Testing of Perceptual Discriminability in Workflow Diagrams by Eye-Tracking Method

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Abstract. Workflow diagrams are used for the design of steps of the algorithm in spatial processing data in geographic information system (GIS). The colour fills, and various shapes are used for basic symbols in the workflow diagram vocabularies. The Perceptual Discriminability and Visual Expressiveness are two basic principles of the theory Physics Notations. This theory revealed the zero visual distance between yellow Built-in Tool symbol and Script Tool symbol (resp. Sub-model symbol) in ArcGIS ModelBuilder. The eye-tracking experiment tested the influence of increasing the visual distance of symbols in workflow diagrams on the user cognition. The visual distance was increased by a change of fill colour for two mentioned symbols. Eye-tracking measuring brought objective results and affirmed that diagrams, where symbols have better perceptual discriminability, have an average lower time of response, lower number of fixations, and shorter length of scanpath. The result is a recommendation for changes of symbols in the visual vocabulary of ModelBuilder that introduce two new symbols for Script Tool and Sub-model.

Keywords: Workflow · Human-computer interaction · Visual programming language · Colour · Shape · Eye-tracking · Perception

1 Introduction

Workflow diagrams are used for the graphical design of algorithm. The tools for the visual design of workflow diagrams are called visual programming languages (VPL). The Geographical Information Systems (GIS) offer several graphical editors for the workflow diagram design. The overview and of graphical editors in GIS are described in some articles [1, 2]. Besides the functionality of workflows also the cognitive aspects have an influence on the effective utilisation of workflow diagrams by users. The aesthetical properties of workflow diagrams have important from the point of perception and cognition. In an article [3] is described the influence of the bends on connectors lines in workflow diagrams to reading diagrams.

The evaluation of cognitive aspects of workflow diagrams belongs to the area of Human-Computer Interaction (HCI). The research in HCI area brings improvement of software and their interface and also to the resulting product in case of workflow diagrams. For evaluation of cognitive aspects are frequently used the theory of Physics

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of Notations [4]. This theory is used and helped to achieve the higher level of cognitive effectiveness of workflow diagrams.

A research group at Department of Geoinformatics of Palacky University has made an effort to evaluate visual programming languages in the area of GIS software from the point of cognition. The evaluation by the theory of Physics of Notations was supplemented by the empirical testing in eye-tracking equipment in the laboratory. The graphical editor ModelBuilder for ArcGIS software was centred in empirical research. The basic graphical vocabulary is described in the documentation [5]. The set of workflow diagrams designed in ModelBuilder was prepared for eye-tracking testing. The main target was verified the perceptual discriminability and visual expressivity of symbols in workflow diagrams. Some preliminary evaluation only by theory Physics of Notation was presented in a previous article [6]. The subsequent eye-tracking testing brought comparison and confirmation of result obtained from evaluation by theory Physics of Notations. Moreover, some new facts discover the eye-tracking testing.

2 Methods and Materials

Theory “Physics of Notations” defines nine base principles for evaluation and design of cognitively effective visual notations [4]. One of the principles is “Perceptual Discriminability”. This principle states that different symbols should be clearly distinguishable from each other. The principle of “Visual Expressiveness” states that the full range of visual variables and their full capacity should be used to represent the symbols [4]. According to both two principles, the emphasis is on the basics symbols in the graphical vocabulary of visual programming language. These two principals have high synergy. The symbols have the highest discriminability if different visual variables are used. The basic visual variables are the colour, shape, size, brightness, texture and orientation.

Pairwise comparison of symbols from graphical vocabulary brings an overview of the fulfilment of both two principles. The Table 1 record the visual distance of symbols. The distance means how many visual variables differ for two symbols each other. The final evaluation of perceptual discriminability is in the last column of Table 1.

In the case of symbols of Derived Value and Input Value (Input Value), there is a small difference in colour shade. So the discriminability of symbols by colour is not satisfied. The discriminability is good only in cases where the distance is equal 2 or 1 (various tone of colours). The discriminability of Iterator and Stop symbols is medium because both shapes (hexagon and octagon) are from the same set of geometrical shapes (regular polygon). The distinguishing only by a small inner icon in case of Built-in Tool, Script Tool and Model Tool symbol is not satisfying. The inner icons add the semantic meanings, but they are not assumed as a visual variable. The discriminability of these rectangle yellow symbols is bad because the visual distance is zero.

The results of the application of method Physics of Notation were empirically verified by eye-tracking testing. The main research question was if the increasing of visual distance decrease the time of user response and increase the effective cognition. The worst situation was discovered according to theory Physics of Notation in

Table 1. Pairwise comparison of symbols from visual vocabulary of ModelBuilder

Symbol 1	Symbol 2	Visual Distance	Discriminability
Input Data	Built-in Tool	2 – shape, colour	good
Iterator	Input Data	2 – shape, colour	good
Iterator	Built-in Tool	2 – shape, colour	good
Input Data	New Derived Data	1 - colour	good
Built-in Tool	Script Tool	0	bad (only icon)
Model Tool	Script Tool	0	bad (only icon)
Derived Value	Input Value	0	bad
Derived Value	Input Data	1 - colour	medium
Stop	Built-in Tool	2 – shape, colour	good
Iterator	Stop	2 – shape, colour	medium

comparing the three yellow rectangle symbols that differ only by inner icons. They were Built-in Tool, Script Tool and (Sub)-Model Tool (Table 1).

