MASTERARBEIT

An Empirical Study on the Effectiveness of Animated Cartograms

Ausgeführt am Department für Geodäsie und Geoinformation der Technischen Universität Wien

unter der Anleitung von

Prof. Georg Gartner, Techniche Universität Wien

und

Prof. Benjamin Hennig, Universität Island

durch

Sarah Palmer

Ich erkläre hiermit, dass ich die vorliegende Arbeit selbständig angefertigt habe. Die aus fremden Quellen direkt und indirekt übernommenen Gedanken sind als solche kenntlich gemacht. Die Arbeit wurde weder einer anderen Prüfungsbehörde vorgelegt noch veröffentlicht.

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Unterschrift (Student)

Wien
20.12.2019

MASTER'S THESIS

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Conducted at the Department of Geodesy and Geoinformation of Vienna University of Technology

Under the supervision of

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and

Prof. Benjamin Hennig, University of Iceland

by

Sarah Palmer

I hereby declare that the thesis submitted is my own unaided work. All direct or indirect sources used are acknowledged as references. This paper was not previously presented to another examination board and has not been published.

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Vienna
20.12.2019

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20th December 2019

Acknowledgements

I would like to acknowledge my thesis supervisors, Georg Gartner and Benjamin Hennig, for their advising efforts. Thanks also to Barend Köbben for serving as my thesis reviewer.

WorldMapper graciously provided some of the cartograms used in this study.

Thanks to the participants of my survey for helping me complete my research.

I am very grateful for the Psychologische Studierendenberatung for helping me navigate through very challenging times.

Alexandra, your work enabled mine. I admire your brave efforts!

Nancy, your encouragement and advice have impelled all of my achievements. I couldn't have done this without you.

Vanessa, you are the light of my life. Your constant companionship and love have kept me going through all of this. Thank you for your daily lessons on love, trust, and peace.

Molasses, you are a truly wonderful friend. I'm grateful for every dinner, every cup of tea, every walk we've had together. You've taught me so much. Thank you for always being there for me.

Abstract

New innovations in cartographic media and technology have enabled the development and implementation of new cartogram visualizations. The use of animation and interactive features with cartograms has become more popular recently, but very little is known about how effective cartograms with these features are in communication.

Through an online survey, this study examined whether animation influences cartogram effectiveness. Traditional static cartograms with inset maps were compared to interactive and non-interactive animated cartograms. Four cartogram reading tasks were tested for each cartogram. Participants were also asked to their impressions and emotional reactions.

The results show that animation and interactive animation influence cartogram effectiveness, with differing results depending on the task type.

Key Words: cartograms, animated cartograms, cartogram effectiveness, thematic cartography, computer cartography, interactive cartography.

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1 Introduction

1.1 Motivation and problem statement

Cartograms are thematic maps in which geographic units, such as countries or states, are proportionally geometrically distorted to show a variable of interest, such as population or election results. They are popularly used to communicate social, political, and economic data in news reports, magazines, textbooks, and scientific publications. Due to their anamorphosed appearance, cartograms can be uniquely provocative and visually appealing to map users. (Nusrat, Alam, and Kobourov 2018) However, because map readers do not interact with or understand cartograms in the same way as they do other maps, using cartograms without insight about how people use them may hinder effective communication.

Since the first scientific reference to cartograms in 1851, there have been many methods for making cartograms proposed and implemented. The introduction of digital computing to the field of cartography in the late 20th century enabled a rapid development of innovations in cartogram generation. (Tobler 2004) In addition to the field of Cartography, cartograms are a topic of interest for the fields of Computer Science and both Scientific and Data Visualization. Despite this strong interest, studies evaluating the communicative effectiveness of cartograms have not kept pace with the innovations in cartogram generation and design. (Nusrat and Kobourov 2016) Because new developments in cartogram generation continue to add more possibilities for creating cartogram visualizations, more research into the communicative effectiveness of cartograms is needed. Further understanding of this effectiveness will support better user understanding and thus more user-centered cartogram design.

There are many ways of creating cartograms, and they can be divided into four main groups: contiguous, noncontiguous, Dorling, and rectangular.[1] Each group has certain strengths and weaknesses which contribute to its suitability for different applications. Because no cartogram can perfectly preserve geographic shapes and topological relationships while accurately representing the quantitative data, they can be classified by their strengths: geography preserving, topology preserving, or statistically accurate. (Nusrat, Alam, and Kobourov 2018) For example, a cartogram which preserves topology, such as a contiguous cartogram, is more suitable for a map reading task which requires determination of adjacency of regions. Some studies

1 Sometimes contiguous cartograms are referred to as “continuous.” While both words make sense in this context, contiguous is a better descriptor because it specifies that the adjacent units share borders.

have already provided information about the effectiveness of certain types of cartograms for certain types of tasks, discussed later in Chapter 2. In addition to this diversity in cartogram type, recent innovations such as adding interactivity, animation, or 3D effects also present new opportunities for research. It has also been suggested that certain graphical elements such as inset maps and symbols to indicate numerical values improve effectiveness. (Dent 1975)

Two of the most popular innovations in cartogram design currently are the use of animation and/or interactivity. These design techniques are currently popular in cartography in general, and some studies have evaluated their effectiveness for cartographic applications. But because this research on the use of these innovations in cartographic design is not related to cartograms, their results cannot be assumed to hold true for cartograms because of their fundamental uniqueness.

When a map reader (or, in the case of an interactive map, map *user*) uses a cartogram, their brain has to match the cartogram with their mental map of the spatial extent in order to understand the meaning of the distortion. If a person does not have a well-formed mental map, the cartogram by itself will not be effective in communication. The classic solution to this problem is to include an inset geographic map alongside the cartogram which provides a supplemental comparison tool to support understanding of the cartogram. As Dent found in 1975, inset maps are very helpful in increasing users' understanding of cartograms. An inset map in a cartogram augments the user's mental map by giving them a visual reference tool. (Dent 1975) This can lead to better understanding, higher efficiency, and higher accuracy when performing some map reading tasks.

But what if, instead of an inset map, the cartogram has an animated transition from a geographic map to a cartogram? Instead of separately displaying the geographic map and the cartogram, an animated transition effect could improve user understanding because the user does not the burden of comparing two separate maps. The map reader can directly visualize the anamorphosis of the map into the cartogram. The animated transition could even be user-controlled, so that the user could take the amount of time they need to understand the map and the cartogram. Animating the transition from map to cartogram reduces the workload of the map reader, because they do not have to refer to another map. This reduced workload could, in turn, lead to higher efficiency and higher accuracy in certain cartogram use tasks, and thus a more effective communication method.

1.2 Research objectives

The overall objective was to evaluate the communicative effectiveness of animated transition cartograms through a mixed-methods empirical approach. This involved performing a user study and conducting an experiment with human subjects using cartograms to perform tasks and then measuring effectiveness with the quantitative and qualitative data.

The intended audience for this research consists of cartographers, data visualization experts, and anyone interested in the topic of cartograms and how to effectively communicate with them. This research will lead to improved understanding of whether animation and interactive animation affect cartogram effectiveness for different cartogram-reading tasks.

1.3 Research questions

The hypothesis is that transition animation influences the effectiveness of cartograms. The research is therefore designed to investigate this hypothesis.

- Do animation and interactive animation influence cartogram effectiveness?
- For which cartogram-reading tasks are these design features more effective and therefore most suitable as compared to traditional static cartograms?
- What are users' impressions of and emotional reactions to cartograms with these design features?

1.4 Methodological approach

This research followed the empirical cycle suggested by A.D. de Groot (Wagenmakers, Dutilh, and Sarafoglou 2018):

1. Observation: The observation of a phenomenon and inquiry concerning its causes.

2. Induction: The formulation of new hypotheses.

3. Deduction: The formulation of predictions and design of experiments that will test the hypotheses.

4. Testing: The testing of hypotheses and collection of data.

5. Evaluation: The interpretation of the data and the formulation of a theory.

1.5 Structure of the work

Based on the current research in the fields concerning cartogram design, a hypothesis about the effectiveness of animated cartograms was formulated. Chapter 1 has discussed the motivation, objectives, and hypothesis and the currently existing research will be discussed in the following chapter. Chapter 3 discusses how the experiment was designed to test this hypothesis. The experiment was then conducted through an online survey with human map readers as test subjects. Following the experiment, the data was analyzed and evaluated and the results of this are presented in Chapter 4. Discussion of the results and some critical reflection about the research can be found in Chapter 5. Finally, some theoretical conclusions were formed, as outlined in Chapter 6. The Appendices contain the survey questions used in the experiment, as well as the code and data for the interactive cartogram used in the experiment, and the results of a statistical test performed on the data from the results of the survey experiment.

1.6 Key term definitions

In this research report, it is critical to define and understand the following concepts in this context.

Cartogram

A cartogram is a type of map and diagram which has anamorphosed spatial areal units to match quantitative data values. See Chapter 1.1 for further discussion.

Animation

Animation is a way of producing a visual illusion of movement by displaying a series of slightly different images shown in a sequence. In some animation visualizations, viewers/users can interact with the product to affect the display of the image series, e.g., pausing, adjusting frame rate.

Effectiveness

This can be defined in many ways and is dependent on the desired outcome. For this research, the definition of ISO 9241 was used. Effectiveness is defined as the extent to which a product can be used by specified users to achieve specified goals (task completion by users) in a specified context of use (users, tasks, equipments & environments). Because cartograms can be used for different types of tasks, and in many different contexts, there are many ways of measuring effectiveness. The method in this research is defined later in Chapter 3.1.

2 State of the Art

2.1 Existing research

Since the creation of cartograms in the mid-20th century and the development of animation techniques around the same time, both visualization methods have experienced a swift evolution in their creation and dissemination techniques since the introduction of computers and their subsequent development in both hardware and software.

Both cartograms and animation have long been topics of interest in the field of cartography, but very little research has been conducted on the use of animation *with* cartograms. The combination of the two visualization methods has come relatively recently, with first discussions published in the early 1990s. Several studies have evaluated the communicative function of cartograms, but just a few scientists have written about the effectiveness of the use of animation with cartograms, and some of these have to do with the visualization of spatiotemporal data, e.g., time series or flow data, not animated transition cartograms.

