DESIGNING STATIC AND ANIMATED MAPS FOR USERS FROM DIFFERENT AGE GROUPS DEDICATED TO ELECTRONIC PAPER VISUALIZATION DEVICES

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Abstract
In the research reported here, the author analysed and synthesised the possibilities and limitations related to the use of e-paper visualization devices for displaying static maps and spatio-temporal cartographic animations to users in different age groups. Based on an analysis of the technical limitations on the employment of visual variables in designing animations meant to be displayed on e-paper devices, as well as the impact of these limitations on the potential employment of related cartographic methods of presentation, the author proposes a modification of previously proposed tables of rules for the use of combinations of static and dynamic visual variables and sound variables and related cartographic methods of presentation for different age groups, as well as general guidelines for the design of static and dynamic maps for users from different age groups.

Keywords: *e-paper, Animated maps, Static Maps, Age groups, Methodology*

INTRODUCTION

It is commonly supposed that the first type of electronic paper – Gyricon – was developed in 1974 by Nicholas K. Sheridon at Xerox's Palo Alto Research Center (Crowley et al. 2011). In the 42 years since then, eleven different e-paper technologies have been developed, tested and refined, but it is only since 2004 that applications of visual displays of this kind have become really widespread – following the commercialization of the first e-reader, Librié EBR-100EP (employing E Ink Corporation e-paper), by Sony in 2004. In the last ten years, different types of electronic paper have found various applications, such as in e-reader displays, mobile phones, wristwatches, smart watches, smartcards, keyboards with dynamically changeable keys, information boards, electronic shelf labels, digital signage, military equipment, as well as status displays on UBS flash drives.

One of the most dynamic and promising sector of this market has been that of e-readers. Between 2004 and 2011 the number of e-reader models available surged from 1 to 78, and the number of e-reader producers from 1 to 38. However, it should be stressed that in 2011 nearly 88% of all e-readers were employing the electrophoretic e-paper produced by E Ink. Its limitations, as well as competition from new LED display technologies (and graphene applications in LED and OLED technologies since 2016), resulted in a dramatic decrease in the numbers of models and producers, down to 46 and 16, respectively, in 2016. It is possible, that this situation may change with the advent of new market-ready e-paper technologies, which are now the subject of intensive research and development work. It should be emphasized that even now, e-paper has many merits. As it reflects light like paper, it is more comfortable for readers than other displays. E-paper contrast ratio is better than in the case of other displays (which allows readers to use it even in direct sunlight). Other good points are wide viewing angle, easy zoom, reduced weight, flexibility, low energy consumption. Moreover, in 2016, at least two types of this display available on the market and four prototypes supported the visualization of animations. The first electrophoretic electronic paper e-reader supporting the visualization of animations was commercialized in 2011. In February 2012, D. Dukaczewski presented in IGiK a monochrome cartographic animation of changes in industrial employment in Warsaw over the 1913 – 1995 period prepared in December 2011, employing an electronic paper e-reader (Dukaczewski 2015) (*Figure 1*). In October 2012, the company Vivit demonstrated a colour cartographic animation of changes in Arctic Sea ice thickness employing the prototype of a new e-paper kit.

