Polish Cartographical Review
Vol. 50, 2018, no. 3, pp. 127–140
DOI: 10.2478/pcr-2018-0008
Received: 20.07.2018
Accepted: 28.09.2018

KAMILA ŁUCJAN
Maria Curie-Skłodowska University, Lublin
Department of Cartography and Geomatics
Lublin, Poland
orcid.org/0000-0002-3213-2580
k.lucjan@poczta.umcs.pl

PAWEŁ WOJTANOWICZ
Maria Curie Skłodowska University, Lublin
Department of Geographic and Tourist Education
Lublin, Poland
orcid.org/0000-0002-3996-4056
pawel.wojtanowicz@poczta.umcs.lublin.pl

Continuous or discontinuous? Empirical study on animated maps

Abstract. Advancements in computer technology that have occurred in recent decades have enabled an intensive development in cartographic methods for direct representation of phenomena dynamics. Even with the appearance of ever more advanced technical solutions, the theoretical basis still needs supplementing. The previous cartographic literature emphasises the importance of congruence and isomorphism principles preservation that aims at increasing the effectiveness of dynamic displays. Nevertheless, it is frequently the case that discontinuous phenomena are depicted with the use of smooth transitions. For this reason, it is vital that experimental research should lead to defining which representation methods are appropriate for a given type of content. Our study was focused on the cartographic design of scene transitions in animated maps. Two main conclusions of the research indicate that 1) mode of transition influences the interpretation of the content of cartographic animation depicting discrete changes, 2) maps executed in a *smooth* mode demonstrate lower effectiveness when compared with animations using an *abrupt* and *abrupt with decay effect* transitions.

Keywords: animation, perception, discontinuous changes, smooth transition, abrupt transition

1. Introduction

The use of animation in cartography can positively influence the understanding of the character of processes and spatial relations, as well as regularities in the occurrence of phenomena (M.-J. Kraak, F. Ormeling 1998). In caring for an accurate representation of the nature of change, an author of animation has the possibility to present the dynamics of a process in a vivid way that allows the map reader to interpret correctly the specific nature of phenomena (J. Rutkowski 1984).

As T. Opach (2007) stressed, what is remarkably important in the case of animated maps is the preservation of changeability isomorphism (apart from other isomorphic relations: the location, shape, and content). In order to improve correctness of feature representation, an author of an animated map "should direct their efforts (…) by means of the principles of isomorphism where changeability isomorphism is to set the relation between the display of features changing on an animated map and the occurrence of respective changes in the real world" (T. Opach 2007, p. 3). B. Tversky et al. (2002) noticed that the natural way of portraying a discontinuous motion is to depict it in discrete steps rather than in a continuous animation.

However, it is still frequently the case that there are discrepancies between the specifics of the changeability represented on an animated map and the nature of real-life phenomena. What proves particularly problematic is the representation of discontinuous dynamics (e.g. changes in administrative and political boundaries) that are repeatedly presented with the use of smooth transitions[1]. A question

[1] Examples of this solution are: https://www.youtube.com/watch?v=66y49BnxLfQ&t=48s, https://www.youtube.com/watch?v=zX00OjlwcIM, https://www.youtube.com/watch?time_continue=194&v=caxAAZsL-wQ, http://sydney.edu.au/arts/timemap/examples/map_animation.shtml

arises whether the representation of discontinuous changes in a smooth mode can cause a misinterpretation of the nature of processes depicted on the animated map.

Still in 2010, as the first of six important unanswered questions associated with the effectiveness of animations, S. Battersby and K.P. Goldsberry (2010, p. 27) identified: "Does achieving congruence between cartographic transitions and the natural change behaviour for a mapped phenomenon influence the way readers interpret the nature of the change(s)?".

This article addresses perceptual issues related to animations depicting discontinuous changes. Our special attention was focused on the *smooth* vs *abrupt* mode of representation. We conducted our empirical research in order to ascertain the impact of the cartographic design of scene transitions on the content of animated maps.

2. Background literature

A development in computer technology that has occurred in recent decades has enabled the widespread application of the animation technique to cartography. Numerous methods have been developed for presenting phenomena changeability in a dynamic manner. Nevertheless, an increasing popularity of animated maps has brought about merely slight improvements in the formulation of rules for efficient animation design.

Undoubtedly, there is still a need for some in-depth research into issues connected with the perception of animated maps' content. It is crucial to deliver a deeper understanding of a specific nature of animated maps, as well as their advantages and limitations, and to set what type of content can be particularly efficiently represented with their use (M. Harrower 2007).

Even with the growing interest of cartographers in cognitive questions that has arisen in recent years a relatively low number of studies concerned animated maps. Experiments of this type were conducted, inter alia, by: B. Köbben and M. Yaman (1995; evaluation of perceptive properties of dynamic visual variables), R.M. Edsall et al. (2003; a comparison of different types of temporal legends), P.-C. Lai, A.G.-O. Yeh (2004; the assessment of dynamic symbols effectiveness), S. Biswas (2004; the evaluation of the use of prototype animation with linked graphics), T. Opach (2007; a study of the efficiency of animated maps presenting phenomena dynamics).

The 1992 work by A. Koussoulakou and M.-J. Kraak is one of the most significant publications in the field. Its authors compared properties of two types of maps depicting dynamics: animated and static ones. In order to simplify the experimental procedure and to achieve a possibility to control test results, no interactivity was introduced. Conducting the tests proved that users need less time to interpret spatiotemporal data when they are represented with the use of animation than in the case of traditional maps with the same content.

