Empirical Testing of Bends in Workflow Diagrams by Eye-Tracking Method

Zdena Dobesova(✉)

Department of Geoinformatics, Faculty of Science, Palacký University,
17. listopadu 50, 779 00 Olomouc, Czech Republic
zdena.dobesova@upol.cz

Abstract. Workflow diagrams consist of nodes and connectors to express the steps of processing in the form of a visual program. The graphical vocabulary and the layout of the diagram have an influence on the user cognition of diagram. The aesthetic aspects also have an impact on users understanding. One aesthetic recommendation – "minimize beds in edge" was tested in workflow diagrams from ArcGIS ModelBuilder. Eye-tracking measuring in the laboratory was prepared for objective empirical testing. Five couples of diagrams with and without orthogonally bends were showed to 26 respondents. The user executed specific tasks above diagrams. Eye-tracking measuring brought interesting objective results. Eye-tracking metrics affirm that diagrams with orthogonal bends on connector lines have an average higher number of fixations, longer length of scanpath, shorter average time of fixation and longer duration time. The result is that the using of straight lines brings effective cognition of workflow diagrams in case of spatial data processing in geographic information system (GIS).

Keywords: Workflow · Human-Computer Interaction · Visual programming language · Eye-tracking · Aesthetic · Cognition · Geographic information system

1 Introduction

Workflow diagrams are used for graphical expression of steps of the process (algorithm). In the area of geographical information systems, the workflow diagram designs the processing of spatial data. Different graphical editors are available in geographical information systems (GIS) for design workflows. These types of GIS software and their workflow editors exist:

- ArcGIS for Desktop (editor ModelBuilder),
- Erdas Imagine (editors Model Maker and Spatial Model Editor),
- IDRISI (editor Macro Modeler),
- AutoCAD Map 3D (editor Workflow Designer).

Moreover, two open source GIS software have workflow editor:

- QGIS (editor Processing Modeler),
- GRASS GIS (editor Graphical Modeler).

R. Silhavy et al. (eds.), *Software Engineering Trends and Techniques in Intelligent Systems*,
Advances in Intelligent Systems and Computing 575, DOI 10.1007/978-3-319-57141-6_17

The overview and description of these graphical editors are in the article [1].

All workflows diagrams belong to the group named visual programming languages [2]. Visual programs are easier understood than textual programs. The workflow editors are possible to describe from the point of the method of design, the amount of functionality or describe the symbols from their graphical vocabulary. The phase of diagram design and utilization belongs to the Human-Computer Interaction (HCI) research area. The graphical vocabulary (notation) is important from the point of user perception and cognition. Moody in his theory "Physics of Notations" stated that is necessary to use cognitively effective visual notations [3]. Cognitively effective means optimized for processing by the human mind.

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 mentioned above. The aim is finding the level of cognitive effectiveness and aesthetics of visual vocabularies and diagrams subsequently. For evaluation were used the theory of Physics of Notations, the rules of aesthetics and empirical testing by the eye-tracking equipment in the laboratory. Several tests for various diagramming language from GIS software experimented from 2014 to 2016. Application of these methods in the area of HCI discipline brings improvements and recommendations for user design of workflow diagrams. The article describes the result of the empirical test for diagrams with straight and orthogonally curved connector lines for a set of workflow diagrams from ArcGIS ModelBuilder.

2 Methods and Materials

Theory "Physics of Notations" defines nine principles for evaluation and design of cognitively effective visual notations [3]. One of the principles is "Principle of Cognitive Interaction". This principle states that it is necessary to include explicit mechanisms to support the integration of information from different diagrams. In the phase of design or reading diagrams is a demand on simple navigation and transitions between diagrams. Connector lines in one separate diagram are also important for simple navigation in the diagram. Connector lines help in wayfinding and contribute to answering to a set of questions:

- *Orientation:* Where am I?
- *Route choice:* Where can I go?
- *Route monitoring:* Am I on the right path?
- *Destination recognition:* Am I there yet?