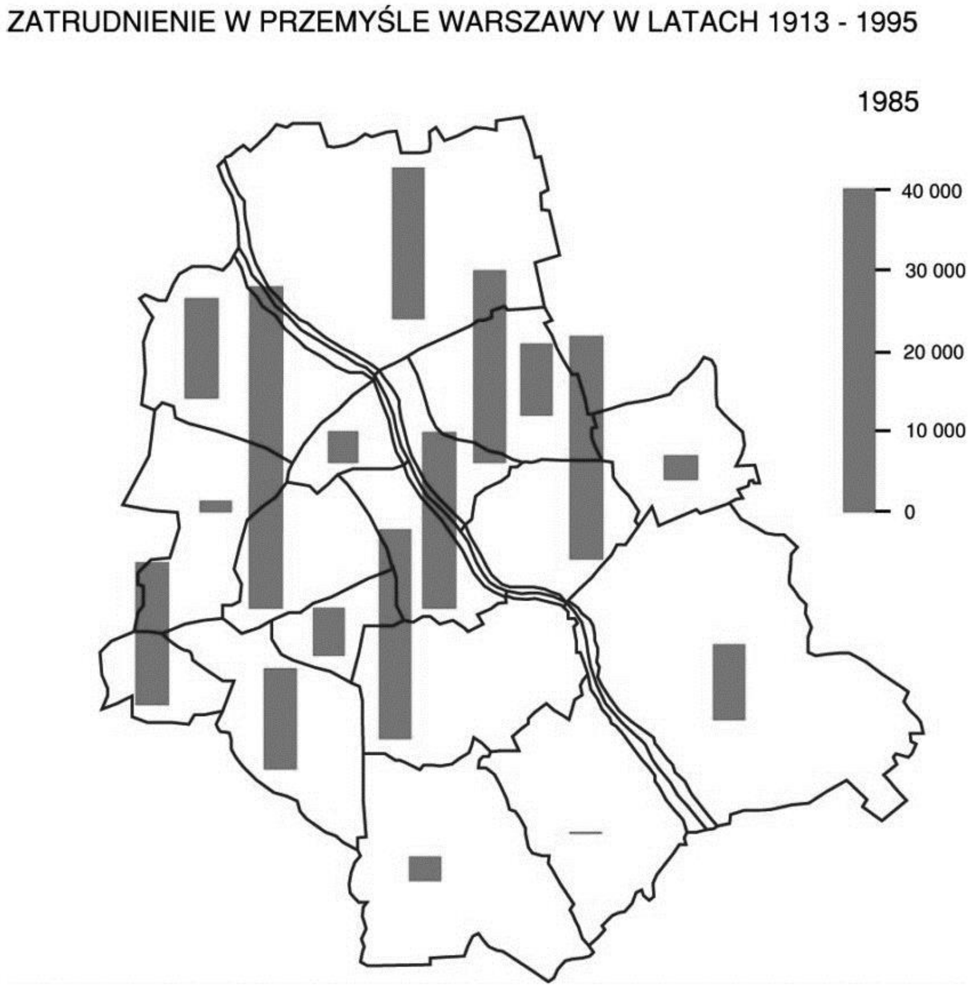

Figure 1. *Frame of author's animaton 'Changes in industrial employment in Warsaw over the 1913 – 1995 period' displayed on e-paper reader in 2011.*

All these strong points and recent advancements in e-paper technologies make them a very interesting and promising type of display, which could be employed as mobile viewer of static and dynamic scientific and educational cartographic visualizations. Electronic paper displays can be also very practical as mobile viewers of e-maps and e-atlases. E-readers employing such displays are very promising tools that can be used in teaching (especially for biology, chemistry, history and geography).

However, not all current types of e-paper have all these merits. In 2016 only a few e-paper products employed in the e-readers available on the market were able to display animations, but it was very difficult to find a product was allowing to do so in colour (*Table 1*). Thus, one of the 'proper' visual variables (Dukaczewski 2003), which plays a very important role in our perception of dynamics (Hanewinkel and Tzschaschel 2005) is present in displays, but is achromatic. This may result, according to Kraak and Ormeling (1996), in a loss of the ability to distinguish 7 classes in the case of point and line entities and 8 classes in the case of area entities. An alternative (modest) solution involves the use of the visual variable of value, which allows only 3 classes to be distinguished in the case of point entities, 4 in the case of line entities and 5 in the case of area entities. Research on visual and aural perception of animations by users of different age groups representative for the population of Warsaw (Dukaczewski 2014) has confirmed that perception of the visual variable of colour is very sensible, and its appropriate employment is of big significance for the correct comprehension of presented processes. According to the extracts of medical statistics from Warsaw Medical University and the tests carried out two times on 287 representatives of the eight age groups from Warsaw[11] the significance of these variable were ranked as 8 (in 1 – 10 scale) in the case of first group, 9 for the second, third and fourth group, 8 in the case of fifth age group, 6 for the sixth group, 4 and 3 for the seventh and eighth groups respectively. This is the maximal rank from the first till the sixth age group.