2.1.1 Cartograms

In 1934, Raisz wrote a short article about the use of the statistical cartogram, which he argues, “is not a map.” The cartograms he created are hand-drawn rectangular contiguous cartograms of the United States. He proposes that the purpose of these not-maps is for education and business planning. He does not illuminate his methodology for creating the cartograms. (Raisz 1934)

Tobler wrote in 2004 a historical survey of computer-based generation of cartograms. He discussed the concept of cartograms and their initial development, citing examples of early published cartograms. He wrote about his career in the study of cartograms, beginning in 1959. His work resulted in several computer programs for generating cartograms. He also writes about others’ work in cartogram generation that was contemporary to his and also some of the work that came after his. He briefly mentions animated cartograms as being “made possible by the iterative nature of the algorithms.” (Tobler 2004)

Dent wrote in 1972 about the importance of preserving unit shape in cartograms to enable effective communication. He performed some tests and found that map readers used a mental generalization of geographic units that was similar in shape to the actual geographic units. He theorized that the shapes of the map units are critical

in enabling map readers to identify them and that cartograms which do not preserve shape characteristics will fail to effectively communicate information. (Dent 1972)

In 1975, Dent studied map readers' attitudes toward a cartograms and concluded that people found the cartograms "confusing and difficult to read. At the same time they appear interesting, generalized, innovative, unusual, and having–as opposed to lacking–style." (Dent 1975)

Griffin studied in 1983 the ability of map users to identify locations on a cartogram from a corresponding map and vice versa and found that users had more difficulty cognitively transforming locations from the cartogram to the map than vice versa. (Griffin 1983)

Krauss performed a study in 1989 of the effectiveness of noncontiguous cartograms by evaluating the results of three information retrieval tasks of different levels of specificity. She found that the noncontiguous cartogram was effective for communicating general information, but ineffective for communicating highly specific information. (Krauss 1989)

Rittschoff et al. wrote in 1996 about the effects of region familiarity and distortion on learning from cartograms with a focus on the use of cartograms in educational contexts. They performed an experiment in which they asked participants to look at a map of a familiar or unfamiliar region and then subsequently look at a cartogram or data map of the same region. Following this, the participants were asked to draw the first map from memory and match map data levels to the recalled map. They found that familiarity with the region was necessary for successful use of the cartograms. Participants using cartograms of unfamiliar regions had more inaccurate reconstructions in their drawn maps and lower levels of data recall. They suggest that cartograms come with a potential for misuse and provide some recommendations to prevent this misuse. They recommend: 1) using cartograms only when users have long-term familiarity with the region, 2) avoiding use of cartograms for regions with a small number of units, 3) providing accurate geographic size visualization tools (e.g. inset map), and 4) using cartograms for learning region or unit names. (Rittschof et al. 1996)

Sun and Li studied the effectiveness of cartograms with two different experiments in 2010. One experiment compared thematic maps and cartograms and the other compared user preferences for different types of cartograms. They found that the cartogram was more effective in communicating qualitative data, while the thematic map was more effective in communicating quantitative data. (Sun and Li 2010)

The results of another study on the usability of cartograms was published in 2017 by Han et al. They used GlobeLand30 data, a global land cover dataset with 30m resolution produced by the Chinese government. Their experiment tested the usability of cartogram visualization for this dataset. They found that the thematic map was more suitable for the representation of quantity, while the cartogram was better for representing distribution and spatial relationships. They also noted that the usability of the cartogram was strongly affected by the unit shape irregularities. They found no significant difference in efficiency between the thematic map and the cartogram, but they did find that more people preferred the cartogram. (Han et al. 2017)

Kaspar et al. reported in 2011 the results of a study comparing the effectiveness and efficiency of contiguous cartograms and choropleth maps with graduated circles. They found that cartograms were as effective as choropleth maps for simple spatial inference tasks whether the map units were regular or irregularly shaped. However, the cartogram was less effective than the choropleth map for complex tasks when the units of the map were regularly shaped. They attribute this to the topological transformation of the units in the cartogram. (Kaspar, Fabrikant, and Freckmann 2011)

Ullah et al. reported in 2016 the results of a study of the usability of travel time cartograms. They performed two experiments comparing different designs of cartograms with geographic maps: an online survey, designed to evaluated accuracy, response time, and preference, and a laboratory test. The laboratory test employed eye-tracking, thinking aloud, and video recording. The results indicated that the centered time cartograms performed best, particularly when the task had a strong time component. (Ullah et al. 2016) This study was based on previous work by Ullah and Kraak which created the method of constructing the time cartograms used in the study. (Ullah and Kraak 2015)

Hong et al. developed a tool to communicate real-time travel time for the city of Seattle using a distance cartogram (i.e., the cartogram distortion is based on the travel time). They tested the cartogram tool with participants and found that users perceived it as useful and intuitive for assessing current travel time. Participants spent, on average, more time using the cartogram than they did using the standard map. (Hong et al. 2018)

Döll wrote in 2017 about the use of cartograms for communication of climate change risks. She proposed that cartograms are able to communicate climate change risks (a combination of hazard, exposure, and vulnerability), while traditional maps are only able to communicate hazard. She recommends using bivariate gridded cartograms

with hazard in color, and population by distortion. She suggests the opportunity for empirical research about the effectiveness of these risk communication cartograms for conveying complex information and their ability to trigger moral emotions. (Döll 2017)

Nusrat and Koburov used task taxonomies from cartography and information visualization to develop a task taxonomy for specifically for cartograms in 2015. (See *Table 1*.) They wrote that, "despite the popularity of cartograms and the large number of cartogram variants, there are very few studies evaluating cartograms. In order to design effective cartograms we need to compare cartograms generated by different methods on a variety of suitable tasks. Before such comparisons can be made, we need to understand the visualization goals and to explore the possible tasks suitable for cartograms." (Nusrat and Kobourov 2015)

task	**example**
Detect change	Given a cartogram of population change in the past decade, "Has Ireland grown, shrunk, or stayed the same?"
Locate	Given a European population cartogram, "Locate Ireland."
Recognize	Given Ireland on a map and both Ireland and Lithuania on a cartogram, "Which of these is Ireland?"
Identify	Given a grey/blue cartogram of European population and European Union countries, "Is Ireland a member of the EU?"
Compare	Given a European population cartogram, "Which is larger, Ireland or Lithuania?"
Find top-k	Given a European population cartogram, "Which country has the highest population?"
Filter	Given a European population cartogram, "Which countries have a higher population than Ireland?"
Find adjacency	Given a European population cartogram, "What countries share a border with Lithuania?"
Cluster	Given a European population cartogram, "Which countries have roughly the same population as Ireland?"
Summarize	Given a European seismic hazard cartogram, "Is the seismic hazard evenly or unevenly distributed among the countries?"

Table 1: Cartogram task taxonomy proposed by Nusrat and Koburov, 2015

Nusrat et al. published in 2018 a comprehensive study of the effectiveness of cartograms. Using the previously proposed taxonomy of cartogram tasks, the authors studied the effectiveness of four different types of cartograms: contiguous, noncontiguous, rectangular, and Dorling for four different cartogram tasks: locate, compare, find adjacency, and summarize. They measured effectiveness by quantitative analysis of time and error and also analyzed user preferences with an attitude survey. They found significant differences in effectiveness and user preference among the four types of cartograms. The contiguous and Dorling cartograms were the most effective and most preferred. Familiarity with the cartogram type also affected participant performance and preference. They also found a statistically significant difference in male vs. female performance, with females answering with higher accuracy but similar response times. They did not find a difference in performance based on age or education level. They concluded that the optimal choice of cartogram type depends on the expected tasks during map reading. They suggest using interactive features such as mouse-over data display to improve cartogram effectiveness. (Nusrat, Alam, and Kobourov 2018)

2.1.2 Animation

Campbell and Egbert wrote in 1990 about the lack of use of animation in cartography. They argue that despite new technologies bringing new capabilities for map creation and display, static maps continue to rule. They cite several reasons for this phenomenon. One reason is limited financial resources and low drive for innovation in geography. Another reason they perceive is the negative attitude towards academics who develop and sell computer software for profit. Their final explanation is the problem of distributing animations given that they cannot be published in traditional printed journals and map users may not have the necessary hardware to use the animated map products. They provide a very in-depth survey of the use of animation in cartography, though much of their information is now obsolete. (Campbell and Egbert 1990)

DiBiase et al. wrote in 1992 a general overview of animation in maps for scientific visualization. Following the visual variables proposed by Bertin, (Bertin 1967) they proposed three additional visual variables that apply to dynamic visualizations: scene duration, rate of change of scenes, and order of scenes. (DiBiase et al. 1992)

Johnson and Nelson performed an experiment in 1998 to compare a traditional time series visualization on paper with both a computer-based map series and an animated time series visualization. They found that animation did not improve the learning of quantity values, but did improve learning of trend patterns. They found a significant difference in performance by sex, with females preferring and completing

tasks more accurately with the paper map series. Males, on the other hand, preferred the animated map series but did not have a higher accuracy rate with it. As a whole, the participants preferred the paper map series over both the animated map series and the digital map series. They wrote that one of the suggested improvements for the animation technique was to allow users to directly control the animation. (Johnson and Nelson 1998)

Lowe wrote in 2000 about the effectiveness of animated meteorological maps versus static meteorological maps for non-meteorologists. The experiment tested whether the participants could predict weather change for the next day given the two forms of meteorologic maps. The results suggested that the animation strongly influenced what participants were able to learn and remember from the maps. He attributes this to the participants extracting information based on perceptual salience. (Lowe 2000)

Harrower wrote in 2003 about some challenges in designing animated maps and how to overcome them. By nature, animation causes some things to disappear, which can cause difficulty and frustration for the map reader. His suggested solution for this is to allow the user to loop the animation, control the playing of the animation, and/or control the frame rate. Another challenge for users of animated maps is knowing where to look or what to do. Some solutions to this are map sequencing, sound or voice prompts, and dynamic symbols to grab and direct attention. Excessive use of these, however, can be very annoying to the user. Yet another challenge is designing animated maps with the balance between complexity and simplicity. He argues that many animated maps fail because they try to do too much, and that “effective animated maps are often highly generalized so that only the most important trends or feature emerge.” The final challenge he discusses is that of user confidence. Because people typically have more experience reading static maps, animation can be intimidating and/or overwhelming to the user. To assuage this, he suggests providing a preview animation and making the interface simple. (Harrower 2003)

Slocum et al. conducted several related experiments in 2006 comparing choropleth map sequences with traditional static choropleth maps. They found that most participants preferred the map sequences over the static maps. Their data suggested that the users acquired information more readily with a traditional static map, but that they remembered information better with a map sequence. However, the results were not significant. They concluded that map sequences may be used because users showed enthusiasm for them and they did not appear to have a negative effect on map learning. (Slocum, Robeson, and Egbert 2006)

2.1.3 Cartograms + Animation

Dorling and Openshaw wrote in 1992 about using animation to visualize space-time patterns and briefly mentioned the idea of using animation to show space-time data on a cartogram. (Dorling and Openshaw 1992)

In 2000, Ouyang and Revesz wrote about using algorithms to animate time series data within a cartogram. To test their algorithms, they made a cartogram of precipitation by year between 1948 and 1998 for the continental United States. They stated that, "... animations allow everyone to make similar observations without even knowing anything about statistics." (Min Ouyang and Revesz 2000)

Ware studied in 1998 the effectiveness of three types of cartograms each for both a familiar and an unfamiliar region. The three cartogram types were: static, animation with a slider bar, and animation with a play button. She found significant differences between the mean scores of the different cartograms. The animated cartograms were more effective than the static ones, and the effectiveness improvement was even stronger for the cartograms of the unfamiliar region. She also found that participants greatly preferred the animated cartograms over the static cartograms. (Ware 1998)

2.2 Innovation and comparison with existing research

As previously mentioned, cartograms are a popular visualization technique with many different applications, from education to entertainment to scientific visualization. Some previous studies have shown cartograms effective for certain tasks, while less effective for other tasks. However, the technology behind cartogram generation has rapidly developed and evolved since most of these studies were performed. This research focuses how animated transitions cartograms influence effectiveness. Only one study has previously evaluated the effectiveness of animated cartograms, but this study was twenty years ago and the technological capabilities in cartography and computer science have changed. The results of this research will add to the domain of knowledge about the effectiveness of cartograms, particularly those employing animation and interactive animation.