2.1 Eye-Tracking Experiment

The eye-tracking measurement was used for evaluation of cognition and discriminability of visual symbols in workflow diagrams. The complex eye-tracking experiment consisted of 22 workflows diagrams from ModelBuilder. We tested several diagrams with various functions, different arrangements of the orientation of flow (vertical and horizontal directions) and with a change of colours of symbols. The workflow diagrams were presented individually on the screen in random order to prevent "learning effect" [7].

The respondents were the students of the second grade of bachelor study Geoinformatics and Geography at the end of the semester. They had the subject “Programming 2” where the design of workflow models in ModelBuilder was lectured. They practically design various diagrams with different functionality and with various numbers and types of symbols. The group of respondents was assumed as advanced users. The total number of respondents in eye-tracking testing was 27. One of then was excluded due to bad calibration of gaze. The group consists of 6 women and 20 men finally, with age from 22 to 25. The test proceeded in May of 2016 [3].

The testing was run at an eye-tracking laboratory in the Department of Geoinformatics at the Palacky University in Olomouc (Czech Republic). For the experiment, we used eye-tracker SMI RED 250 with software SMI Experiment Suite 360°. To define the test, we used SMI Experiment Center program; to visualise the results we used SMI BeGaze. The evaluation was also done in software Ogama 4.5. The size of the monitor to record eye movement was 1920 × 1080 pixels for displaying diagrams. The sampling frequency was 250 Hz [3].

The term stimulus is used in the process of eye-tracking testing [8]. The workflow diagrams were used as stimulus. “Comprehension tasks” are joined to the stimulus to record the cognitive process. Response time and correctness of user answers could be measured for the user answers for each “comprehension tasks” [9–11]. The set of workflow diagrams or maps with “comprehension tasks” are often used for evaluation of usability of visualisation methods in cartography and GIS [12, 13].

2.2 Experimental Workflow Diagrams

Two couples of diagrams with the same functionality were incorporated into the eye-tracking test. The first couple is in Fig. 1. The second couple is in Fig. 2. In the case of the first couple, the symbol of Script tool with a script named “Connect” was changed to light yellow colour fill (Fig. 1 upper diagram). This diagram with origin (unchanged) yellow colour was also tested (Fig. 1 bottom).

In the case of the second couple of diagrams, the symbol of Sub model was changed. There is sub model named “Interpolate and Reclas”. The origin yellow colour was used in workflow diagram in Fig. 2 (bottom). The changed green-brown (khaki) colour was used for the symbol in workflow diagram in Fig. 2 (upper).

In both cases, the colour was changed from the original colour. The graphical editor ModelBuilder allows manual changes of the symbol colour of the symbol by the user. This opportunity was applied in the design of both models for eye-tracking. The small inner icons in symbols of Script tool and Sub model remained. The icons were only indicators for finding symbols in testing by respondents. The users (respondents) did not inform about the change of colour in diagrams. They assumed the only original form of symbols in workflow diagrams. The changes of symbols were unexpected.

The same comprehension tasks were used for diagrams in diagram couples:

- “*Click on the symbol where the Script tool is called.*” (models in Fig. 1)
- “*Click on the symbol where the Sub model is called.*” (models in Fig. 2)

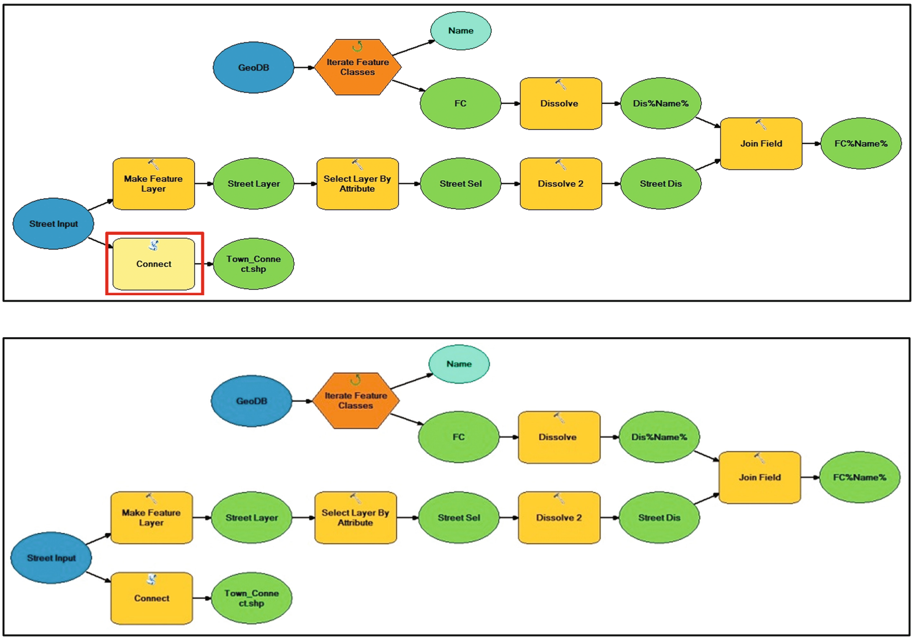


Fig. 1. Diagram with the change colour for symbol script – highlighted by rectangle (upper) and original symbol of script (bottom)