[11] 1: nursery (4 – 6 years), 2: late childhood (7 – 9), 3: adolescence (10 – 15), 4: advanced adolescence (16 – 19), 5: early adulthood (20 – 30), 6: middle adulthood (31 – 60), 7: late adulthood (61 – 80), 8: advanced age (over 80). The particular age ranges of the groups may differ depending on the country

Technology	Firm	Properties				
		Animations / refresh rate (ms)	Colour	Contrast	Viewing angle	Flexibility
Electrophoretic	E Ink	AC (50)[12]	AC[13]	10:1	90º	Yes
	SiPix	X (500)	W	6:1	180º	Yes
	Bridgestone	AP (0,2)	AP	8:1	180º	Yes
Electrowetting	Amazon (Liquivista)	AP (12-13)	AP	18:1	180º	P
Interferometric Modulator Display, MEMs	Qualcomm (Mirasol)	AC[14] (10) W	AC W	20:1	70º	X
Electrokinetic	Folium Optics	P	AP	10:1	180°	Yes
Electrofluidic	Gamma Dynamics	AP (30)	AP	10:1	180°	Yes
Gyricon	Visitret Displays	X	X	8:1	180°	Yes
Electrochromic	Aveso, Ntera, Ricoh	X	AP	20:1	180°	Yes
Cholesteric liquid cristal display - ChLCD	Fujitsu	X	AC	10:1	180°	Yes
	Hitachi	X	AP	10:1	180°	Yes
	Kent Display	X	AS	25:1	180°	Yes
Zenithal bistable display	ZBD	X	X	20:1	160º	Yes
Photonic Crystal	Opalux	X	AC	1000:1	180°	Yes
REED Technology	Zikon	AP	W	10:1	160º	Yes

Table 1. *Types of e-paper and its properties (autumn 2014).*

Key: **AC** – achieved & market accessible; **AS** – achieved & specialized market accessible, **AP** – achieved, still not market accessible, **W** – works, **P** – possible in the future; **X –** still not possible

The perception of the colour deteriorate especially from 40 till 60 years old[15]. An inability to dynamize the variable of colour in the case of animations dedicated to e-paper devices also results in reduced potential application of certain methods of cartographic presentation. It should be emphasized that not all recently commercialized e-paper visualization devices employ alpha blending. As such, some of them do not use the visual variable of aura. Other limitations include impediments in the placement of buttons for interactive functions of animations in the case of e-readers. The function of zoom is not active during the presentation of the animations.

All these limitations complicate the process of designing animations meant to be displayed on electronic paper devices. This process demands great caution and special attention paid to the principles of semiotics and cartographic methodology. In the present author's opinion, one way to avoid impairment of the process of spatio-temporal information transfer in the case of persons of different age reading animations displayed on e-paper devices is to take these limitations and restrictions into account in the tables of rules and general guidelines for designing simple and complex animated maps addressed to users from different age groups. The colour e-paper devices of moderate refresh rate can be employed to visualize the static maps, but due to the specificity of e-paper devices it is also necessary to modify tables of rules and general guidelines for designing the maps for users from different age groups.