Results of the studies on animated maps perception are varied. A. Koussoulakou and M.-J. Kraak (1992), N. Gershon (1992), and D.K. Patton and R.G. Cammack (1996) came to the conclusion that cartographic animations are more efficient than traditional maps. On the other hand, studies of T.A. Slocum et al. (1990), T.A. Slocum and S.L. Egbert (1993), M.E. Cutler (1998), and H. Johnson and E.S. Nelson (1998) proved that the effectiveness of static and dynamic maps is comparable, with just a slight advantage of animated displays (T.A. Slocum et al. 2001).

C. Fish et al.'s (2011) research concerned the issue of change legibility in dynamic geovisual displays, on an example of animated choropleth maps. One of the results indicated that the cartographic design of scene transitions (smooth or abrupt) does influence change detection accuracy. The study demonstrated that participants performed better using animated maps with smooth transitions between adjacent scenes than abrupt ones. The results of C. Fish et al.'s (2011) experiments shed light on the problem of change detection on animated choropleth maps. However, what the impact of the mode of transition on the interpretation of the nature of changeability is, to our best knowledge, remains still untested.

3. Empirical study

3.1. Research goals and questions

The user tests conducted for the needs of the present work fit in the trend of recent cognitive studies on the effectiveness of animated maps. With our experiment, we attempted to answer the question of whether the cartographic design of scene transitions influences the perception of animations depicting discontinuous dynamics.

We understand discontinuous dynamics as changes that occur in leaps, rapid, abrupt, having intervals or gaps (*Oxford Dictionaries*), e.g. changes in state boundaries. The fact that there are no transitional states between situation A and situation B is an essential feature of this type of dynamics. One can speak of continuous dynamics when there are a series of transitional stages between situations A and B (e.g. a plane flying from A to B). It is worth stressing that continuous changes may be either of uniform or nonuniform character, also with temporary halts (e.g. changes in ranges of species).

Changes in political boundaries are the issue that is most frequently presented with animated maps. In most cases, map makers utilise smooth transitions between adjacent ranges. When phenomena that are actually discontinuous in their character are animated in a smooth mode, they can be erroneously treated by users as continuous. This is the result of creating fictitious transitional states between subsequent, actual changes and can potentially influence the interpretation of spatiotemporal relations.

For an example, when using smooth animation the map reader can have a wrong impression that the town of Siena was included in the area of the Amberland state already around 1150 (actually, it was not until 1200 that it was incorporated). This is the consequence of generating the state boundary in a place where it never existed (fig. 1).

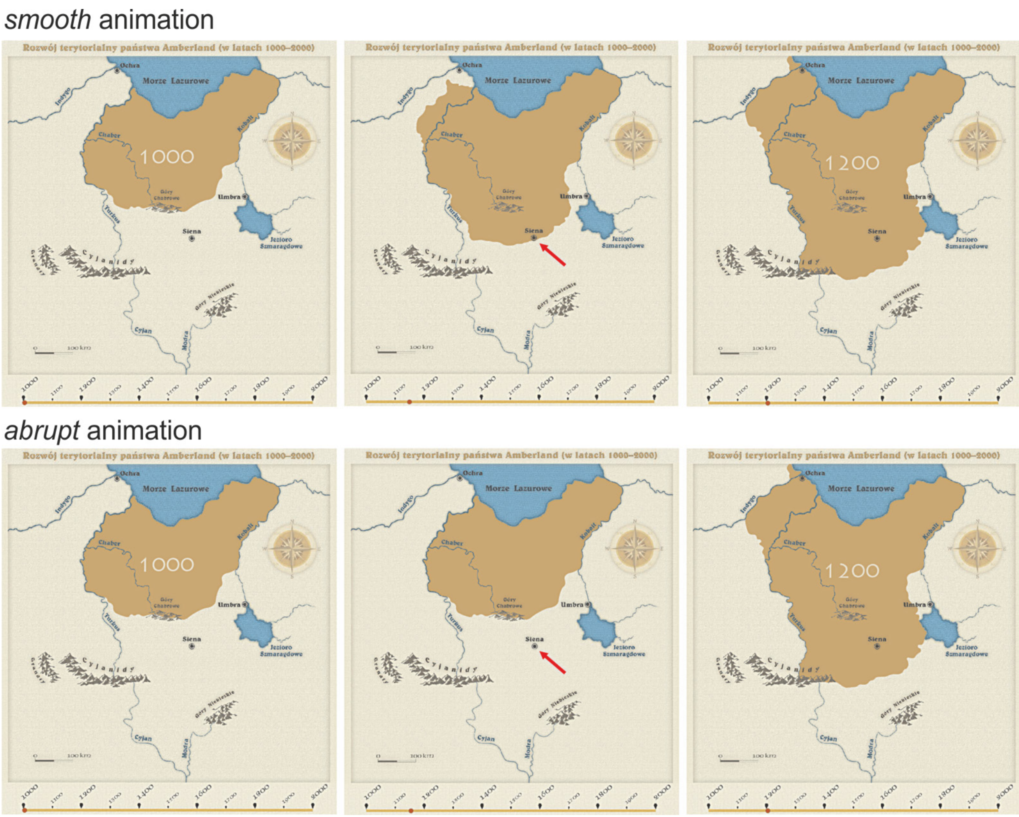


Fig. 1. The difference between *smooth* and *abrupt* animations illustrated on selected frames. In 1000 and in 1200 both ranges are identical, but between those set moments in time there are significant differences in the course of the state boundary (middle frames)

The above observation led us to the adoption of the following theoretical hypothesis: a mode of transition between adjacent scenes of animated map significantly influences the interpretation of the character of discontinuous dynamic phenomena being represented.