3 Methodology

3.1 Study method

To test the hypotheses, human subjects were recruited to participate in the online cartogram survey from social media groups. Following recommendation from Roth et al., an attempt was made to recruit a diverse pool of participants with regard to age, gender, education level, etc. by posting the invitation to participate in the survey in social media groups with different themes and purposes in order to avoid "convenience sampling." (Roth et al. 2017)

The survey responses from subjects who reported any education in cartography or an uncorrected vision deficiency, e.g., color blindness or vision loss, were excluded from the results. People with an education in cartography were excluded because they presumably have a tendency to read maps differently than the average person, and thus may skew the results. People with an uncorrected vision deficiency were also excluded because of the necessity to view detailed visualizations and answer questions about them. In all, 31 people completed the survey, and of these, 4 were excluded from the results–1 due to red-green color blindness and 3 due to education in cartography.

The user survey collected three types of data: users' background information, the cartogram effectiveness responses, and answers about preferences and attitudes. Due to legal and ethical reasons, the survey was designed to not collect any personally identifying information such as names, contact information, IP addresses, etc.

The survey examined the effectiveness of cartograms with interactive transition animation by having users answer task-based questions using one interactive animated cartogram which transitions from geographic map to cartogram with the click of a button. *See Figures 1 and 2.* The responses to these questions were compared with the responses to corresponding questions with a visually similar static cartogram with an inset map. *See Figure 3.*

Likewise, the survey examined the effectiveness of cartograms with non-user controlled transition animation by having users answer task-based questions using an animated cartogram which continually transitions from geographic map to cartogram with no action or input from the user. *See Figures 4 and 5.* The responses to these questions were compared with the responses to corresponding questions with a visually similar static cartogram with an inset map. *See Figure 6.*

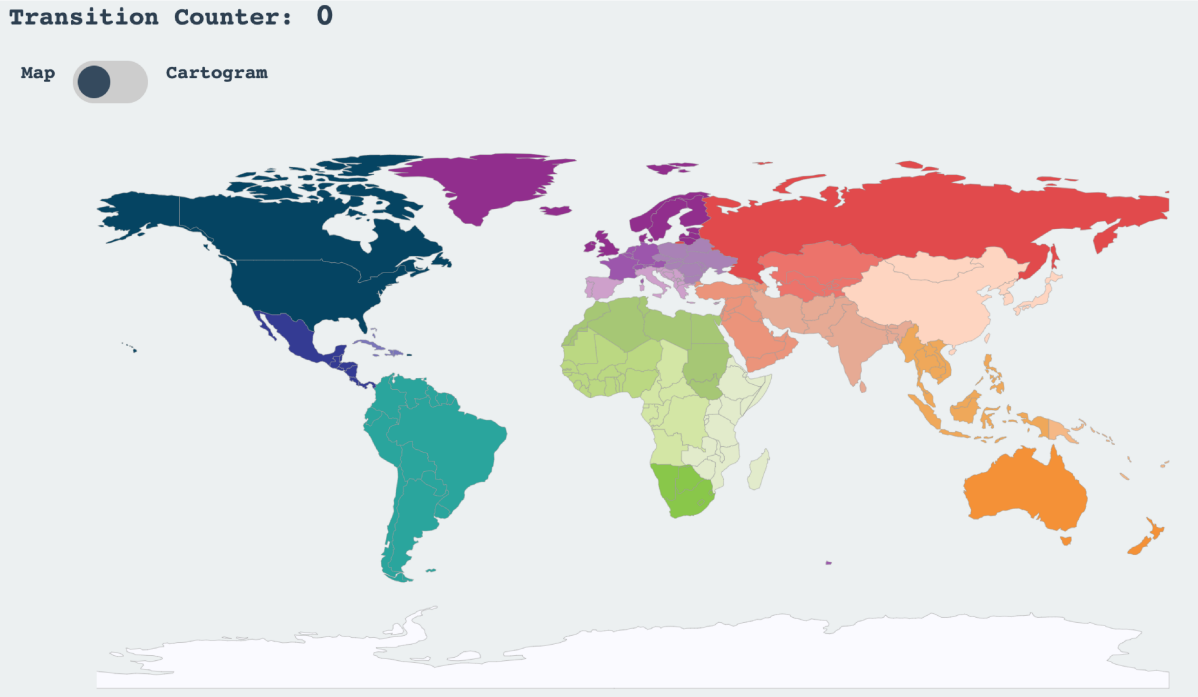

Figure 1: User-controlled animated transition cartogram showing onion production worldwide in 2000. This image shows the map state. Created by the author.

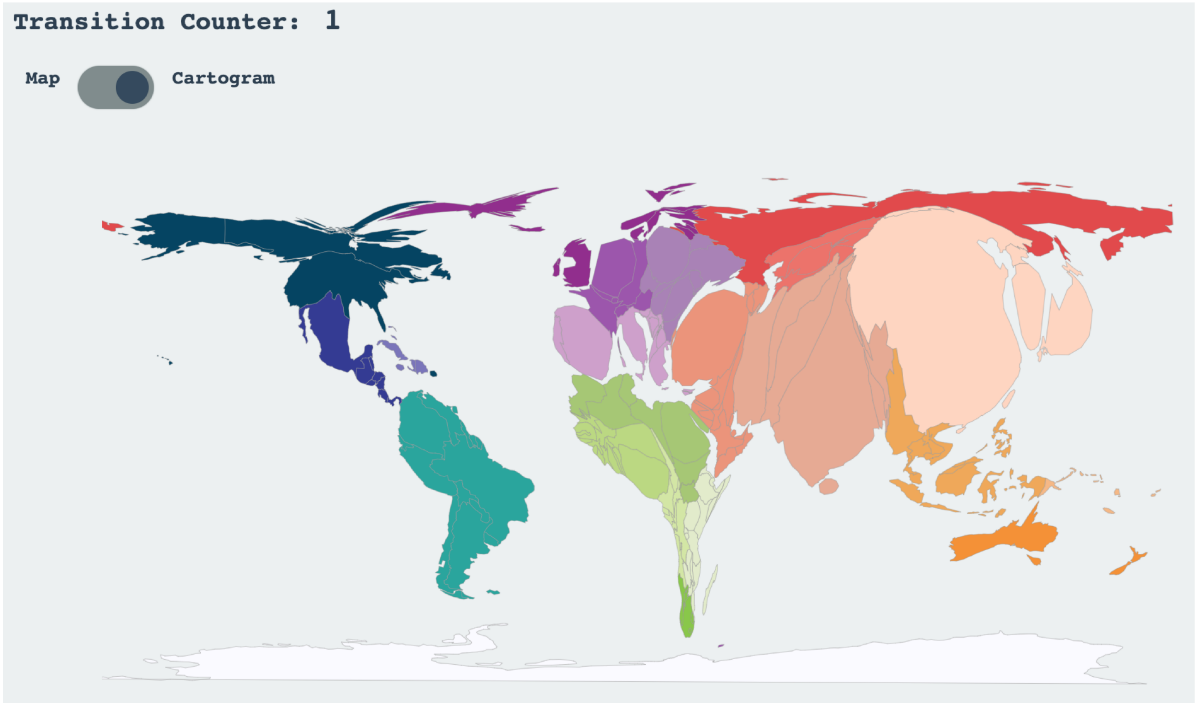

Figure 2: User-controlled animated transition cartogram showing onion production worldwide in 2000. This image shows the cartogram state. Created by the author.

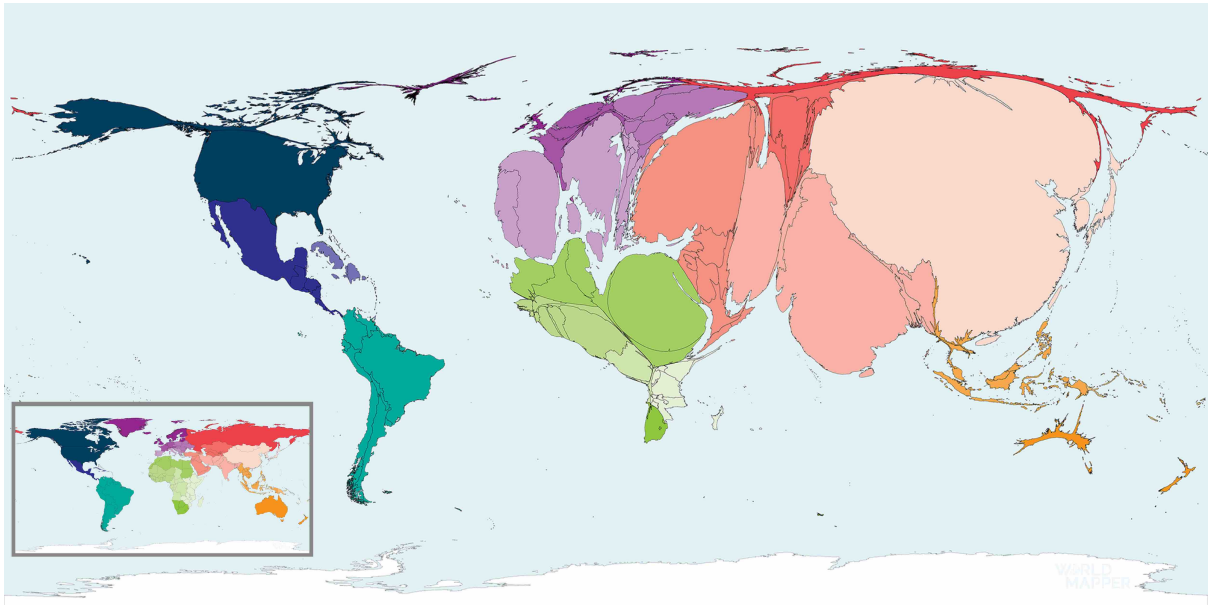

Figure 3: Static cartogram with an inset map showing tomato production in 2000. Created by WorldMapper.