[12] With accelerator (fast page turn mode)
[13] The refresh rate of the first electrophoretic colour display (introduced into the market 15 January 2012) was 120 ms, ruling out the use of animations.
[14] Commercialized in 2011 – 2012, discontinued due to the high price
[15] In the case of this group the risk of confusion of green, blue and purple is growing fast

OBJECTIVES, APPROACH AND METHODS

The first aim of this research was to investigate how the procedural methods for designing simple and complex animated maps for users from different age groups, elaborated by author need to be modified, to make them applicable to the design of age-group-tailored animations meant to be displayed on electronic paper devices. The second goal was to investigate which part of the tables of rules and general guidelines elaborated for this goal is applicable for designing static maps addressed to users from different age groups. The methodological point of reference here is the set of rules and guidelines proposed by the author for the *entities–cartotrophic method* of designing simple animations[16] and the *entities–polystaymic method* of designing complex animations[17], tailored for users belonging to one of eight different age groups (Dukaczewski 2014). To elaborate this set of rules it was necessary, first of all, to identify the perceptual determinants influencing the possibilities for (and limitations on) the use of particular variables in the presentation of spatio-temporal phenomena, verifying which of them can be parameterised. The next stage involved the analysis and synthesis of available information on factors affecting the visual and aural perception of variables, related to user age, generation and education level. On the basis of medical literature (ie. Cavanagh, Mather 1989, Conway et al. 2010, Crognale 2002, Crognale et al.2001, Elliott et al. 2012, Fiorentini et al. 1996, Ishihara et al. 2001, Knoblauch et al. 2001, Pokorny et al. 1987, Schefrin et al. 1993, Shinomori et al. 2001), the opinions of specialists from Warsaw Medical University, and extracts of medical statistics, it was possible to distinguish eight age groups of differing types of perceptions. The analysis and synthesis of the available data allowed to propose the ranking of the variables in terms of utility for each age group. This allowed to propose the guidelines concerning the use of static and dynamic visual and sound variables, together with related methods of cartographic presentation for each age group. This made it possible also to propose general recommendations concerning the design of animations, stemming from investigations into their perception, as well as remarks about the user interface. The utility of these guidelines was then tested on groups of representatives, employing prepared test animations[18]. The results of these tests allowed the ranks of variables and related methods of cartographic presentation to be further refined. Based on these modified guidelines, tables of rules were proposed for the use of variables and methods for each age group. The modified animations were tested a second time, and the results were evaluated using the method of average quality metrics (Kolman, 1983; Dukaczewski, 1978). The details of this work were described in Dukaczewski (2014). This research has thus far been shown to be representative and valid for the tested population in Warsaw. However, it should be stressed that the same or a similar procedure can be carried out for other populations, leading to the development of appropriate tables of rules and general recommendations concerning users from different age groups. The carried tests and their results were described in detail in other publication (Dukaczewski 2014).

Till now the number of animated maps dedicated to e-paper visualization devices is small and design of such a maps is relatively difficult. In author’s opinion one of the solution could be application of the procedural methods for designing simple and complex animated maps for users from different age groups, employing the modified set of rules and guidelines. To achieve this goal, it was necessary first to identify the technical limitations on the usage of visual variables in designing animations meant to be displayed on electronic paper devices, to analyse the influence of these limitations on the possibilities for employing related cartographic methods of presentation, and to propose substitute solutions. This made it possible to modify the tables of rules for the usage of combinations of static and dynamic visual variables and sound variables, as well as tables of rules for the application of related cartographic methods of presentation for each age group. The next stage involved an analysis and synthesis of the identified limitations concerning the functionalities of cartographic animations to be displayed on e-paper devices, as well as possibilities and limitations related to the design of key frames, legends and texts. This made it possible to modify the proposed general recommendations for designing animations for each age group. The results of these analyses and syntheses led to modifications of the *entities–cartotrophic method* of designing simple animations and the *entities–polystaymic method* of designing complex animations, tailored for users belonging to eight age groups. The additional stage of investigation was to verify which part of general guidelines and tables of rules elaborated previously can be applicable in the case of designing of static maps for users from different age groups.