Additionally, the set of aesthetic rules and recommendations for diagram design is mentioned in literature:

- *Minimize bends in the edge* (the total number of bends in polyline edges should be minimized) [4, 5]
- *Minimize edge crossing* (the number of edge crossing in drawing should be minimized) [6]

- *Maximize minimum angle* (the minimum angle between edges extending from a node should be maximized) [7, 8]
- *Orthogonality* (fix nodes and edges to an orthogonal grid) [4, 9]
- *Symmetry* (where possible, a symmetrical view of the graph should be displayed) [10]
- *Good continuity* (minimize angular deviation from straight line of one bended edges or two followed edges connecting two nodes) [11]

Aesthetic rules concerns both to the connector lines (edges) both the layout and arrangement of symbols in the diagram. Some rules have a positive or negative influence on other rules. Empirical study Cognitive Measurement of Graph Aesthetics [11] verified the aesthetic rules. The respondents tried to find the shortest path above diagrams. Their testing proved that response time depends on the number of edge crossing and continuity of graph. Good continuity will be more readily received if nodes in the diagram are not in a zigzag pattern but form a smooth continuous sequence. Also, zigzag connecting lines are perceived worse.

In this type of studies are used "comprehension tasks" to measure response time and correctness of user answers [12–14]. The set of diagrams or pictures (maps) is often used for evaluation of usability of visualization methods in cartography and GIS [15, 16]. In our research, we tried to empirically verify the influence of orthogonal bends in connector lines to the effective cognition. We prepared the workflow diagrams and comprehension tasks (questions) for experimental test.

2.1 Workflow Modeling in ArcGIS ModelBuilder

ArcGIS (producer Esri) has an embedded graphical editor called ModelBuilder to create and execute the steps of spatial data processes. The workflow diagram is called model process in this editor. The design of flow is very easy, only by drag and drops the spatial functions (tools) to the canvas. The functions are represented by the yellow rectangle symbol, and blue/green ovals represent data. Moreover, the orange hexagon expresses the iterator for the construction of cycle. The connectors between symbols are black lines ended by an arrow that expresses the orientation of flow. The workflow is expressed as a fluent chain of input data, functions, and output data. The basic graphical vocabulary is described in the documentation [17]. The basic evaluation according to theory Physics of Notation was made in previous work [18].

The basic setting of diagram properties allows the automatic change of orientation of diagram. There is also an option to set the connection routing type. The user can switch between "Orthogonal routing" and "Straight routing" of connectors. The whole diagram is automatically redrawn according to the selected option.

Straight routing is the default. Form of workflow diagram with "Orthogonal routing" is in Fig. 1.

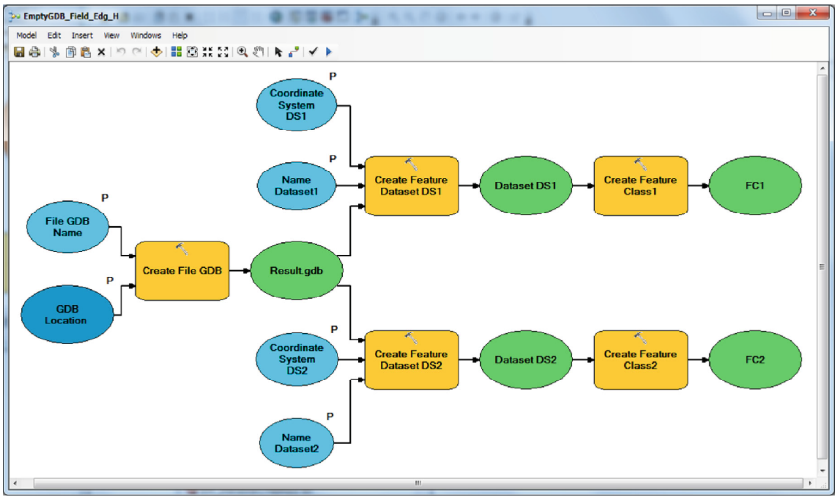

Fig. 1. Interface of ModelBuilder with workflow diagram

2.2 Eye-Tracking Testing

The eye-tracking measurement was used for evaluation of cognition of workflow diagrams. The test consists of 22 workflows diagrams from ModelBuilder. We tested several diagrams with various complexities, different arrangements of symbols and orientation of flow (vertical and horizontal directions), with a change of colors and also with straight and bend connector lines.

