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Search for Quantitative Parameters of Scan Path of Image Viewing by Biologically Motivated Model

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Abstract: The model of viewing scan path formation to search for quantitative parameters of scan path type is presented. In computer simulations, it was revealed that the structure of artificial scan path (focal or spatial ones) significantly ($p<0,05$) correlates with the number of return fixations of input window on recently viewed image areas. It was revealed that with the decrease of the coefficient of IOR, the model in most cases forms trajectories of focal type. On the contrary, as the coefficient of the IOR increases, model spatial type trajectories dominated. In addition to differences in the number of return fixations of the input window of the model between focal and spatial trajectories, a trend of differences between the two types of model trajectories in the amplitude of window jumps was found. The model assumption about the possibility of a quantitative characteristic of the trajectory structure based on return fixations is confirmed at processing the results of psychophysical tests of free viewing and search for modified fragments of complex images. It was shown that the number of gaze return fixations is significantly ($p<0,05$) higher in tests of free image viewing compared to search tests. The results obtained allow us to consider the probability of return fixations as a quantitative criterion to determine of scan path type.

Keywords: Inhibition and Facilitation of Return, Model of Scan Path, Complex Images, Return Fixations of Input Window

1. Introduction

According to the theory of Active Vision (see for review, [18]), the Yarbus' outstanding results [21] and the scan path theory [16] the structure of the viewing scan paths of images and scenes is considered as an important key to understanding the mechanisms of visual attention. It is assumed that the type of scan path allows us to evaluate the contribution of the dominant type of visual attention (focal or spatial ones). Despite intensive research of this problem using experimental methods and mathematical modelling, many fundamental aspects of it remain unresolved first of all, quantitative parameters of scan path type. Present work is aimed at the search for such parameters by modelling inhibition and facilitation of the return.

2. Overview

Possible participation of mechanisms inhibition and facilitation of return in the realization of different visual functions is discussed in many papers [1, 3, 4, 6 – 10, 14, 15, 20]. More facts are accumulating the phenomena of Facilitation of Return, but up to now the concept of Inhibition of Return has dominated [9, 14]. The oculomotor, endogenous, and exogenous factors that determine the occurrence of the phenomenon of inhibition of return, its spatial and temporal properties are analyzed in detail. It is shown that the ratio of the phenomena of facilitation and inhibition of return and their interaction depends on many factors (including the visual task, the nature of the stimuli used in the experiment, and the method of recording the response of the subjects) and is regulated by the mechanisms of the lower (bottom-up) and upper (top-down) levels [10]. It is assumed that the mechanisms of inhibition of return dominate in solving visual search tasks and examining simple images [6, 9]. On the contrary, the phenomenon of facilitating return is often found when examining complex images and solving complex visual tasks [4, 8]. However quantitative analysis of the contribution of various factors is unknown up to now. The results of our previous studies [12, 17] as well as the results of special studies [5] allows us to propose that properties of eye movements such as return fixations and peculiarities of scan path can be measurable parameters for such analysis.

3. Results and Discussion

The developed model for the formation of the artificial visual scan path while the presentation of images and scenes is based on the model created earlier [13, 17]. Like the previous model, the algorithm for feature map formation and procedure of next fixations choosing for the model input window simulates several properties of real active visual perception, first of all, space-variant representation of input information from center to periphery of the visual field. The new version of the model (Figure 1) has differed from the previous one in some relations.

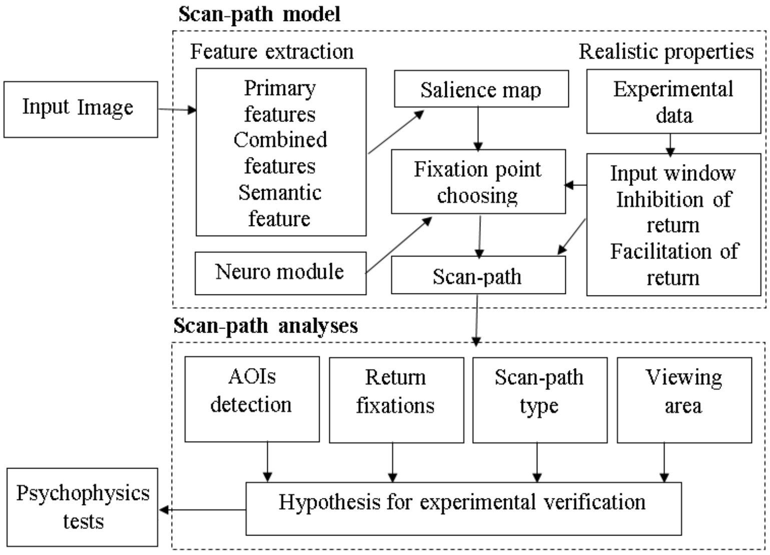

Figure 1. *The basic structure and operations of the model for the formation of artificial visual scan path while viewing images and scenes.*

In particular, the feature map (Figure 2) of viewing image consists of the distribution of many primary features (not only oriented edges) and its combinations (corners, long lines, areas with sharp changes in brightness, etc.), areas of semantically significant objects (people, people's faces, inscriptions, signs), and an algorithm for identification of areas of interest. In both modelling and experimental studies areas of interest were identified by quantitative analysis of the spatial distribution of all fixations using the modified method of the nearest neighbour [17]. The main procedure in the model of scan path formation is to determine the next point and time (the number of model circles) to fix the input window. The sum of all meanings of the feature map is calculated for each node of the model input window identified in its «receptive field». In the single model circle, the value of each point of the feature map in the foveal area of the input window (r=2,5°) is decreased by the meaning of the coefficient of «inhibition of return». The values of the feature map at the current fixation point are increased by the meaning of the coefficient of «facilitation of return» («FOR») after at least 3 shifts of the model input window.