[16] including only one animation

[17] Including a number of sub-animations, allowing to present more information about the correlated dynamic processes and/or about their causes (Dukaczewski 2007)

[18] The first three groups consisted of 32 six-year-old, 86 nine-year-old, and 32 twelve-year-old children from Primary School No. 212 in Warsaw. The fourth age group was represented by 32 eighteen-year-old pupils from the 44th Secondary School in Warsaw, and the fifth group by 31 students aged 22-23 studying in different faculties at Warsaw University. Tests concerning the sixth group (31 people) and seventh group (32 people) were carried out on a population of members of ActiFrance interdisciplinary club. The tests were also performed on a small population of 11 people aged over 80 years.

RESULTS

For technical, financial and organizational reasons, in autumn 2014 the sole e-paper e-readers and evaluation kits allowing chromatic animations to be displayed were prototypes, unavailable on the commercial market. This technical limitation had methodological repercussions. The achromatic visual variable of *colour* was present, like other 'proper' visual variables (*size, value and shape*) in monochrome animations, but it was not possible to employ it as a dynamized variable (depicting changes), or even use it to signal the diversity of static information. For technical reasons it was also not possible to employ the static variable of *aura*.

The tests carried out have demonstrated the possible usage of all dynamic visual variables, as well as sound variables (the latter in the case of e-readers). Due to the limitations concerning the usage of *colour* and *aura* variables, the number of correct (and applicable) combinations of static and dynamic visual variables and sound variables, appropriate for the different age groups, was limited from 127 to 95. This situation resulted, in 17 cases, from the inability to use the variable of *colour*, in 14 cases from the inability to employ the variable of *aura*, and in one case from both of these. The analysis carried out led to a modification of the table of rules for '*evaluation of the combination of static and dynamic visual variables and sound variables for users of different age groups*'. The resulting table is available in Appendix 1 at http://www.igik.edu.pl/upload/File/dr-dd/_95_Appendix1.pdf.

The inability to employ *colour* and *aura* likewise resulted in the limitation of the number of cartographic methods of presentation, related to the combinations of static and dynamic visual variables and aural variables at different levels of measurement. The number of such combinations was reduced from 127 to 80 (in 24 cases because of the inability to use *colour*, in 18 cases because of the same inability in the case of *aura*, and in 5 cases due to both of these). The most frequently abandoned methods in the case of combinations employing *colour* were: quantitative point signatures (Sαc), ordinary line signatures (Sβb), ordinary line choropleth maps (Kβb), ordinary line cartodiagrams (Kdβb), isoline maps (Ic), qualitative line signatures (Sβa), quantitative line signatures (Sβc), quantitative line choropleth maps (Kβc), quantitative line cartodiagrams (Kdβc), chorochromatic method maps (MCa)[19] and range maps (MZa), while in the case of *aura* these were mainly: ordinary point signatures (Sαb), ordinary point choropleth maps (Kαb), ordinary point cartodiagrams (Kdαb), quantitative point choropleth maps (Kαc), quantitative point cartodiagrams (Kdαc), quantitative point signatures (Sαc), ordinary line signatures (Sβb), and ordinary line choropleth maps (Kβb). This analysis led to a proposed modification of the table of rules for the '*evaluation of the combined application of static and dynamic visual variables, sound variables and related methods of presentation for users of different age groups'.* The resulting table of rules is available in Appendix 2 at http://www.igik.edu.pl/upload/File/dr-dd/_95_Appendix2.pdf.

