new concept of visibility: the viewpoint-based salience. Thus, my "cognitive observer-based landmark-preference model" looks as follows:

$$s_t = 0.616\left(d * o * v_{vis} * s_u\right) + 0.384 s_v \text{ with}$$

$$vpbs = d * o * v_{vis},$$

with s_t = total salience, s_u = structural salience, s_v = visual salience, $vpbs$ = viewpoint-based salience, d = distance, from the person's point of view to the object's center on a straight line (normally there are more than one landmark, than $d = \frac{|d|}{|d_{max}|}; d \in [0, 1]$), o = orientation, orientation of an object in relation to an observer; relevant is the angle between the view axis (which is in a right angle to the view direction) and the landmark: $o = 1 - \sqrt{\left(1 - \frac{\alpha}{180}\right)^2}$ for $o \in [0, 1]$; v_{vis} = visible part; $v_{vis} = \frac{vp_l}{ts_l}$, for $v_{vis} \in [0, 1]$, with vp_l = visible part of the landmark and ts_l = total size of the landmark.

With this model it is possible to compute the best landmark position for specific locations in a city, if the view direction is known.

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