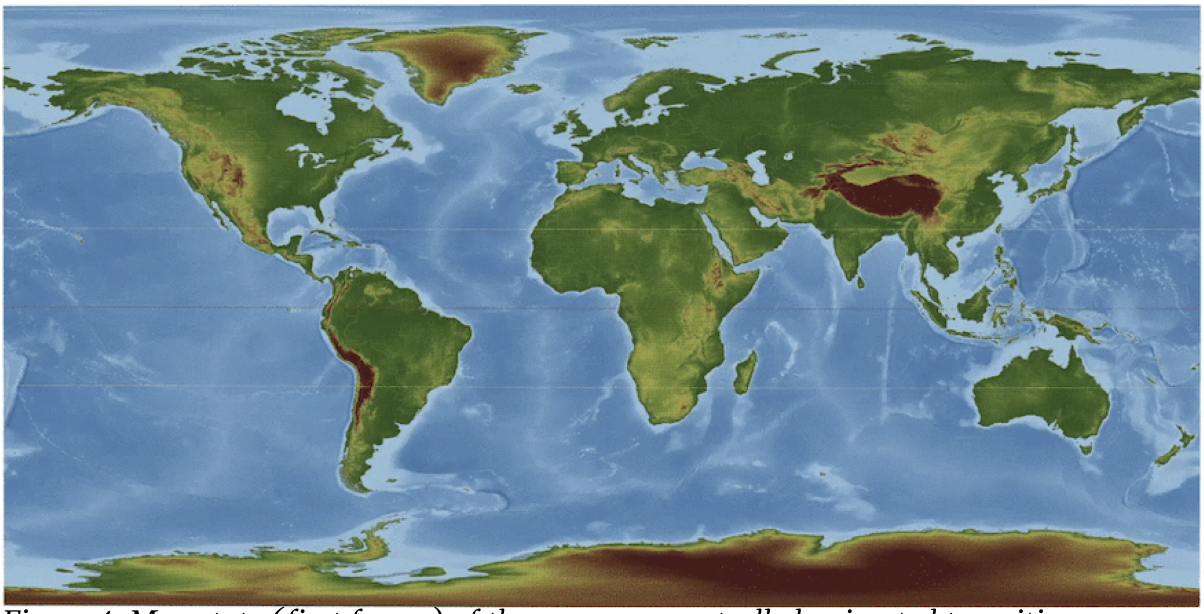

Figure 4: Map state (first frame) of the non-user-controlled animated transition cartogram showing world population. Created by WorldMapper.

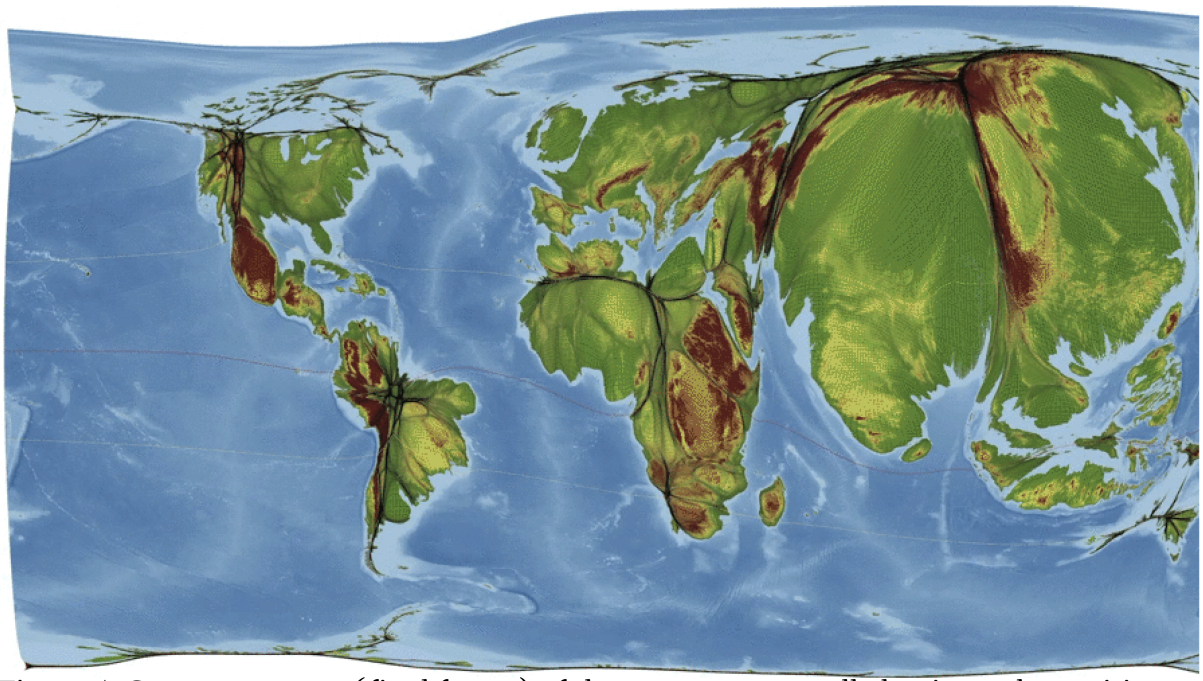

Figure 5: Cartogram state (final frame) of the non-user-controlled animated transition cartogram showing world population. Created by WorldMapper.

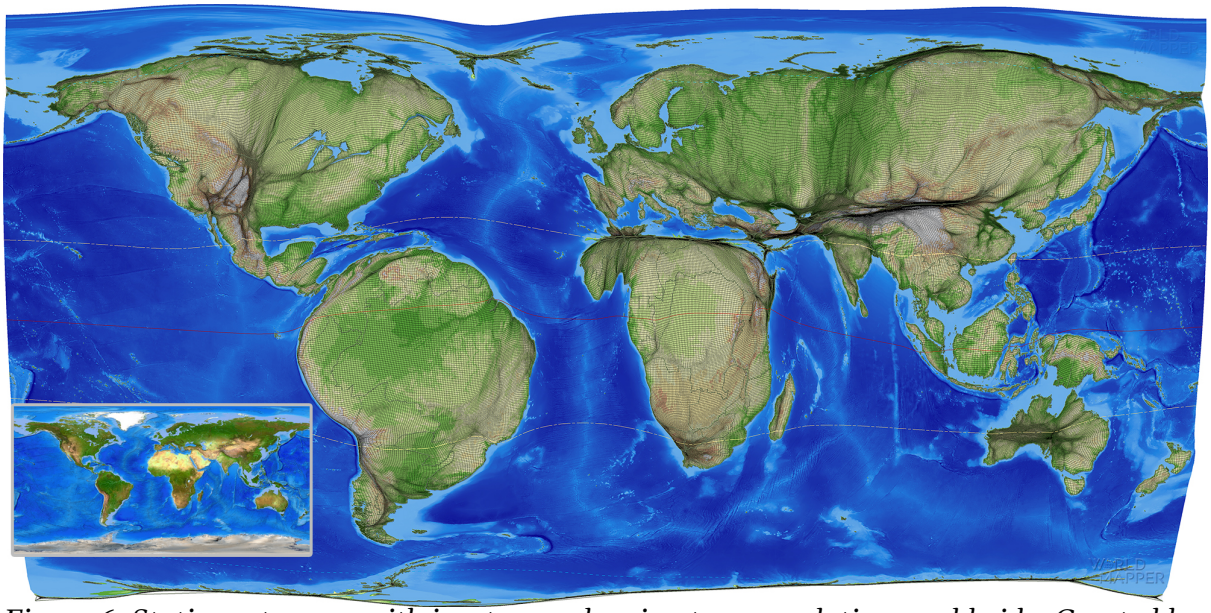

Figure 6: Static cartogram with inset map showing tree population worldwide. Created by WorldMapper and altered by the author.

The cartograms were designed so that those that were being compared to each another would be visually similar in terms of colors, layout, scale, texture, etc. so the results could be reliably compared. The cartograms were designed to be nearly identical except for their data communicated and whether they were animated or not.

To measure effectiveness, four questions were developed for each cartogram based on four map reading tasks: detect change, compare, filter, and summarize. It is easy to quantitatively evaluate accuracy based on user responses to these tasks. Effectiveness was defined by the accuracy of the users' responses to the tasks. For each question, a multiple choice format was used. The detect change, compare, and summarize task questions were formulated to accept only one answer per question and the possible answers were, for example, "A," "B," or "Unsure." The filter task questions had two correct answers each out of four possible answer options and the survey form accepted up to 4 answers per question, i.e., "A," "B," "C," "D". For these questions, a disclaimer was made that the question may have more than one correct answer.

For the interactive animated transition cartogram, users were asked to enter the number of transitions they made using the cartogram. The cartogram was coded to count and display this number of transitions in a visible location next to the slider button controlling the transition.

In addition to measuring effectiveness, the survey asked users some qualitative questions about each cartogram, to understand participants' preferences and attitudes. For this, the semantic differential method was employed. This method has been very commonly used to measure attitudes since its development in 1957 by Osgood et al. (Al-Hindawe 1996) These qualitative questions consisted of bipolar adjective word pairs which the user evaluated on a 5-point scale. To avoid any misunderstanding or misinterpretation caused by using numeric values on the scale, the choice was made to label the scale with "<<" "<" "-" ">" ">>" with "<<" being completely the first word, and ">>" being completely the second word, and the middle values "<" and ">" in between and "-" being neutral. *See Figure 7.*

Figure 7: The user interface in the survey for the semantic differential scale. Each word of the bipolar pairs is displayed on opposite sides.

One of the greatest advantages of this semantic differential method is that it forces participants to give a response indicating their attitudes regarding certain predefined attributes, while still allowing for neutral responses. Four word pairs intended to evaluate data quality impressions, e.g., “simple–detailed,” and five word pairs to evaluate emotional reactions, e.g., “exciting–calming” were selected. These word pairs were adapted from Petchenik, who proposed using this method as a way to characterize maps. (Bartz Petchenik 1974)

Data quality impression word pairs	Emotional reaction word pairs
approximate–precise	exciting–calming
authoritative–casual	chaotic–organized
generalized–specific	casual–formal
simple–detailed	modern–traditional
	lively–dull

Table 2: The bipolar word pairs used for the measurement of participant attitudes towards the cartograms using the semantic differential method.

An additional cartogram with questions corresponding to the experiment questions was used to perform a pretest before the participants answered the cartogram effectiveness questions. The accuracy of participant responses to these questions gives a baseline with which to compare the experiment results.

3.2 Design methods and materials

Designing the cartograms for the experiment required a lot of effort and iterations. As previously mentioned, four different cartograms were required to perform the study. The two pairs of cartograms needed to be very similar to each other while different from the other pair. This was difficult to do because of the very different methods of generating and displaying the cartograms.

The two static cartograms were provided by WorldMapper, and edited to include inset maps with the vector design software Adobe Illustrator. (“Worldmapper” n.d.)

The continual animation cartogram was also from WorldMapper. It was presented to participants in GIF format. It has 69 frames and a frame rate of 10 frames per second.

The interactive animation cartogram was coded using HTML/CSS and JavaScript with d3.js and cartogram.js. (Bostock 2019; Allen [2012] 2017) Both JavaScript libraries, d3.js is for data visualizations and cartogram.js is an implementation of the

classic cartogram generation algorithm created by Dougenik et al. in 1985, which is contiguous and preserves most topology. (Dougenik, Chrisman, and Niemeyer 1985)

The cartogram used for the pretest was created by WorldMapper and used GIF format. ("Worldmapper" n.d.)

All these files were hosted on a website and linked within the an open source statistical survey application LimeSurvey. (Limesurvey GmbH n.d.) The survey was created on the LimeSurvey web application and user data collected through it. At the end of the survey, participants were asked to indicate whether they experienced any difficulties while taking the survey. One person commented that they experienced the maps being slow to load, which may be due to the web hosting service or the LimeSurvey website, but probably it was due to the participant's internet and/or computer speed because only one person mentioned having this difficulty.

4 Study Results

In this chapter, the cartograms used in the survey will be referred to by both their themes and their characteristics. Please refer to the following table.

Bioproductivity	Onions	Tomatoes	Population	Trees
animated	animated	static	animated	static
temporal	transitional	inset map	transitional	inset map
non-interactive	interactive	non-interactive	non-interactive	non-interactive

Table 3: Survey cartogram descriptors.