3.2. Materials

The illustrative material used in experiments were non-interactive simplified animated maps that showed changes in state boundaries. Maps were executed in the old style, which was done on purpose to stress the historic character of represented content, and at the same time made the image more attractive for school-age audience. Three animations developed specifically for that task were used. Two main modes of transition were applied: *smooth* and *abrupt*. The third design (*abrupt with decay effect*) was proposed as a new way of depicting discontinuous changes, with two assumptions adopted: 1) it is methodologically correct (as opposed to the smooth mode it meets the congruence as well as changeability isomorphism principles), 2) due adding the effect of gradual appearance and disappearance of symbols it facilitates the comparison of subsequent temporal states in a more effective way than the *abrupt* mode.

In a typical *abrupt* animation, the transition between contiguous ranges is very rapid (frame to frame), thus map readers may experience problems with a mental connection of respective temporal states contents. The use of gradual transitions between adjacent ranges was intended to point user's attention to the very moment the change occurs. To that end, we used the outline of the state boundary, shown as successively appearing before being fully filled with colour. This solution allows a user to see both temporal ranges at the same time: the actual and the future one (fig. 2).

The decay effect was not the authors' original invention. This technique had already been described in the literature (M. Harrower 2003) and it was applied in practice, inter alia, in the

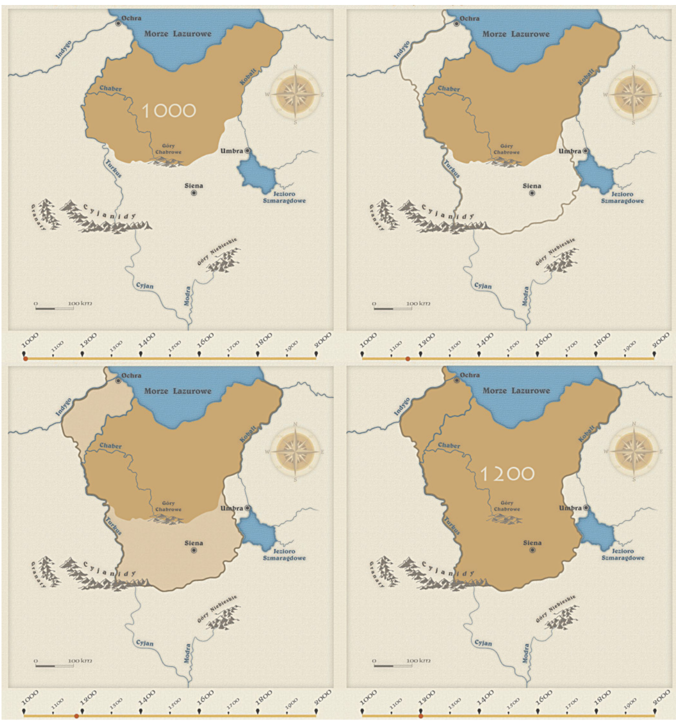


Fig. 2. Selected frames of *abrupt with decay effect* animation

BBC produced animated maps that represent the Italian campaign during World War II (https://www.youtube.com/watch?v=PMKos-CcsYY). Still, as opposed to animations that are the object of the present work, these maps concern continuous phenomena. Furthermore, their execution is different – with only the effect of a gradual appearance of symbols utilized. Due to the character of the depicted content, no decay is presented here. Object outlining was also not applied.

The maps developed for the needs of our experiment depict the territorial changes of fictitious state of Amberland throughout 1000 years of its existence. We chose this range of map content, as changeability of state boundaries are some of the most common issues with a discontinuous course that are visualized with animations. In order to prevent any influence of participants' previous knowledge on experiment results, we decided to apply the fictitious content.

In designing the animated maps only limited interactivity was provided. Participants were able to replay animation with the use of a browser's function to refresh the page. Our goal was to preserve a correctness of experimental conditions. Even an addition of the simple pause function could significantly influence the test outcome. The smoothness of the presentation is the most significant feature of the first investigated animated map, which differentiated it from the two other ones. By pausing the animation the user loses that property. Furthermore, in order to secure a proper course of the experiment, it was also important to make sure the interface did not engage map reader's attention excessively.

The animated map legend was included in a separate file. During the experiment, students were asked to familiarize themselves with explanations prior to playing the animation. This solution was adopted to avoid dividing users' attention between the map and its legend. Additionally, the maps used in the experiment were so generalised that they could be read intuitively.

The temporal legend was represented by a slider in the map window that included the whole timeframe. In order to stress important moments, and also to emphasise the discontinuous nature of the dynamics, an appearing and disappearing text was added (dates of state boundary changes). To simplify the content of animation even more, we decided to use equal time spacing between subsequent events.

3.3. Procedure

The experiment was preceded by a group interview among the employees of the Department of Cartography and Geomatics of the Maria Curie Skłodowska University in Lublin. We discussed and evaluated prototypes of animated maps that were to be subsequently used in tests with user participation. The reported remarks concerned both the content, the legend, and the representation modes applied. We modified animations between two phases of the interview. This stage resulted in a valuable feedback concerning solutions that could be incomprehensible or misinterpreted by participants.

The between-subjects experimental design (where the various experimental treatments are given to different groups of subjects) constituted the main part of the research procedure. The independent variable had three levels (conditions): *smooth*, *abrupt* and *abrupt with decay effect*. The dependent variable was a score in a test.