The respondents were the students of the second grade of bachelor study Geoinformatics at the end of the semester. They had the subject "Programming 2" where the design of workflow models in ModelBuilder was explained and detailed practiced in four lectures. Also, students accomplished four home works with the construction of complexity diagrams. The group of respondents was assumed as skilled users. The total number of respondents 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 age of respondents was from 20 to 25. The test proceeded in May of 2016.

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 visualize 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.

2.3 Diagram Stimulus

The term stimulus is used in the process of eye-tracking testing [19]. The stimulus could be any picture, photo, map or drawing like graph or diagram. In the case of testing of workflow models the series of 20 various diagram was prepared as an experiment. The diagrams were presented individually on the screen in random order to prevent "learning effect" [20].

Each stimulus was accompanied by the special task to record the understanding, comprehension and cognition of diagram. The users solved the task by finding and clicking on the correct symbol(s) in the diagram.

The eye-tracker collected the position of gaze above stimulus. From the raw data, the position of eye fixations and the scanpath (the path between eye positions) were calculated by OGAMA software. The response time and total time of each user were also measured. Two or more correct answers (symbols) exist in some diagrams (depends on the task). All mouse clicks were recorded. Moreover, other numeric characteristics (metrics) from eye-tracking data were calculated. They are the total length of scanpath, the average time of fixation, frequency of fixation per second, fixations/saccade ratio, average saccade length, path velocity in pixel per second and others. Aggregation of respondent scanpaths brings clear evidence of reading patterns. The orientation of and continuity of reading patterns follow mainly the orientation of connector lines [21].

Ten diagrams were present in the eye-tracking experiment for the testing of the influence of bends in connector lines. All ten diagrams consist of five couples of the same diagrams. The functionality of the diagrams was the same for each couple. Also, the tasks solved above a couple of diagrams were the same. Examples of one couple are in Figs. 2 and 3. The first is with straight connector lines and the second is with orthogonal bends on connector lines. The question solved above the diagrams was "*Mark input data of function Select Layer By Location.*" The places with correct answers are marked by a red dot in Figs. 2 and 3.

The respondent had to find the yellow rectangle with function "*Select Layer By Location*" firstly. After that, the gaze moved to the green ovals and marked them as answers by mouse clicks. The connectors are straight between the yellow symbol of function and green ovals (Fig. 2) or with two orthogonal bends (Fig. 3). In fact, the lines with orthogonal bend are longer than straight lines.

The research task was if the variant shapes of connectors have an influence on any eye-tracking metrics. The hypothesis was that bended lines are worse for reading and aesthetics perceive. Firstly the scanpath of individual respondents was explored. The fixations are mainly on the color symbols in the ModelBuilder workflow diagrams.