4.1 Survey participants

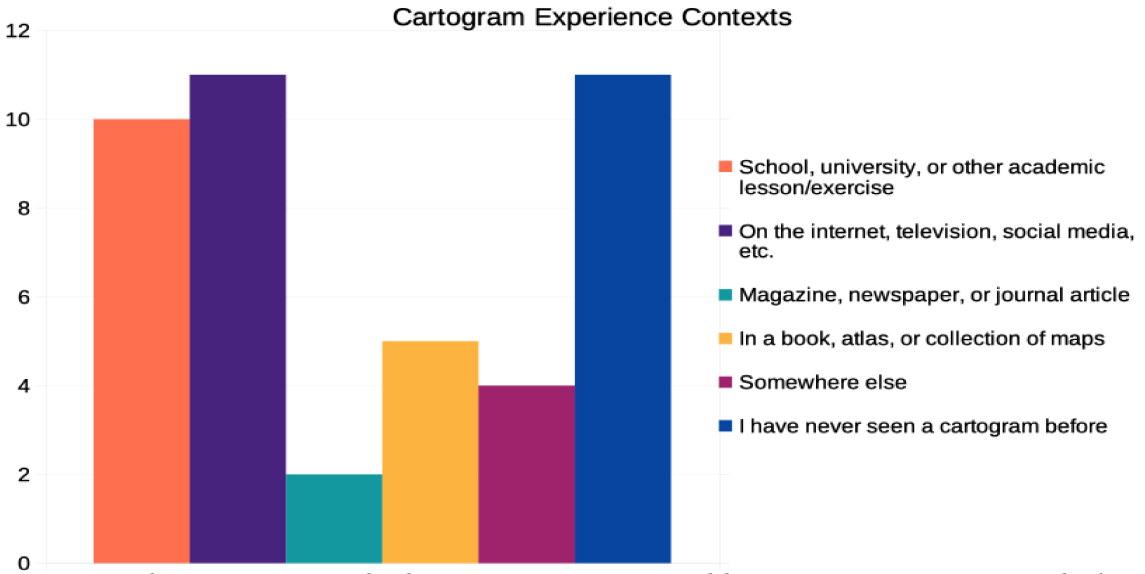

Figure 8: The contexts in which participants reported having seen a cartogram before taking the survey. n=27

After discarding the results of the 4 participants who reported uncorrected vision problems or education in cartography, the results of 27 participants remained. Of these, 10 were male and 17 were female. The average age was 33.3 years, with the minimum age of 23 and the maximum age 51. Most had higher education, with 12 participants reporting having a Bachelor degree, 13 reporting having a Master degree or Diplom, 1 reporting having a Doctorate degree, and 1 reporting some University or College education. The English skill level of participants was very high, with 18

reporting Native English and 9 reporting Fluent English. Just over 85% reported low familiarity with cartograms and 40% of participants reported never having seen a cartogram before. The contexts for participants' prior experiences with cartograms were mainly in education and new media such as the internet and television. *See Figure 7.*

4.2 Statistical analysis

Using a Repeated Measures ANOVA test to measure statistical significance found a strong significance in the task results of the study. The type of cartogram undoubtedly affected the performance scores. The null hypothesis was that the mean scores from each cartogram for each task would be equal. If the mean scores were equal, that would indicate that the cartogram type did not affect the performance scores. The hypothesis was that animation transition would influence cartogram effectiveness. The calculated F with 3 and 12 degrees of freedom was 20.57. With alpha as 0.05, the critical value is 3.4903. Because the F-value is much higher than the critical value and the p-value was calculated as 0.000051, the results show strong statistical significance and the null hypothesis is not valid.

n=27	**Detect Change**	**Compare**	**Summarize**	**Filter**	**Means**
Bioproductivity	22	24	19	4	17.25
Onions	9	22	17	9	14.25
Tomatoes	23	21	24	13	20.25
Population	25	22	16	21	21
Trees	17	21	21	19	19.5
Means	19.2	22	19.4	13.2	18.45

Table 4: Correct scores and means by task and cartogram. For this scoring and analysis method, only participants with fully correct answers were counted.

4.3 Task results analysis

4.3.1 Task results: Detect Change

Sample survey question: "*Did Sweden grow or shrink?*"

For each of these tasks, participants were asked to look at a country and answer whether there was a change in that country's size between the map and the cartogram. This task examines whether people are able to notice that a country in the cartogram is significant, because the country's size is anamorphosed according to the data values. The results show that the participants were able to detect change most readily with the non-interactive animated transition cartogram. The performance was also fair with the static cartograms, but the participants were less

sure about the correct answer. The interactive animated cartogram showed the worst performance, with only 33% of participants selecting the correct answer, as well as a high rate of unsureness.

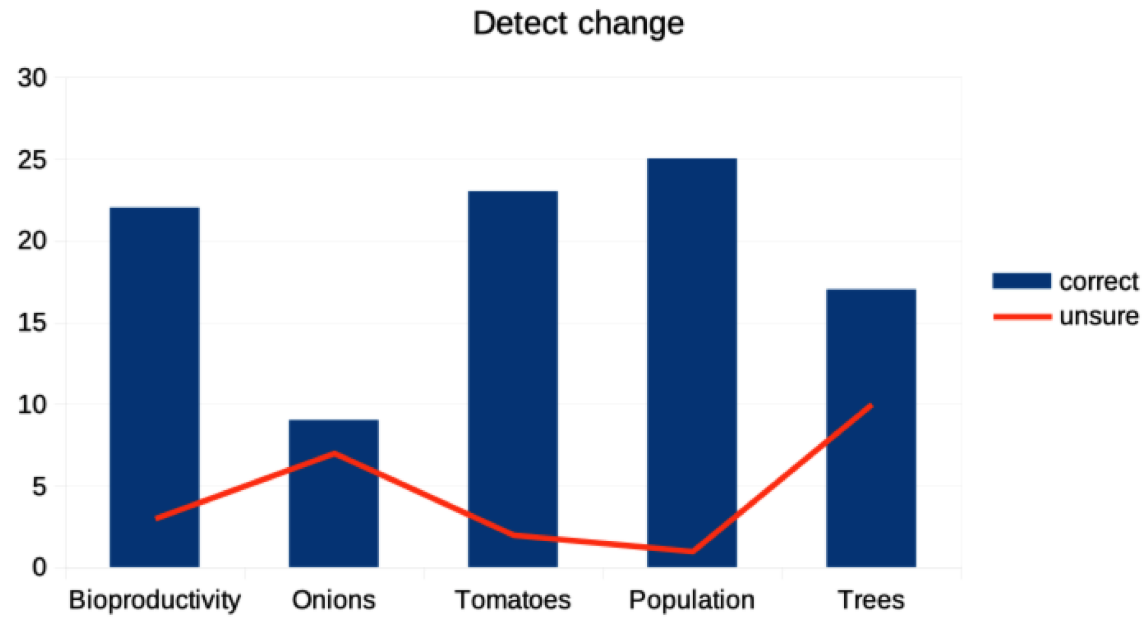

Figure 9: Effectiveness of the cartograms for the Detect change tasks.

4.3.2 Task results: Compare

Sample survey question: "*Which country produced more onions: Turkey or Ireland?*"

For these tasks, participants were asked to compare two countries and answer which one had a higher value. Unlike the other tasks, this task does not necessitate comparing the cartogram to a geographic map or a mental map. It simply requires the map reader to look at the sizes of two countries on the cartogram and determine which is larger. The results show that the performance was much more even between the cartograms for this task type. The animated cartograms, both interactive and not, had a slightly better rate of correct answers. Both of the static cartograms with inset maps had a slightly higher rate of unsureness compared to the animated cartograms.

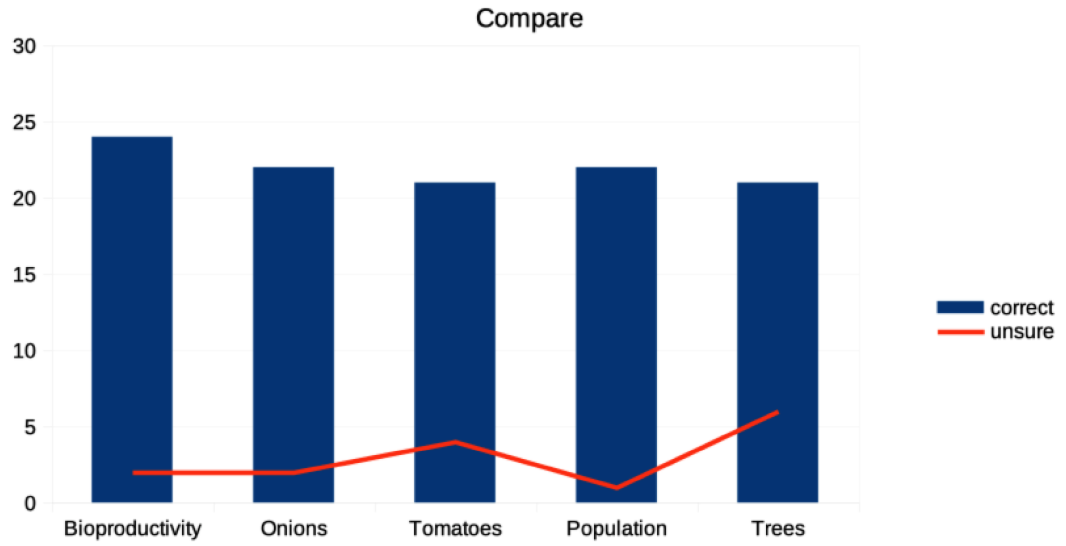

Figure 10: Effectiveness of the cartograms for the Compare tasks.

4.3.3 Task results: Summarize

Sample survey question: *"Is tomato production relatively evenly or unevenly distributed on the Asian continent?"*

These tasks are intended to examine whether participants can comprehend the distribution of the values in the cartogram visualizations. This task requires some change detection of multiple areal units in order to determine whether the region is evenly anamorphosed or not. The results showed that participants answered the questions more often when using the static cartograms. The interactive and non-interactive animated cartograms had very similar performances. Overall, the difference in the rates of correct answers across the cartograms was more than with the Compare tasks, but less than with the Detect change tasks.