The study was conducted in one of Lublin's schools among 13 to 14-age students (a total of 102 participants: 70 girls and 32 boys). The choice of participants' age was dictated by the curriculum range. It was important that on the one hand, the students had a basic historical knowledge and elementary map reading skills. On the other hand, the knowledge should not be advanced enough for the content presented during the experiment to be obvious to participants.

The tests were conducted in an IT classroom in 9 groups of 8 to 14 students each. All participants received identical sets of paper-printed tasks (appendix 1). Each group was divided into 3 conditions: G1, G2, and G3. Participants in each condition were using different animated map: *smooth*, *abrupt* and *abrupt with decay effect.* During the test, the students played the animations themselves, everyone using his/her own computer. The participants were seated in a way that prevented them from looking at sheets other than their own (to a degree that the conditions of school IT classroom allowed).

The experiment was preceded with an oral instruction. The participants were informed about experiment's purpose, its anonymity and the fact that the data represented on the animated maps was fictitious. They were also instructed how they could replay the animation and the legend. The main part of the test consisted of 9 tasks: 1 to 3 concerned point objects, 4 to 6 linear ones, and 7 to 9 – areas (appendix 1). The tasks 2, 5 and 8 consisted of marking an answer on pictures included in the test. The questions were answered using the animated map on the computer. The time of testing was limited by the duration of the lesson unit (45 minutes).

4. Data analysis

The research material gathered in the result of user testing was then subjected to statistical analysis. The output data were the participants' score for completing the test. 1 point was awarded for a task solved correctly (and nil for an incorrect answer or no answer).

4.1. Basic statistical measures

The attached graph (fig. 3) illustrates the distribution of test frequencies in the whole group. None of the respondents achieved the minimum (0) nor the maximum (9) score. The modal (most frequent) value was 6 points. The arithmetic mean for all test results was **4.25**.

Fig. 4 clearly demonstrates that the first experimental group was dominated by low scores (with a modal value of 1) and scores of 7 and 8 were not present at all. This group also demonstrated the lowest arithmetical mean of **M_1 – 2.12**, similar to the percentage of correct answers – 24 (tab. 1).

The second group recorded no lowest values (1,2 and 3) and the modal value was 6 (highest of all groups) the arithmetical mean (**M_2 – 5.8**) and the percentage of the correct answers (65) were also highest in this group.

The third group recorded intermediate results. Values ranging from 1 to 8 were observed, with the arithmetic mean **M_3 = 4.82** and the modal value of 5. The percentage of correct answers was 54.

Table 1. The comparison of basic results in respective experimental groups

Condition	Modal value	Arithmetic mean (M)	Percentage of correct answers
G1	1	2.12	24
G2	6	5.82	65
G3	5	4.82	54
Whole group	6	4.25	48

4.2. Verification of hypothesis

Then we went on to test the significance of differences between the means, and thus to verify our research hypothesis. In order to achieve that we:

1. Defined the empirical variables:

a) the independent variable – the mode of transition (nominal variable) with following conditions: G1 (*smooth*), G2 (*abrupt*), G3 (*abrupt with decay effect*),

b) the dependent variable – the test score (the quantitative variable) with values ranging from 0 to 9 points.

2. Defined the operational hypotheses:

a) H_0: $\mu_1 = \mu_2 = \mu_3 = \mu$, mode of transition has no significant impact on test results,

b) H_1: mode of transition has a significant impact on test results; at least one of the means μ_1, μ_2 or μ_3 does significantly differ from at least one of the remaining variables.

3. Checked whether the following assumptions were met in order to select the test and determine the distribution of the statistics:

a) the normality of the distribution – the Shapiro-Wilk test proved that the variable had a normal distribution in only one of the subpopulations (G3) of the independent value.

b) the homogeneity of variance – the groups were selected from the population with different variances (differentiation of results between the groups was significant).

The variance analysis (ANOVA) is the most appropriate statistical method for more than two independent groups. Still, since the assumptions of normality of distribution and homogeneity of variance were not met, the very application of variance analysis to this case is debatable.

G. Wieczorkowska et al. (2004) believe that in order to use the F test (used in the variance analysis to compare average squares of de-

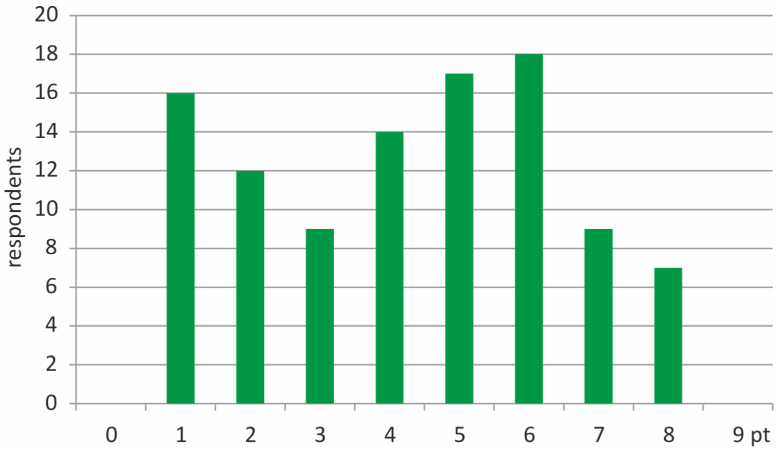


Fig. 3. Summarized frequencies for all respondents' results (102 people)