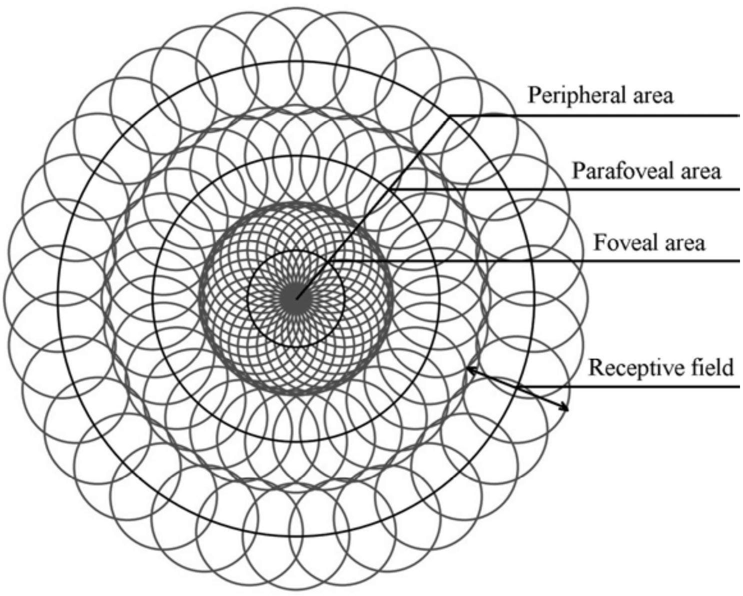

Figure 2. *Scheme of the model input window.*

Center of the input window shifts at the node where the received input is the maximum of all values that exceed the threshold. Thus, a new fixation point is formed, in other case normalized sums of features in each node of the input window are calculated repeatedly, they add to meanings determined on previous model circles. If two nodes of the input window had equal meanings of feature attraction, then the neural network module turns on which takes into account information from context nodes and selects only one node by "winner – take - all" algorithm. The duration of fixation at each point is determined by the number of model circles during which window was located before moving to the next fixation point. The formation of the scan path has been completed after 100 fixations of the model input window.

In biologically motivated models of image viewing, as a rule, an empirical coefficient for inhibition of return is introduced to prevent looping on the model scan paths and the possibility of facilitation of return not taken into account. Formalization of the relationship between facilitation and inhibition of return allows us to develop a more realistic model of image viewing. In our computer simulation, the scan path structure and number of return fixations of the model input window were estimated with varying coefficients of inhibition and facilitation of return, as well as the coefficient of feature attraction. At the present stage, computer simulations are performed to search quantitative parameters while a variation of inhibition of return power. As visual stimuli were used a freeze-frame video clip from Annotated Creative Commons Emotional Database (http://liris-accede.ec-lyon.fr) [2] and reproduction of Shishkin`s painting "Countess Mordvinov's Forest".

It was revealed that with the decrease of the coefficient of IOR, the model in most cases forms trajectories of focal type (Figure 3a). On the contrary, as the coefficient of the IOR increases, model spatial type trajectories dominated (Figure 3b).

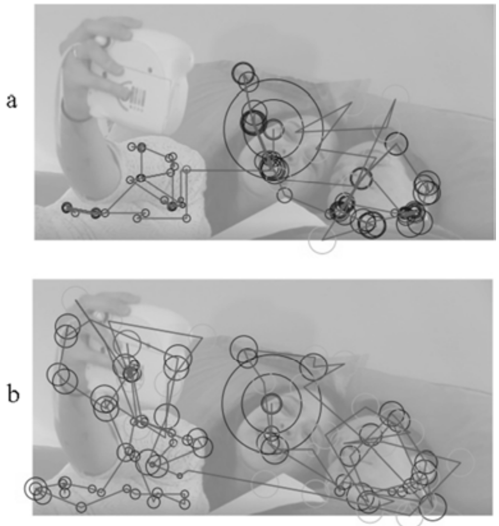

Figure 3. Examples of model scan paths at the processing of still frame of video clip #9748 from LIRIS-ACCEDE database. In both cases, the diameter of small circles is proportional to the fixation duration of the input window in current points. a) scan path of focal type (coefficient of IOR is equal to 1); b) scan path of spatial type (coefficient of IOR is equal to 5).

The probability of return fixations was correlated (Figure 4, Table 1) with the structure of the scan path, it is significantly higher for focal trajectories than for scanning one ($p<0,05$ by the t-Students criteria for independent groups).