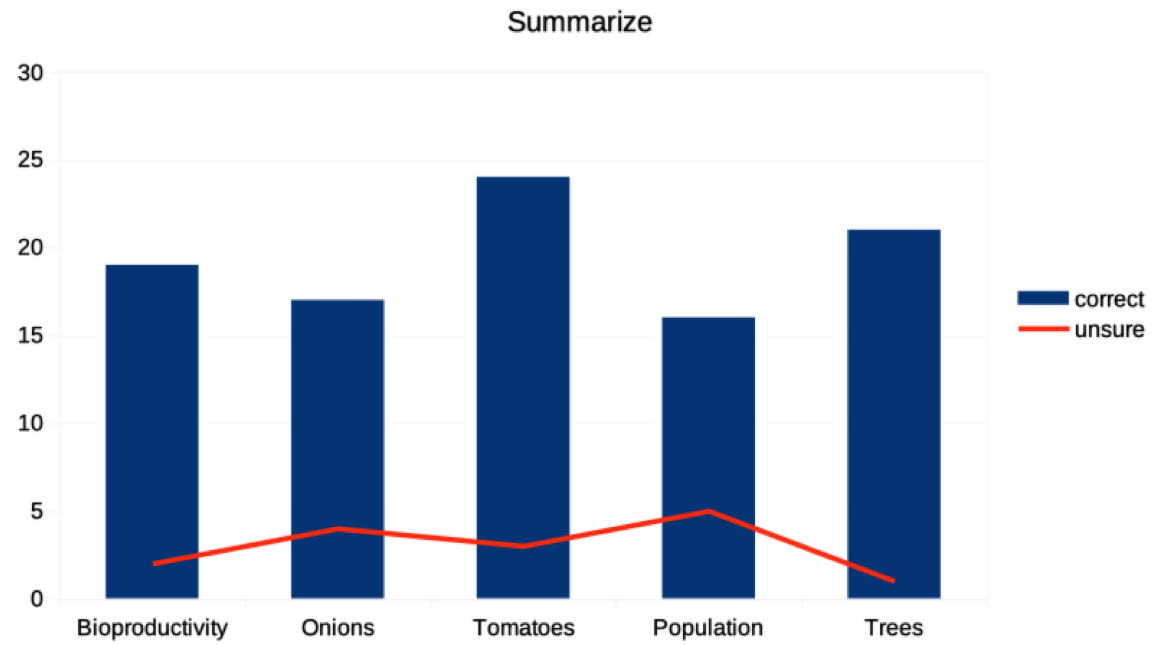

Figure 11: Effectiveness of the cartograms for the Summarize tasks.

4.3.4 Task results: Filter

Sample survey question: "*Which of the following countries has a higher population than the United States of America?*"

To answer this question, participants have to examine the size of one country and compare it to that of the other countries to understand whether there are other countries with a greater size in the cartogram. These questions were formulated to have four answer options and two correct answers. Correct answers were defined as both correct answers selected, and no incorrect answers selected. Partially correct answers were defined as all other responses with at least one correct answer. For this task type, the non-interactive animation showed the best performance. For most of the cartograms, most participants were able to get at least one answer correct.

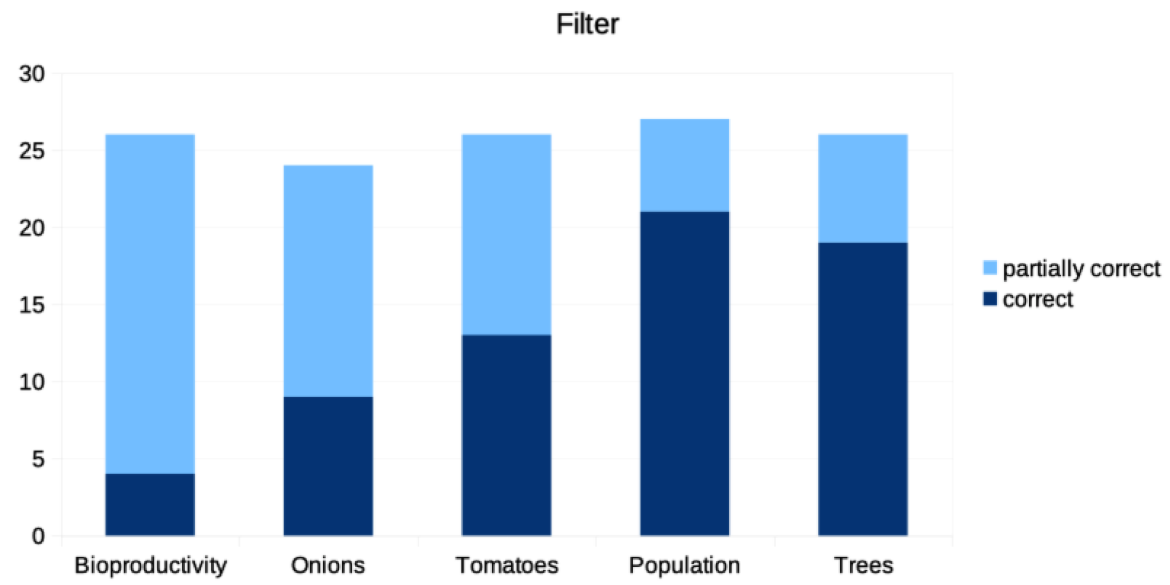

Figure 12: Effectiveness of the cartograms for the Filter tasks.

4.4 Discussion of task results

One of the interesting insights from these results is that no matter the type of cartogram, participants performed best in the Compare tasks. This can be attributed to the lower workload of the task. Map readers do not need to consult any reference map, they can simply look at the cartogram to determine the answer.

With a mean task score of 15/27, the interactive animated cartogram was overall the least effective, with the most significant difference in the Detect change task performance. The non-interactive animated transition cartogram Population showed the highest effectiveness, with a mean score of 21.25/27. However, the non-interactive temporal animation cartogram Bioroductivity had a significantly lower mean score of 17/27. These results suggest that cartogram animation unequivocally influences cartogram effectiveness, and that the different types of animation influence effectiveness differently.

Some theories for the lower effectiveness of the interactive animated cartogram include: the cartogram design, participant unfamiliarity, and the workload of clicking. The design of this particular cartogram's interactive feature was intended to be as clear as possible. The button to make the transition animation work is prominently displayed above the cartogram, and is clearly labeled so that map readers know what the purpose of the button is and what the two states show. The

survey instructions for the cartogram clearly state, “Use the slider button to transition from map to cartogram and back.”

Participant unfamiliarity is a more likely explanation for this phenomenon, as interactive animated cartograms are relatively rare and it is likely that a majority of participants had never used one before. It is possible that participants, and map readers in general, are simply not familiar with this visualization format and feel confused or overwhelmed by it. Nusrat et al. found in their study that familiarity with cartogram type increases effectiveness and preference for that cartogram type. (Nusrat, Alam, and Kobourov 2018)

Another likely explanation is the effort of interacting with the cartogram. The participants must first notice the button and understand its purpose, and then click on it several times in order to make the transition animation function. This is additional work for the map reader, who is already tasked with reading a cartogram and understanding something from it. As the histogram in Figure 13 shows, participants reported a very large range of transition numbers, with many only using the transition animation once or a couple of times. Because there were four different tasks for this cartogram, each requiring the participant to focus on a different map unit, map units, or map region, it is difficult to believe that participants were using the interactive cartogram as intended. Some preliminary investigation of the survey responses seems to indicate that both a very high and a very low number of transitions reported used was correlated with a higher rate of incorrect and unsure answers. Because the survey was not designed to study this, no formal analysis was done.

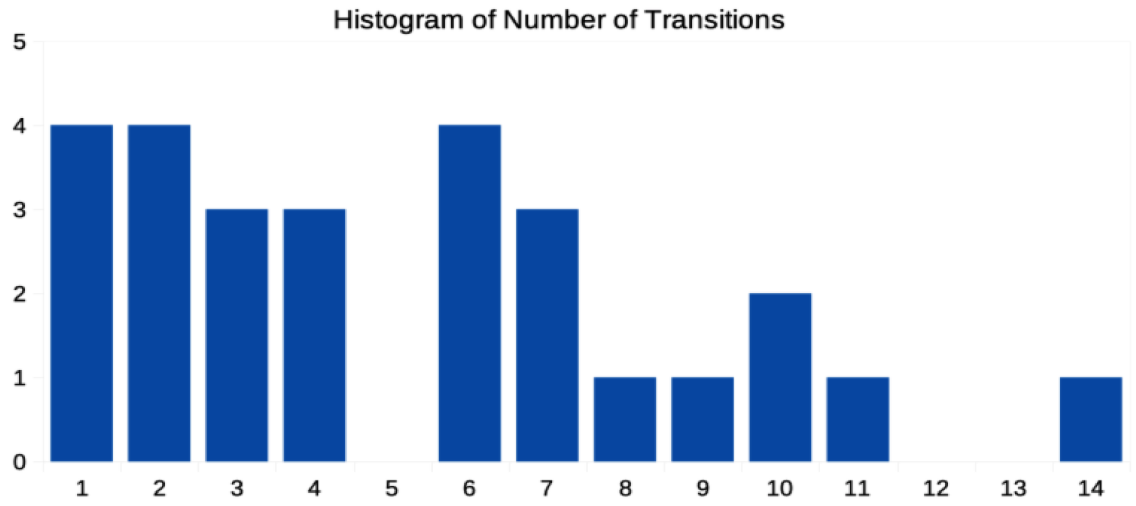

Figure 13: Frequency distribution for the number of transitions participants reported using with the interactive animated cartogram.

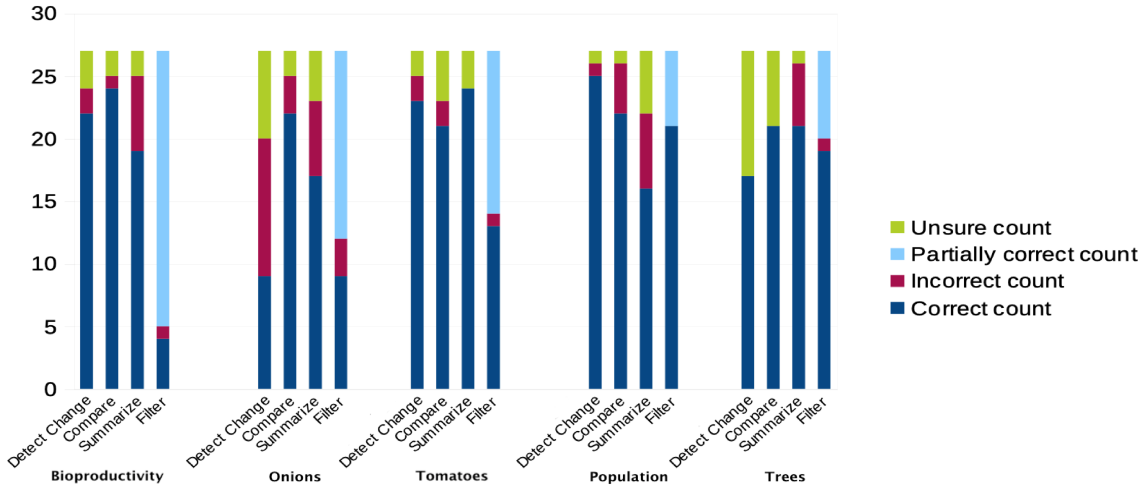

Figure 14: Answer responses for all of the task questions.

Overall, the results show significant differences in the effectiveness of the cartograms for different tasks. It is clear that animation can be used for effective communication with cartograms, but there are many different factors to be taken into consideration when designing and displaying cartograms with animation. What tasks are expected of the users is one very important consideration, and also the design elements and whether interactivity is used are also critical.