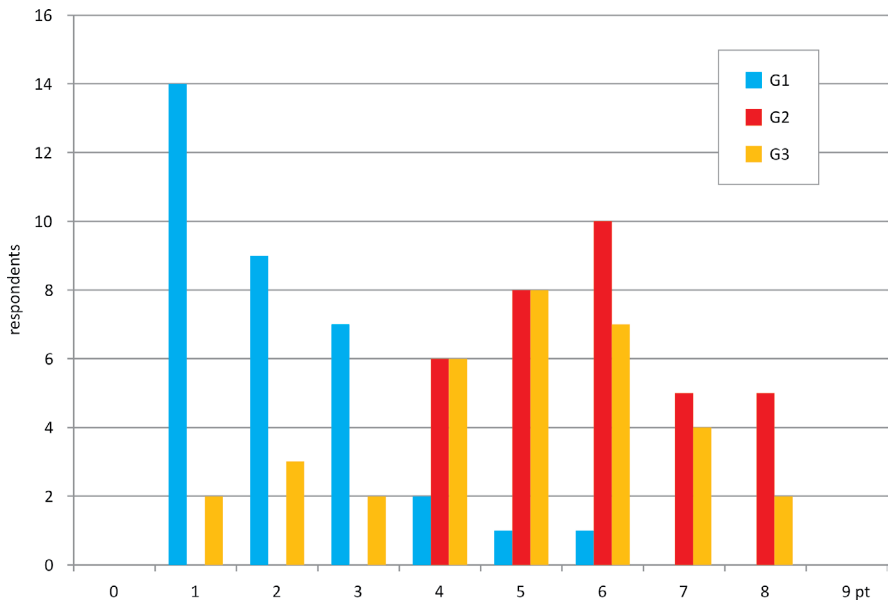


Fig. 4. The comparative graph for frequencies in the respective experimental groups: G1 – *smooth* condition, G2 – *abrupt* condition, G3 – *abrupt with decay effect* condition

viations between groups with the group-internal square of deviation) "the variable should have normal distribution in the population, still the F test proves quite resilient to failure to meet the requirement of normality of distribution" (G. Wieczorkowska et al. 2004, p. 191). Lindman, in turn, proved that the F statistic is completely resistant to the infringement of assumption of homogeneity of variance, especially when the groups are equally numerous and their populations are larger than 10 (*Elektroniczny podręcznik statystyki, StatSoft*).

4. In order to be certain about the reliability of interpretation of experimental results, we

decided to conduct both a single factor variance analysis and the Kruskal-Wallis test, which is an alternative for a single factor variance analysis.

a) Single factor variance analysis:

For significance level of $\alpha = 0.05$, degrees of freedom $df_B = 2$ and $df_W = 99$, the critical test value is $F_{crit} = 3.1$. $F_{result} = 56.25$ and is larger than F_{crit}, that is why at $\alpha = 0.05$ we abandon H_0 and adopt the alternative hypothesis of H_1: mode of transition has a significant impact on test results; at least one of the averages μ_1, μ_2 or μ_3 does significantly differ from at least one of the remaining variables.

b) Kruskal-Willis test:

The probability P of achieving the observed H value is lower than the significance level $\alpha = 0.05$, and thus the result of Kruskal-Willis test justifies the abandonment of the initial hypothesis H_0: $\mu_1 = \mu_2 = \mu_3 = \mu$, mode of transition has no significant impact on test results.

4.3. Mistakes respondents made

Having finished the statistical procedure, we went on to perform a detailed analysis of the research material, aiming at ascertaining what type of mistakes was made by participants while solving the test.

Type of content interpretation by respondents is best illustrated by answers to open-ended questions. In question 2 (*mark the moment in which the town of Umbra was first included in the boundaries of Amberland with a vertical line on the time axis below*) the participants of the G1 group (which was shown the *smooth* animation) most frequently indicated the timeframe of 1300-1370 (tab. 2). These answers were more frequent than the correct ones. This fact proves that the respondents erroneously treated the territorial development of Amberland as a continuous process, with boundaries gradually moving in time between subsequent actual changes.

Similar mistakes were made by participants in task 3 (this issue was partially discussed in item 3) and 6. In each of these questions, there were only 5 correct answers recorded. As many as 18 persons replied incorrectly '100' to the question: *For how many years did the boundary of Amberland run along the Indigo River?* (task 6). It is most likely the result of the fact, that with the *smooth* mode of transition, this boundary, after just 100 years, begins to move back in the direction of the Turquoise River. Actually, it changes its location only after 200 years.

What is worth stressing is that in only one case were the correct answers dominant (Task 7: *Please state the year in which the Emerald Lake was first included in the boundaries of Amberland*). It is hard to explain why 23 of 34 participants replied correctly '1600' to that specific question (even with the *smooth* animation showing the Emerald Lake completely within state boundaries already around 1550).

Table 2. The analysis results for responses of G1 respondents

Question	Number of correct answers	Number of incorrect answers	Most common wrong answer (number of people)
1*	5	**29**	Answer B: 1200–1300 (25)
2*	11	**23**	Most frequent dates marked on the axis between 1300 and ca. 1300 (19 in total)
3*	5	**29**	1000–1100 (13), 1000–1150 (6)
4*	5	**29**	Answer A: in the years 1800–2000 (15), answer C: in the years 1900–2000 (14)
5*	2	**32**	Boundary shape as: in 1600 (13), between 1400 and 1600 (9)
6*	5	**29**	100 years (18)
7*	**23**	11	1500 (4), 1550 (2)
8*	15	**19**	Cornflower Mountains and Cyanides (7)
9*	3	**31**	Answer B: in 1000 (17)

* Open-ended question

Due to the common use of *smooth* animation, the type of mistakes made by the respondents from the G1 group is particularly significant. Based on the conducted experiment, we were able to prove that a mode of transition of changes in political boundaries that is remarkably often used in cartographical practice can lead to wrong interpretation of map content.