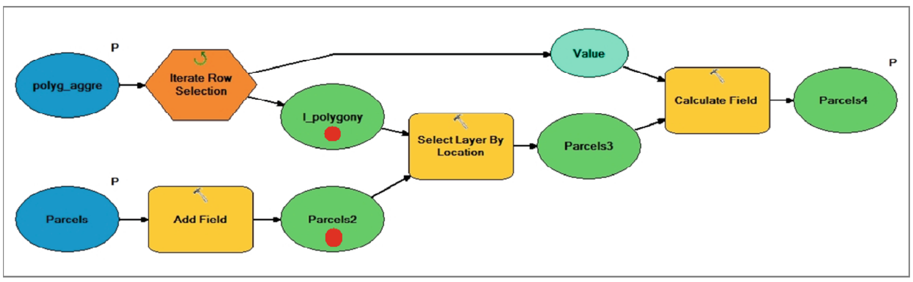

Fig. 2. Workflow diagram with the straight connector lines

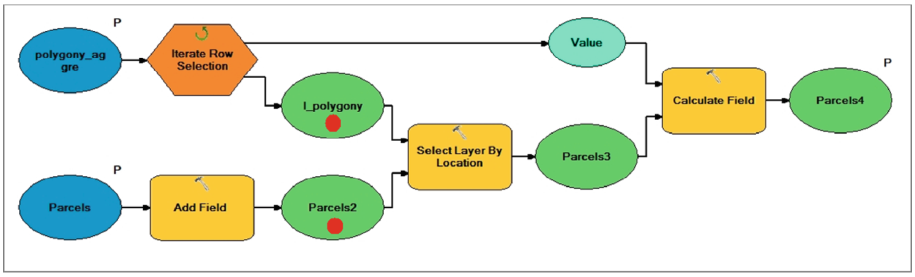

Fig. 3. Workflow diagram with bends in line connectors

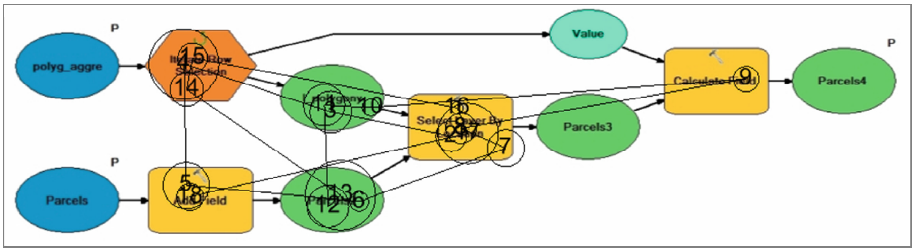

Fig. 4. Scanpath of one respondent with order of fixations

Connectors have nearly no fixations. The fixations are presented by black circles where inner number expresses the order of fixation, and the diameter expresses the duration of fixation (bigger has longer time). Black lines are eye quick movements of the eye between fixations (Fig. 4.). The connector line has mainly influence on the orientation of reading. The scanpath exposes that the user gazes skips between the yellow symbol and green ovals several time forward and backward. Left part and right part of the diagram are not nearly explored by respondents (no fixations are there).

Statistics evaluation of measured eye-tracking metrics was calculated after individual exploration of user recorded scanpaths. The score of correct and bad answers was assessed. All answers were correct for all five couples and 26 respondents. The shape of connector lines does not have negative influence to correct answers.

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 1. Values for B means diagram with orthogonal bends; S means straight line connectors. The average time of response (duration time) is shorter for all diagrams with straight lines in comparison with the same diagrams matched in couples. An average number of fixations is greater for diagrams with the orthogonal bends in line connector than for diagram with straight lines. Also, shorter

Table 1. Average value of eye-tracking metrics for orthogonal bend (B) and straight (S) lines

Diagrams	Type of lines	Duration time [s]	Number of fixations	Length of scanpath [px]	Avg. time of fixation [ms]
Couple 1	B	10	25	3 373	223
	S	9	22	3 219	241
Couple 2	B	11	30	7 104	197
	S	10	29	6 425	205
Couple 3	B	16	44	9 449	215
	S	14	37	9 136	217
Couple 4	B	11	26	3 813	211
	S	10	25	3 593	231
Couple 5	B	11	29	3 695	224
	S	9	19	2 459	247

average scanpaths is for straight lines. The most interesting result is the average time of fixation. The straight lines have a longer time of average time fixation.

We assumed that the gaze is sputtered in the case of orthogonal bends. There are longer response time, longer scanpath and bigger count of total fixations and more repetitive gaze movements. The statistical evaluation does not validate the statistical significance of compared metrics. A significant difference has only for the last couple of diagrams where the diagrams have the vertical orientation. The difference was significant for duration time metric.

Subsequently, the number of fixations was calculated only for Area Of Interest (blue rectangle AOI) nearly to the place of the correct answer (Fig. 5). The green ovals (express input data) and yellow rectangle (with mentioned function in question) were incorporated to AOI together with the lines. These two connector lines have an influence on the number of fixation. The AOI with straight lines has 281 fixations (total for 26 respondents) (Fig. 5 left). In the second case, the AOI has 319 fixations also for 26 respondents (Fig. 5 right).