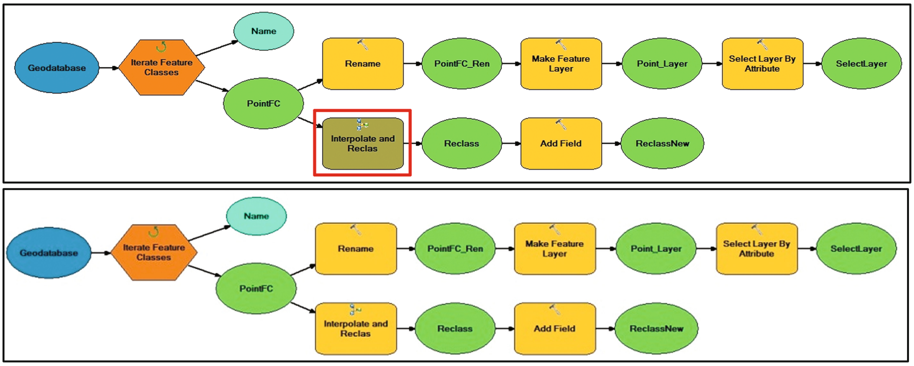


Fig. 2. Diagram with the change colour for symbol sub model – highlighted by rectangle (upper) and original symbol of sub model (bottom)

2.3 Statistical Evaluations of Eye-Tracking Metrics

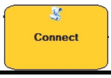
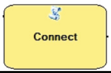
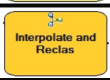
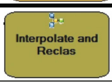
The eye-tracker collected the position of gaze above stimulus for each respondent and diagram. The response time (time of mouse click on the symbol) and total time of each user were also measured. Moreover, other eye-tracking numeric characteristics (metrics) from eye-tracking data were calculated. They were the total length of scanpath, the average time of fixation, the frequency of fixation per second, fixations/saccade ratio, average saccade length, path velocity in pixel per second and others. Aggregation of respondent scanpaths together brings clear evidence of reading patterns. The orientation of and continuity of reading patterns follow mainly the orientation of connector lines in free-viewing stage [14]. In the case of comprehension tasks, the gaze is mainly after the first scan of diagram directly to the place near the correct symbols.

The research task was if a change of colours has an influence on any eye-tracking metrics. The hypothesis was that the colour change has no influence because is not expected by users.

Statistics evaluation of measured eye-tracking metrics was calculated. The score of correct and bad answers was assessed. All answers were correct for both two couples and 26 respondents. The change of colour is not so surprising for respondents, and all found correct symbols in diagrams. The Shapiro–Wilk test was used to verify the normality of eye-tracking data. The hypothesis of the normal distribution of data was not proving. Subsequently, the non-parametric tests were used. Non-parametric Mann–Whitney U test examined corresponding couples of diagrams. This test verifies null hypothesis H_0: The distributions of both populations are equal.

The calculated metrics are in Table 2. The average time of response (click on the symbol) is shorter for diagrams with changed colour in comparison with the same diagrams matched in couples without colour change. An average number of fixations is lower for diagrams with the colour change of symbols than for diagram with original colour. Also, the shorter average length of fixation and shorter length of scanpaths is for a change of colour. The statistical evaluation does not validate the statistical significance of compared metrics.

Table 2. Average value of eye-tracking metrics for orthogonal bend (B) and straight (S) lines

Symbol	Change of colour	Average time [s]	Number of fixations	Average length of fixation [ms]	Length of scanpath [px]
	NO	87,75	17,3	218	4202
	**YES**	**75,89**	**14,04**	**209**	**3263**
	NO	12,42	30,29	224	5669
	**YES**	**9,95**	**22,95**	**206**	**3836**

The final interviews were led after eye-tracking test with respondents. Some respondents mentioned that noticed the change of colour of symbols. They were also sure that the colour change helped them in searching, but the inner icons were the main determination for finding the correct symbol. The smaller group of respondents (around 5) mentioned that did not notice the change of symbol colour.

3 Results

The eye-tracking testing empirically verified that increasing of the visual distance of symbols bring quicker recognition of symbols in workflow diagrams. In two cases of symbols where the former yellow colour was changed. The light yellow colour was used for the Script toll symbol, and the khaki colour was used for Sub-model symbol. The visual distance was increased from zero to one. These changes produce a shorter time of response, lower number of fixation and shorter average time of fixation and shorter scanpath. The colour changes of two symbols in workflow diagrams were unexpected by the user. In case, the change of colours is a permanent change of basic symbols in visual vocabulary, the better and significant result of eye-tracking measuring would be obtained. The evaluated eye-tracking metrics prove that the recommendation of principles of theory Physics of Notations is valid for workflow diagrams for ModelBuilder in ArcGIS.

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