In the G2 group (*abrupt* animation) correct answers are predominant (tab. 3). Only task 4 (*When did the western part of Amberland boundary move westward?*) and 9 (*When did Amberland have the smallest area?*) the wrong answers were more numerous. Both were multiple choice questions with a single answer. What is most important, both were connected with the outline of the Amberland boundary. While other tasks pertained to relations of the location of different objects (towns, rivers, lakes, and mountains) and the state boundary, questions 4 and 9 concerned the comparison of the area of the state in different moments.

The analysis of answers from the G2 respondents (and in particular to the aforesaid question 4 and 9 with most erroneous answers) does bring us to the conclusion that even when the *abrupt* animation is methodologically correct (pursuant to the congruence and changeability isomorphism principles), it can hinder a comparison of respective moments in the course of animation. This is a result of vanishing symbols that lead to a lack of correspondence in the content of adjacent temporal states.

In our analysis of mistakes made by the respondents of the third group (G3 – *abrupt with decay effect* animation), we also first pointed our attention to questions with most incorrect answers. Similar to the G2 group, most mistakes were made in task 9 (tab. 4). What also seems significant because of a large number of incorrect answers is the open-ended questions (5, 6, 8). It seems that the line that symbolizes "the boundary of Amberland in subsequent period" (as clarified in the legend) proved to be misleading. Most likely, some students treated that line as a boundary that occurred at the moment of its appearance on the map (that is some 100 years earlier than actually).

This brings us to the conclusion that respondents failed to acquire the ability to read complex animation (*abrupt with decay effect*) with the transition effect between the current and subsequent time period. This made it difficult for them to answer the aforesaid questions. We should not exclude that a more comprehensive explanation of symbols in the legend could have allowed the avoidance of this type of mistakes in the content perception. The current description of "the area of Amberland" could be replaced with a more developed "area of Amberland in the year marked on the time axis". A modification of the legend could lead to an increase in the number of correct answers.

Another possible solution that could improve the effectiveness of content communication is the oral introduction (instruction) to the *abrupt with decay effect* animation played or lectured

Table 3. The analysis results for responses of G2 respondents

Question	Number of correct answers	Number of incorrect answers	Most common wrong answer (number of people)
1*	**23**	11	Answer B: 1200–1300 (9)
2*	**27**	7	1600 (2), 1800 (2)
3*	**22**	12	1200–2000 (6)
4*	11	**23**	Answer A: in the years 1800–2000 (18)
5*	**20**	14	Borderline similar to that of 1600 (9)
6*	**25**	9	100 years (4)
7*	**32**	2	Two different answers
8*	**25**	9	Cyanides (4), Cornflower Mountains and Cyanides (4)
9*	10	**24**	Answer B: in 1000 (18)

* Open-ended question

Table 4. The analysis results for responses of G3 respondents

Question	Number of correct answers	Number of incorrect answers	Most common wrong answer (number of people)
1*	**20**	14	Answer B: 1200–1300 (13)
2*	**26**	8	Eight different answers
3*	**25**	9	1200–2000 (3)
4*	**21**	13	Answer A: in the years 1800–2000 (6), Answer C: in the years 1900–2000 (7)
5*	8	**26**	Borderline similar to that of 1600 (22)
6*	17	17	300 years (7)
7*	**29**	5	Five different answers
8*	16	**18**	All mountains ranges (5)
9*	6	**28**	Answer A: in the years 1000–1100 (14), Answer B: in 1000 (14)

* Open-ended question

prior to the main part of the experiment. Still, with the need to preserve identical experimental conditions in respective groups, we purposefully omitted this procedure.

5. Results and discussion

Results of both statistical analyses lead us to the conclusion that the cartographic design of scene transitions has a significant impact on the perception of animated maps depicting discontinuous dynamics. We proved that the results in at least one group (G1) differed significantly from the remaining ones, which shows the diversified effectiveness of content communication by means of the three investigated modes of representation. As long as the use of *abrupt* and *abrupt with decay effect* transitions gave similar results, the students using *smooth* animation scored significantly lower. The in-depth analysis of answers in this group of respondents explains the way of interpreting map content. The majority of mistakes made was most likely the result of receiving discontinuous dynamics (in the form of a change of states' territorial boundaries) as a continuous process.

The second investigated mode – *abrupt* (G2) gave the best overall results. However, the significant number of incorrect answers to questions relating to the comparison of the respective temporal states may indicate that *abrupt* animations are inadequate to this purpose. This was most likely the result of the fact, that changes in boundaries in this type of animation occur rapidly, which may disturb the perception of some dynamic variables (e.g. the direction and size of change).

Due to the fact that the results in group G3 were not much lower than in G2 (tab. 1), we may assume that the *abrupt with decay effect* mode forms an alternative to the *abrupt* transition. We should also consider the question of adjusting the developed mode of representation to map readers' age and experience – it might have been too complicated for 13 and 14-aged participants of the study. The use of the *abrupt with decay effect* animation requires some further investigation and the development of design guidelines for this type of animated maps.