Examining demographic affect on the results found that females had slightly higher rates of unsureness across the board. Besides this, the answer responses from males and females were comparable. *See Figures 15 and 16.*

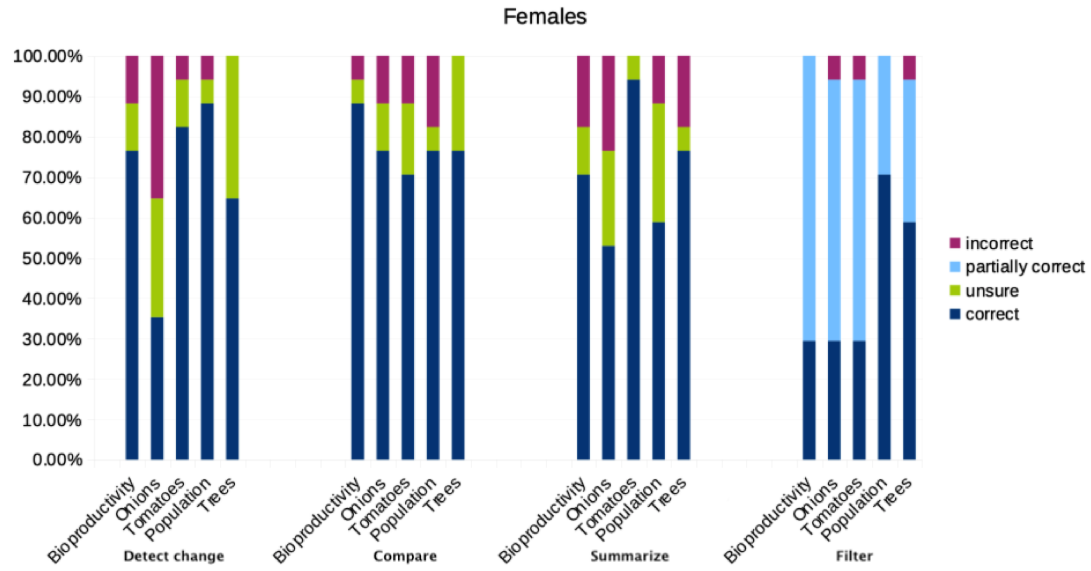

Figure 15: Answer responses from females for all task questions.

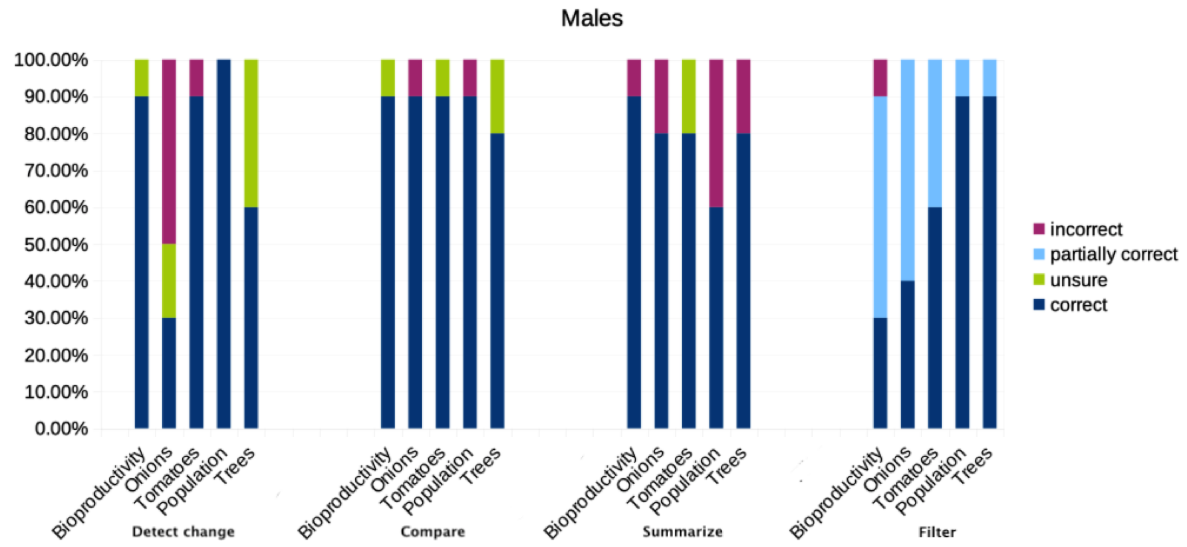

Figure 16: Answer responses from males for all task questions.

4.5 Impressions and reactions analysis

The participants evaluated the animated cartograms as more modern (in contrast to traditional) and more lively (in contrast to dull) than the static cartograms. The reactions to the interactive animated cartogram were significantly different than those to the non-interactive animated cartograms. The interactive animated cartogram was rated the most organized (in contrast to chaotic) out of all the cartograms, whereas the non-interactive animated cartograms were deemed more chaotic.

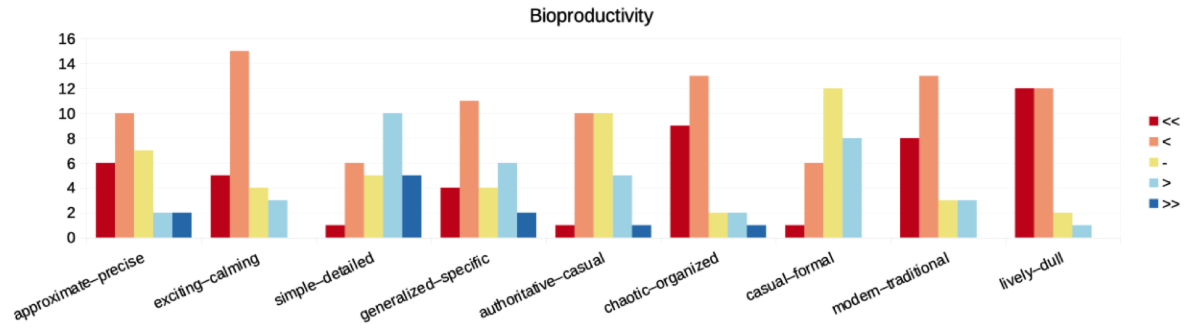

Figure 17: Chart of semantic differential responses for Bioproductivity cartogram.

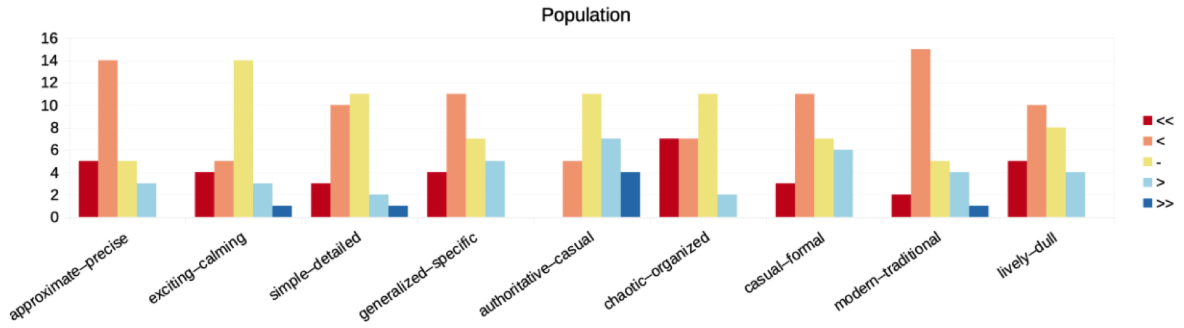

Figure 18: Chart of semantic differential responses for Population cartogram.

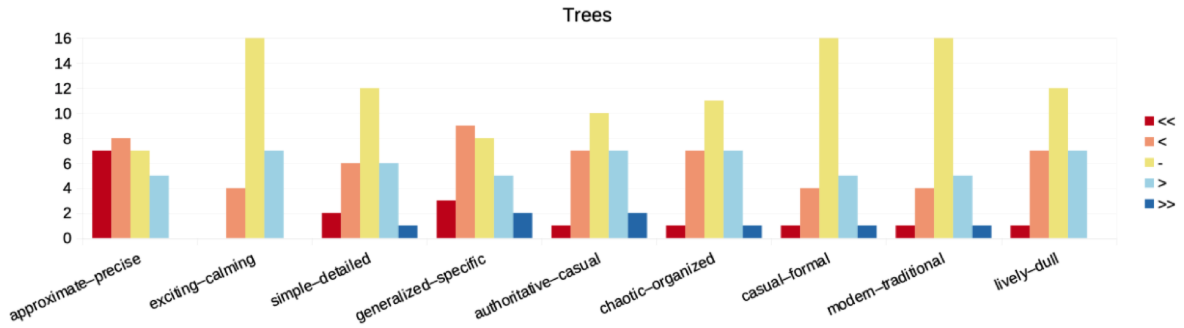

Figure 19: Chart of semantic differential responses for Trees cartogram.

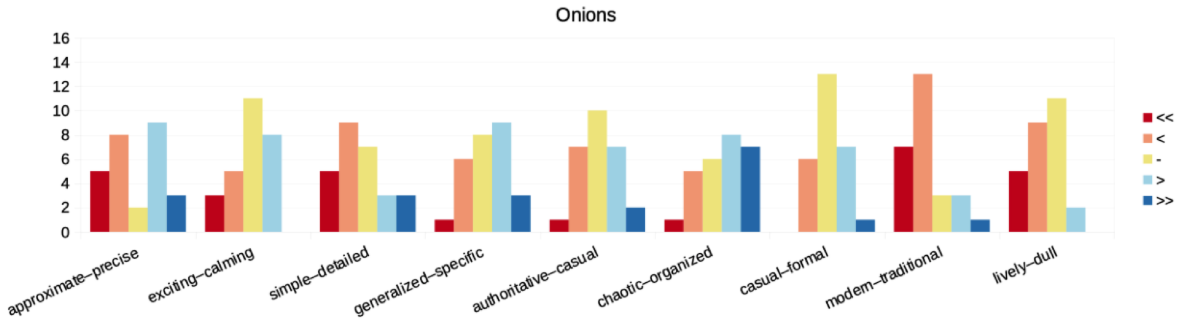

Figure 20: Chart of semantic differential responses for Onions cartogram.

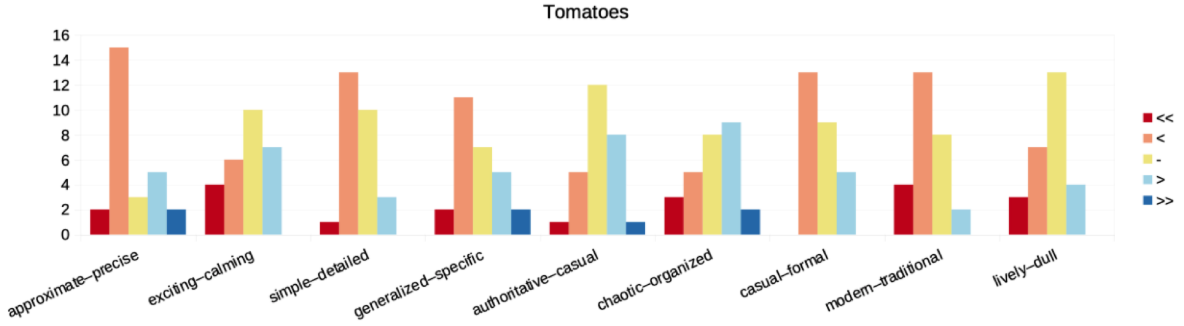

Figure 21: Chart of semantic differential responses for Tomatoes cartogram.