According to this table, *value* may be used as a substitute for *colour* in the case of the methods mentioned above, but this solution is less convenient due to the reduced number of levels visually distinguishable when employing this variable. It should be emphasized that the inability to employ *colour* and *aura* does not rule out the usage of any cartographic method of presentation. Due to the resolution offered by recent e-paper devices[20], however, it is recommended to avoid using complex choropleth maps with Osanna triangle or cross legend, employing 'proper' visual variables and direction. Research has shown that the recent technical limitations of e-paper displays do not restrict any of the proper combinations of cartographic methods of presentation, as shown in appendices 1 – 3 in Dukaczewski (2009). This evaluation was made using general semiotic criteria formulated by Bertin (1967, 1979), as well as the works of Kraak & Ormeling (1996), Rød (1997), MacEachren (1995), Köbben & M. Yaman (1996), Korycka-Skorupa (2002) and Dukaczewski (2003, 2007). Like in the case of animations designed for computer displays, it is necessary to abide by a few general rules. Care should be taken to avoid combinations of the following in the same complex animation:

- the same or very similar entities;
- methods that employ nearly the whole area of the frame;
- methods that use similar signatures, but different legends (for example: ordinary point cartodiagrams (Kdαb) and ordinary point signatures (Sαb));
- ordinary and quantitative methods.

It is of course not possible to use combinations of several of the same methods (ordinary point choropleth maps (Kαb), quantitative point choropleth maps (Kαc), ordinary Bertin's choropleth maps (KαBb), quantitative Bertin's choropleth maps (KαBc), ordinary area choropleth maps (Kγb), ordinary dasimetric choropleth maps (KDγb), and Bürgener pseudo-choropleth maps (KBγc)).

[19] Especially in the case of not simplified land use maps.
[20] usually only 200 – 320 dpi

One of the most important limitations of e-paper displays involves difficulties related to the design of functionalities. In the case of so called 'evaluation kits' the user can try to introduce the functionalities available on external devices. In the case of e-paper readers, in 2014 it was necessary to use only the functions provided by their designers, with functions therefore being limited to *start/stop*, *zoom in* and *zoom out*, as well as *portret/landscape*. It is possible to zoom by touching a screen, but this solution is not possible during the presentation of the animated map. A large share of LCD and LED readers were able to read .wmv, .avi, .flv, .mov, .m4v and .mpeg4 files, permitting the use of the functions of the corresponding formats. The problem is, that in 2014 only four models of e-paper readers were able to read .mov files, but they were unable to display the animations due to the poor refresh rate. In the case of models, which were able to display animations the sole accepted files were .pdf, .gif, .jpeg sequences. This resulted in limitation of the possibilities of design of the user's interface and reduced level of interactivity. According to the typology of levels of complexity of interactive functions of cartographic animations (*Table 2*) the recent e-paper readers allows only to navigate.

7. Analysis of spatio – temporal process
6. Choice of cartographic method of presentation
5. Choice of method of data processing
4. Building of visualization
3. Programming of visualization
2. Choice of visualization
1. Navigation

Table 2 *Typology of levels of complexity of interactive functions of cartographic animations (Dukaczewski 2007).*

It is possible, that future e-paper readers will were able to read .wmv, .avi, .flv, .mov, .m4v and .mpeg4 files. This will allow to prepare animations and applications which can be used in the Android system, which in 2015 was the operating system of 8.5% of e-paper readers. Due to the recent limitations a significant share of animations displayed on electronic paper devices have a relatively reduced level of interactivity.

E-paper displays can visualize both static and dynamic legends. Testing has revealed, however, that the employment of interactive legends was very difficult in 2016. There is no problem with introduction of visual benchmarks and explicative text; however, due to the relatively small dimensions of the displays these attempts may result in visual overload of the frames. Most e-paper readers currently available on the market that can display animations have 6" displays. The larger displays available on the market in 2016 have refresh rates too long to visualize cartographic animations[21]. For this reason, animations meant to be displayed on electronic paper and their accompanying legends should be relatively simple and should employ a reduced number of entities, variables and methods of cartographic presentation.

The testing carried out led to modifications to the '*guidelines of usage of static and dynamic visual and sound variables, related methods of cartographic presentation, and potential functionalities*', tailored for users of different age groups. The resulting table of rules is available in Appendix 3 at http://www.igik.edu.pl/upload/File/dr-dd/_95_Appendix3.pdf.