At this point, it is worth mentioning the issue of *change blindness* as "a phenomenon whereby individuals fail to notice change that occurs in a visual stimulus" (K. Goldsberry and S. Battersby 2009, p. 204). To avoid this problem and draw the user's attention to the change it was suggested to apply *smooth* transitions between display frames (S.I. Fabrikant et al. 2008). However, our experiment pointed out that participants using *abrupt* animation were able to detect changes and they had even better than other groups (using maps with *smooth* and *abrupt with decay effect* transitions) the overall results. The explanation of the outcome of our study could be the *magnitude of change* applied, as this cartographic variable is directly related to the issue of change blindness (K. Goldsberry and S. Battersby 2009). Presumably, the changes occurring on tested animations were large enough to be able to notice even with the use of *abrupt* transitions.

The results of our experiment may also appear to contradict the previous C. Fish et al.'s study (2011), as their outcome indicated the predominance of *smooth* transitions compared with *abrupt* ones. However, the research of C. Fish et al. (2011) concerned the detection of change. Whereas our study was focused on how users interpret the nature of changeability. Furthermore, C. Fish et al. (2011) analysed other type of animated maps – choropleth. These important differences between research goals and materials might be the main reason for the results' discrepancy between the two aforesaid experiments.

6. Conclusion

Research to date mostly concentrated on comparing the effectiveness of animated and static maps. Our experiment is just one of two studies concerning the issue of the cartographic design of scene transitions in animations. The user tests were aimed to ascertain the influence of the mode of representation of discontinuous phenomena on the perception of animated map content. The analysis of the data gathered during the research allowed us to formulate the following conclusions:

1. The mode of representation of phenomena with discontinuous dynamics significantly influences the interpretation of animated map content.
2. Maps designed in the *smooth* mode demonstrate significantly lower content communication effectiveness when compared with the *abrupt* and the *abrupt with decay effect* mode.
3. The low effectiveness of the *smooth* animation may largely be the result of the interpretation of changes in state boundaries as a continuous process.
4. The best test results were attained by respondents from the group that used the *abrupt* animation. Still, fewer correct answers were recorded to questions concerning comparing respective temporal states.
5. Participants solving tasks on the basis of the proposed *abrupt with decay effect* animation recorded slightly worse results than those who used the *abrupt* animation.
6. Further use of this mode of transition requires more qualitative research with user participation. Its results could indicate what editorial corrections should be applied to increase the effectiveness of the content communication.

The present paper contributes to the formulation of design guidelines for the efficient animated maps. The results of the experiment could be a guide for the cartographers. What is important is the need to adhere to the congruence and changeability isomorphism principles in the animation design. Without any doubt, the present paper does not exhaust the issue of the impact of the representation mode on the perception of animated maps. We also recommend further qualitative research in order to provide a better understanding of the way in which users interpret the nature of dynamic processes.

Literature

Battersby S., Goldsberry K.P., 2010, *Considerations in design of transition behaviors for dynamic thematic maps*. "Cartographic Perspectives" Vol. 65, pp. 16–32, 67–69.

Biswas S., 2004, *A conceptual design for visualisation of spatio-temporal data using animation with linked graphics*. http://www.itc.nl/library/Papers_2004/msc/gfm/biswas.pdf

Cutler M.E., 1998, *The effects of prior knowledge on children's abilities to read static and animated maps* (M.S. thesis), University of South Carolina, Columbia, South Carolina.

Edsall R.M., Kraak M.-J., MacEachren A.M., Peuquet D.J., 2003, *Assessing the effectiveness of temporal legends in environmental visualization*. In: *GIS/LIS '97*, Cincinnati, Oct. 28–30, pp. 677–685.

Elektroniczny podręcznik statystyki, StatSoft. http://www.statsoft.pl/textbook/stathome_stat.html?http%3A%2F%2Fwww.statsoft.pl%2Ftextbook%2Fstanman.html

Fabrikant S.I., Rebich-Hispanha S., Andrienko N., Andrienko G., Montello D.R., 2008. *Novel method to measure inference affordance in static small-multiple map displays representing dynamic pro-*

cesses. “The Cartographic Journal” Vol. 45, No. 3, pp. 201–215.

Fish C., Goldsberry K.P., Battersby S., 2011, *Change blindness in animated choropleth maps: An empirical study*. “Cartography and Geographic Information Science” Vol. 38, No. 4, pp. 350–362.

Gershon N., 1992, *Visualization of fuzzy data using generalized animation*. In: *Proceedings, Visualization ‘92*, Boston, Massachusetts, Oct. 19–23, pp. 268–273.

Goldsberry K., Battersby S., 2009, *Issues of change detection in animated choropleth maps*. “Cartographica” Vol. 44, Issue 3, pp. 201–215.

Harrower M., 2003, *Tips for designing effective animated maps*. “Cartographic Perspectives” No. 44, pp. 63–65.

Harrower M., 2007, *The cognitive limits of animated maps*. “Cartographica” Vol. 42, Issue 4, pp. 349–357.

Johnson H., Nelson E.S., 1998, *Using flow maps to visualize time-series data: Comparing the effectiveness of a paper map series, a computer map series, and animation*. “Cartographic Perspectives” No. 30, pp. 47–64.

Köbben B., Yaman M., 1995, *Evaluating dynamic visual variables*. In: *Proceedings of the seminar on teaching animated cartography*. International Cartographic Association, Madrid.

Koussoulakou A., Kraak M.-J., 1992, *Spatio-temporal maps and cartographic communication*. “The Cartographic Journal” Vol. 29, No. 2, pp. 101–108.

Kraak M.-J., Ormeling F., 2013, *Cartography: Visualization of Spatial Data*. Routledge, London and New York.