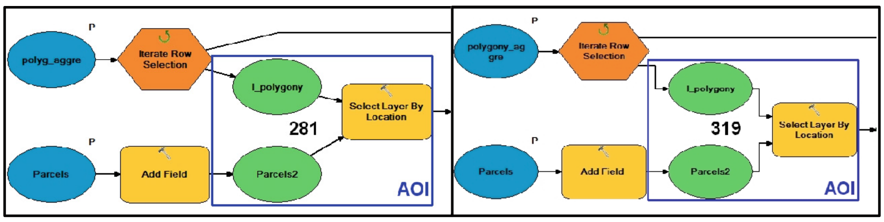

Fig. 5. Comparison of number of fixations in the same area of interest in both diagrams

3 Results

The eye-tracking testing empirically verified the aesthetic rule that state "*Minimize bends in the edge*". Five couples of various diagrams were tested with two modifications with orthogonal bends and without bends. The functionality was the same in couples, and the same comprehension task was assigned. The evaluated eye-tracking metrics prove that straight lines have in average:

- Lower number of fixation (also in AOI near correct place of answer)
- Shorter scanpath
- Longer average time of fixation
- Shorter total time of response (for one couple is statistically significant)

All these eye-tracking metrics were worse in the case of the orthogonal bend lines. In the case of longer average time of fixation, we assume that the respondent reading is calmer for straight lines than in case bends on lines. The orthogonally bended lines disturb the reading and user gaze skips several times between symbols with very short fixations. The presented testing of bends in workflows diagrams from ModelBuilder is valid for design any diagram in ModelBuilder. The finding also supports the validity of the aesthetic rule "*Minimize bends in the edge*" in general. The result is sustained not only by total time of response but by other eye-tracking metrics as number of fixations and scanpath length.

4 Discussions

The default option "Straight routing" of the connector is better than orthogonal routing. The default setting helps to design better aesthetic diagrams than diagram with bends on connector lines by the user in practice. We do not advice to users the intentional switching to a worse type of connectors. Our eye-tracking testing verified one rule from the set of aesthetic principles.

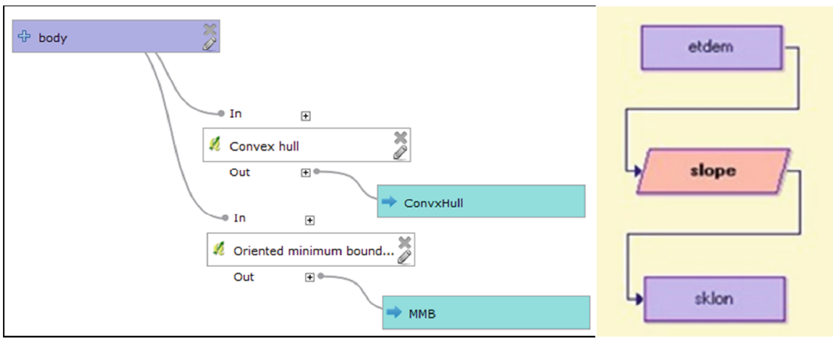

Fig. 6. Workflow with curved lines from QGIS Processing Modeler (left) and orthogonally curved lines in IDRIS Macro Modeler (right)

The result is also applicable to any other diagramming language in GIS and other IT diagramming fields. However, some GIS software does not support the variability of the shape of connectors. E.g. editor Processing Modeler for QGIS software use curved connector lines, and there is not possible to change to another shape. The connector lines are too long and space consuming of canvas (Fig. 6 left). Another example is IDRISI Macro Modeler in the area of GIS software. The lines in vertical (top-down) orientation are automatically orthogonally curved (Fig. 6 right). There is no possibility of user change. The aesthetic and cognitive quality of user workflow diagrams are under the influence of capabilities of the graphical editors and their limitations. The recommendation is: Draw or change to straight lines if there is an option in graphical editors for workflow diagram design.

Acknowledgment. This article has been created with the support of the Operational Program Education for Competitiveness – European Social Fund (project CZ.1.07/2.3.00/20.0170 Ministry of Education, Youth, and Sports of the Czech Republic).

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