According to these guidelines, serious problems with reading cartographic animations displayed on e-paper readers may be encountered by users of the seventh and eighth age group. A few problems with perceiving more complex processes may also be experienced by representatives of the fifth and sixth age group. The tests have moreover demonstrated that complex analytical animations on e-paper readers can be too difficult to read for users of the sixth, seventh and eight age group.

The modified tables of rules (Appendix 1, 2) and guidelines (Appendix 3) can be employed in author's *entities–cartotrophic method* and *entities–polystaymic method* of designing simple animations (http://www.igik.edu.pl/upload/File/dr-dd/_95_Appendix4.pdf) and modified *entities–polystaymic method* of designing complex animations (http://www.igik.edu.pl/upload/File/dr-dd/_95_Appendix5.pdf), facilitating the age-group-tailored design of animated maps meant to be displayed on electronic paper.

The next stage was testing which part of general guidelines and tables of rules elaborated previously can be applicable in the case of designing of static maps for users from different age groups. These investigations were carried out for e-readers employing three types of electronic papers: achromatic (but supporting animations), 'standard' chromatic (of moderate refresh rate) and experimental chromatic supporting alpha blending. The carried analysis and tests allowed to modify the proposed tables of rules and general guidelines. The resulting tables are available in Appendix 6 *'Evaluation of the combination of static visual variables for users of different age groups'* at http://www.igik.edu.pl/upload/File/dr-

[21] Since 2010, at least 4 laboratories have declared that they are working on developing large, fast-refresh e-paper displays

dd/_95_Appendix6.pdf, Appendix 7. *'Evaluation of the combined application of static visual variables and related methods of presentation for users of different age groups'* at http://www.igik.edu.pl/upload/File/dr-dd/_95_Appendix7.pdf and Appendix 8. '*Guidelines of usage of static visual variables, related methods of cartographic presentation and functionalities'* at http://www.igik.edu.pl/upload/File/dr-dd/_95_Appendix8.pdf, which can be a useful tool for designing the static maps for users of electronic e-paper readers.

CONCLUSION

The main aim of this research was to contribute to the discussion about the possibilities for (and limitations on) the design of animated and static maps meant to be displayed on electronic paper devices, tailored to the needs of users belonging to different age groups. Another objective was to further advance the cartographic animation methodology itself. The methodological point of reference was an established set of rules and guidelines, resulting from investigations on age-related differences in perception of cartographic animations (Dukaczewski 2014). The analysis described herein, of the technical limitations on the usage of visual variables for designing animations and static maps meant to be displayed on electronic paper devices as well as the impact of these limitations on the possible employment of related cartographic methods of presentation, led to a proposed modification of the tables of rules for the use of combinations of static and dynamic visual variables and sound variables, as well as tables of rules for the application of related cartographic methods of presentation for each age group. The results of this research and results of analysis on limitations concerning the functionalities, types of animations, design of key frames, legends and texts, were introduced into the general guidelines concerning the design of animations for each age group. These tables and guidelines can be used to design animations meant to be displayed on electronic paper devices, tailored to the needs of specific age groups, employing the *entities–cartotrophic* and *entities–polystaymic* methods. Its simplified and modified versions can be employed to design the static maps meant to be displayed on electronic paper devices, tailored to the needs the same groups. Like in the case of previous research on age-related differences in perception of cartographic animations, the results presented herein are (thus far) representative and valid for the tested population in Warsaw. However, it should be stressed that the same or a similar procedure can be carried out for other populations. The tests carried out have shown that the proposed solutions are operational and may serve as a useful aid for the design of animated and static maps.

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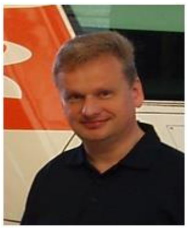
BIOGRAPHY



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