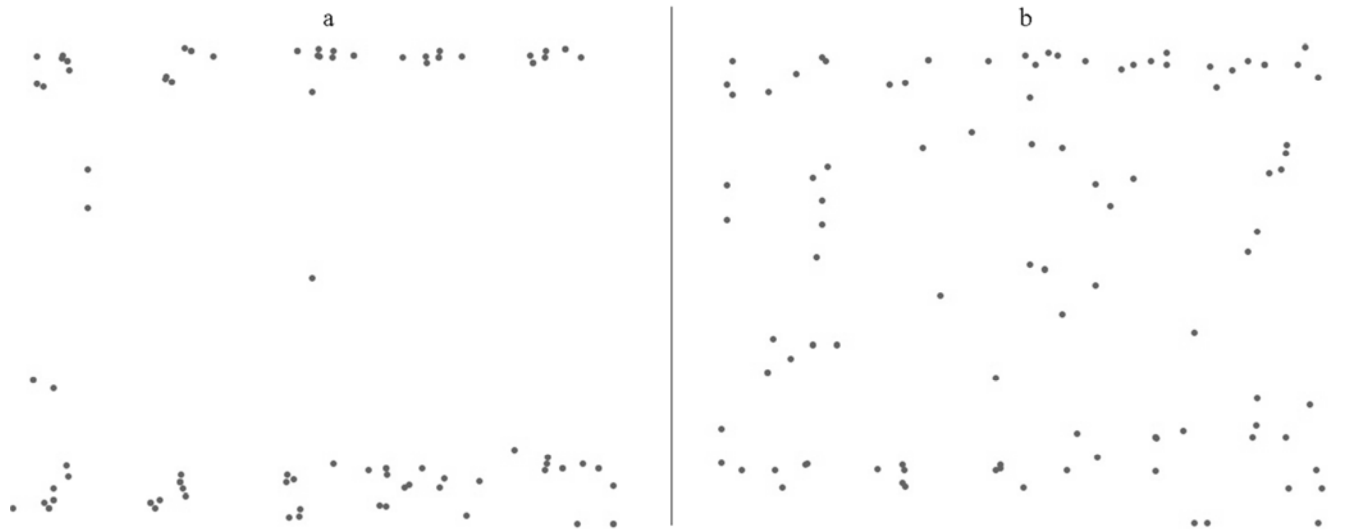

Figure 4. Examples of distributions of return fixations for model scan paths at the processing of reproduction of Shishkin`s painting "Countess Mordvinov's Forest". a) scan path of focal type (coefficient of IOR is equal to 1); b) scan path of spatial type (coefficient of IOR is equal to 5).

Table 1. Dependence of probability of return fixations of the input window from the coefficient of Inhibition of Return.

Coefficient of Inhibition of Return	Probability of return fixations of the model input window
1	0,125
2	0,050
3	0,020
4	0,020
5	0,005

In addition to differences in the number of return fixations of the input window of the model between focal and spatial trajectories, a trend of differences between the two types of model trajectories in the amplitude of window jumps was also found.

The model assumptions were verified by processing the results of our psychophysical tests carried out earlier [12, 13, 17]. We used our experimental data sets obtained on the same sample of volunteers (n=12) when performing two tasks, namely free viewing and the search for modified fragments of three reproductions investigated in detail [21] with various instructions before tests ("Unexpected Return", I. E. Repin; "Countess Mordvinov's Forest", I. I. Shishkin; and "Birch grove", I. I. Levitan). It was revealed that the probability of gaze return fixations was significantly higher during free viewing of images than during solving searching task ($p<0,05$ by the t-Students criteria for independent groups). This result is consistent with the results obtained earlier by other methods, in particular, these two tests differ from each other in the saccade amplitude and the duration of fixations, the number of areas of interest and the square of viewing areas.

It was revealed that the number of model return fixations depend also on the coefficient of feature attraction (Table 2).

Table 2. *Dependence of probability of return fixations of the model input window from the coefficient of feature attraction.*

Coefficient of feature attraction (K_{Fr})	Type of input images	
	Still frames of video clip #9748 from LIRIS-ACCEDE database	Reproduction of Shiskin`s painting "Countess Mordvinov`s Forest"
5	0,08	0,04
10	0,2	0,13
15	0,36	0,14
20	0,35	0,27

4. Conclusion

In computer simulation, it was revealed that the structure of the artificial scan path (focal or spatial one) correlates with the probability of return fixations of the input window. The model assumption about the possibility of the quantitative characteristic of the trajectory structure based on return fixations is confirmed by processing the results of psychophysical tests for free viewing and the search for modified fragments of a complex image, carried out earlier [11- 13]. It was revealed that the number of return fixations significantly more ($p<0,05$ by the t-Students criteria for independent groups) in free viewing tests compare with searching tests. The results obtained allow us to consider the probability of return fixations as a quantitative criterion to determine of scan path type.

In the next stages of research, the contribution of return fixations should be investigated in detail in various experimental conditions in particular for second person neuroscience [19].

Conflict of Interest

The authors declare that they have no conflict of interest.

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