Lai P.-C., Yeh A.G.-O., 2004, *Assessing the effectiveness of dynamic symbols in cartographic communication*. “The Cartographic Journal” Vol. 41, No. 3, pp. 229–244.

Opach T., 2007, *Sprawność map animowanych prezentujących dynamikę zjawisk*. http://www.wgsr.uw.edu.pl/kartografia/Opach_autoreferat/rysunki/Opach_Tomasz_doktorat.pdf.

Oxford Dictionaries. https://www.oxforddictionaries.com

Patton D.K., Cammack R.G., 1996, *An examination of the effects of task type and map complexity on sequenced and static choropleth maps*. In: *Cartographic design: theoretical and practical perspectives*, ed. by C.H. Wood and C.P. Keller, Wiley, Chichester, pp. 237–52.

Rutkowski J., 1984, *Przegląd metod i niektóre problemy związane z kartograficzną prezentacją dynamiki zjawisk w geografii*. In: *Teoretyczne i metodyczne problemy współczesnej kartografii*. Lublin, Sept. 11–12, „Materiały Ogólnopolskich Konferencji Kartograficznych” T. 10, pp. 144–152.

Slocum T.A., Blok C., Jiang B., Koussoulakou A., Montello D.R., Fuhrmann S., Hedley N.R., 2001, *Cognitive and usability issues in geovisualization.* “Cartography and Geographic Information Science” Vol. 28, No. 1, pp. 61–75.

Slocum T.A., Egbert S.L., 1993, *Knowledge acquisition from choropleth maps*. “Cartography and Geographic Information Science” Vol. 20, No. 2, pp. 83–95.

Slocum T.A., Robeson S.H., Egbert S.L., 1990, *Traditional versus sequenced choropleth maps: an experimental investigation*. “Cartographica” Vol. 27, No. 1, pp. 67–88.

Tversky B., Morrison J.B., Bétrancourt M., 2002, *Animation: Can it facilitate?* 262http://serc.carleton.edu/files/NAGTWorkshops/visualize04/Tversky_2002.pdf#search=%22Animation%3A%20Can%20It%20Facilitate%3F%22

Wieczorkowska G., Kochański P., Eljaszuk M., 2004, *Statystyka. Wprowadzenie do analizy danych sondażowych i eksperymentalnych*. Wydawnictwo Naukowe Scholar, Warszawa.

Internet sources

http://sydney.edu.au/arts/timemap/examples/map_animation.shtml

https://www.youtube.com/watch?time_continue=194&v=caxAAZsL-wQ

https://www.youtube.com/watch?v=PMKos-CcsYY

https://www.youtube.com/watch?v=zX00OjIwcIM https://www.youtube.com/watch?v=66y49BnxL-fQ&t=48s

Appendix 1

The set of tasks used during the experiment.

1) In what years did city of Ochra lie within the borders of the Amberland State? Circle the correct answer (A, B or C):
   (A) 1100–1300
   (B) 1200–1300
   (C) 1200–1400

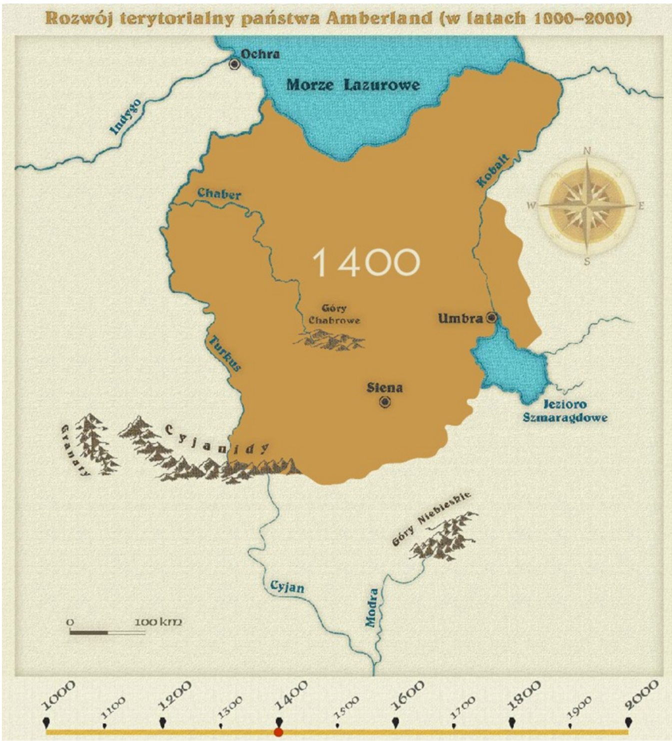
2) In the following timeline, mark with the vertical bar when the city of Umbra was first situated within Amberland.

3) Specify what time interval (from to) the city of Siena was not within Amberland.

   ……..

4) When was the western part of the Amberland border moved to the west? Circle the correct answer (A, B or C):
   (A) in 1800–2000
   (B) in 2000
   (C) in 1900–2000

5) Draw the line to mark the approximate course of the southern border of Amberland in 1500 on the map below (to make it easier, its range from 1400 has been marked).

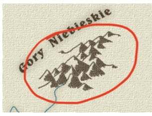


6) Specify how long the Amberland State boundary ran along the Indygo River.

……

7) Specify the year in which the Emerald Lake was wholly within the limits of the Amberland State.

……

8) In the map below, mark (according to the pattern: 

) the mountain range/ranges that was/were wholly found within the Amberland State in 1900.

9) When did the Amberland State have the smallest area? Circle the correct answer (A, B or C):

(A) in 1000–1100
(B) in 1000
(C) in 1000–1200