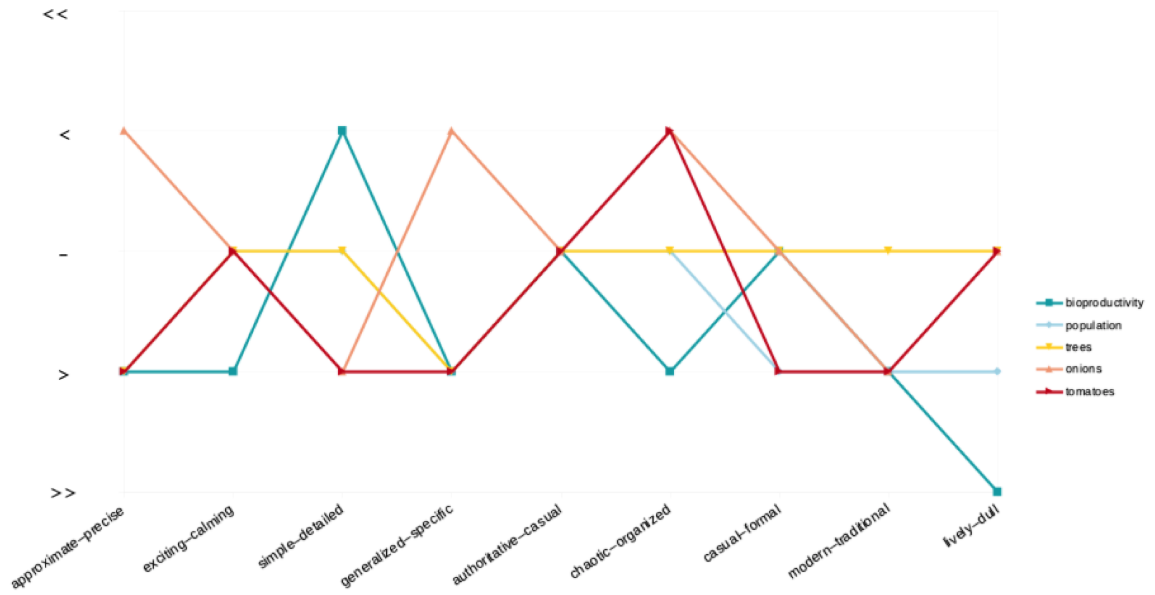

Figure 22: Chart of impressions and reactions mode

4.6 Results summary

The results of the study are able to provide some answers for the research questions put forth in Chapter 1.3.

- *Do animation and interactive animation influence cartogram effectiveness?*

The task results show that both non-interactive and interactive animation influence effectiveness, and in different ways.

- *For which cartogram-reading tasks are these design features more effective and therefore most suitable as compared to traditional static cartograms?*

The results show that non-interactive animation was more effective than any other cartogram type for the Detect change task category. The non-interactive animated cartogram was also the most effective for the Filter task category.

- *What are users' impressions of- and emotional reactions to cartograms with these design features?*

Participants reacted differently to the interactive and non-interactive animated cartograms. They found the interactive animated cartogram organized, while finding

the non-interactive animated cartogram chaotic. In comparison with traditional static cartograms, they found the animated cartograms to be more modern and lively.

5 Critical Reflection

5.1 Comparison with related work

The results show some similarity to the results of Kaspar et al. in terms of the difference in effectiveness depending on the task type. As mentioned previously, they found that cartograms are less effective than choropleth maps for more complex tasks, but comparably effective for more simple tasks. (Kaspar, Fabrikant, and Freckmann 2011) My results also show that the task complexity affects the animated cartograms's effectiveness more than that of the static cartograms. This can be seen especially in the results for the Summarize tasks and the Compare tasks, with participants performing worse with the animated cartograms for the Summarize tasks, but quite well for the Compare tasks.

Nusrat et al. also concluded from their study of cartogram effectiveness that both the cartogram type and task type are critical factors for effectiveness. (Nusrat, Alam, and Kobourov 2018)

Ware concluded from her study that animation changes cartogram communicative effectiveness, and we can also conclude that from the results of this study. Perhaps due to the differences in experiment design (e.g., cartograms of both familiar and unfamiliar regions, using only two task types, laboratory setting, different animation types, different cartogram styles) and the rapid development of technological capabilities for animation since her study in 1998, this study did not find that animated transition cartograms are overall more effective than static cartograms, as she did.

5.2 Discussion of unresolved issues

While the benefits of an online survey are numerous, the inability to control certain factors is a critical issue. This creates some problems with this study. With the online survey, it was not possible to control the environment of the participants, such as their comfort or external sensory input. It is also not possible to observe their behavior, such as multitasking or using external resources. Perhaps most importantly, it is not possible to control the participants' hardware specifications (e.g., processing speed, internet speed, screen size and resolution) and settings (e.g., color and contrast settings). In the introduction to the survey, participants were asked to use a laptop or desktop computer instead of a phone or tablet, but one participant's feedback saying they had trouble viewing the cartograms on their iPhone suggested that not all participants understood and/or complied with these

instructions. They were also asked to not use any external resources, but again, there is no way of assuring participant compliance.

To combat these concerns, the survey could be designed in a different way to make sure users understand the instructions. It is not possible in LimeSurvey to collect participants' screen display parameters, but perhaps in other survey platforms it is. It was also not possible to collect the time each participant spent per question. The LimeSurvey options only allow time stamp collection for question groups, not individual questions. The design of the survey did not allow for a setup with each question having its own group. Therefore the original experiment plan to measure the time taken for each task could not go through.

The best solution to these issues would be to conduct the same or a similar survey in a controlled laboratory setting. This would ensure that all participants use the same hardware, have the same external distractions, and follow the instructions about not multitasking or using external resources. It would also be easier to collect the time data for each question. However, this method presents its own problems, because conducting this type of survey requires much more organization and scheduling as well as access to a physical laboratory. For my research, this method was not feasible.

Another problem is the way the questions and answer options were formulated. I attempted to ask questions and provide answer selections using countries that most people should be familiar with, but many people cannot identify countries easily if they are not labelled. The country boundaries are also not always clearly visible. This experiment may have essentially been a test of basic geographical knowledge. If the survey were designed in a different way to avoid this potential problem, the results might be different. In future work, it is recommendable to test participants' ability to identify the countries asked about in the task questions.

Another potential improvement would be to reformulate the answer choices so that participants can indicate their certainty of their answers instead of allowing an "Unsure" answer option. This would help understand the confidence level of participants in their answers. When the questions are formulated to have one correct and one incorrect answer, it is impossible to determine whether participants are simply guessing. It might be better to have more incorrect answers provided as answer options to prevent this potential for guessing. Likewise, participants who mark "Unsure" may know the correct answer but be afraid to commit to it because they may feel the survey is a test. A general answer certainty response for each question would give a new level of insight into the effectiveness of the cartograms.

Despite the limitations of the study, the results provide rare insight into the effectiveness of animated cartograms and will hopefully pique interest in this topic and commence further research.

5.2.1 Feedback from Participants

Participants were asked at the end of the survey if they experienced difficult completing the survey or if they had any comments about it. Several people entered comments in these fields.

One person was not able to complete the survey because they reported feeling motion sickness when looking at the non-interactive animated cartograms. Another participant commented, “The bioproductivity gif was difficult to decipher at the default speed, so I ended up downloading the gif and viewing the frames individually. I feel as if it would have been more helpful to have a slideshow of these months rather than a single gif.” This is unfortunately a hazard with animation, as discussed by Harrower. (Harrower 2003) Map designers looking to implement animation should be aware of this and try to avoid overwhelming map readers. A design solution for this problem may be to allow the user to control the animation playback speed and pause it, but unfortunately with a GIF this is not easily possible in a web browser.

A couple of people commented that they had difficulty understanding the cartograms and the questions because they were unfamiliar and lacked experience with these types of visualizations. One person mentioned that it got easier once they got more familiar with the visualizations and the question formats. These comments underline the importance of user testing for cartogram design with participants of the target audience.

Surprisingly, several people commented about the cartograms not having legends or color keys. Though the cartograms were designed to be intuitive, the colors did not have any quantitative values, and the questions were not related to the colors, participants apparently missed this common feature of maps. Clearly color choice is very important for cartograms, and when the color is not linked to the data visualization, it may be recommendable to make the colors have a low visual hierarchy level. Perhaps, for audiences not familiar with cartograms, design features such as legends could be vestigially implemented to give users a sense of familiarity.

5.3 Animated cartogram design recommendations

Based on the research, it is clear that some design considerations can improve effectiveness when communicating with animated cartograms. The following tips may help when designing animated cartograms.

- Allow user control of playback and/or playback speed
- Include a slider bar for direct user control of animation, especially for spatiotemporal change animation
- Provide preview of animation or program to make animation continuous unless paused–do not burden the user with having to discover the animation
- Ensure a logical and organized visual hierarchy (consider visual variables such as colors, patterns, text size, stroke width, etc.)
- Employ mouse-over data display for areal unit names, data values, etc.
- Consider the specific cartogram-reading tasks intended for the user and how best to support them
- Test the cartograms with people of the intended audience and ask for their feedback

6 Conclusions and Outlook

The results of this study provide a much-needed insight into the effectiveness of animated cartograms. This topic is increasingly important due to the rise of interactivity and animation effects being used for cartogram visualizations. Though this research has provided some valuable results, still more research is needed in this area.

Future work could include testing more types of cartograms and more types of tasks. This study focused only on contiguous cartograms, and the potential results for other cartogram types are unknown. This research included only 4 of the 10 cartogram task types identified previously. (Nusrat and Kobourov 2015) The type of animation was also very important according to the results of this study, and there are many different types of animation which could be studied. Different types of user-controlled animation should be tested, including methods which allow users to start and stop an automatic animation, and those that allow the user to adjust the frame rate.

Another area for future work in this topic is the use of visual analytics. It would be very interesting to know more about how people physically view animated cartograms, what parts of the cartograms participants' eyes linger on the most, and how eye movement patterns change depending on the task type given or the animation type used.

Most importantly, the results of this preliminary research should be validated with a similar study in a laboratory environment. The unresolved issues relating to the online survey are a major weakness of this study, and a laboratory setting is the only way to resolve these issues.

In conclusion, this study has shown that using animation and interactive animation in cartogram visualizations influences cartogram communicative effectiveness. The task type is a critical component of the effectiveness, with animated cartograms showing different levels of effectiveness for different task types.

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Appendices

i Survey questions

Correct answers are marked with asterisks (*)

```
Welcome to the Cartogram Survey!

During this survey, you will be asked to look at five cartograms and answer
a few short questions about them. Your participation in this survey is
crucial to my thesis research for my Cartography MSc program. Thank you for
helping me with my research!

Your responses to this survey are anonymous and no personally identifying
data will be collected. The survey should take around 20 minutes to
complete. Please do not use any external resources such as Google or a
friend! To ensure you can see the cartogram images, please complete the
survey on a desktop or laptop sized screen, not a small mobile device such
as a phone or tablet.
If you have any questions, you can contact me at cartogramsurvey@gmail.com.


Background info

What is your age?

Please write your answer here:

What is your gender?

Please choose only one of the following:

Female
Male
Other
No answer

What is your level of education?

Please choose only one of the following:

Secondary school or less
Some college or university
Bachelor degree
Master degree or Diplom
Doctorate degree
Other

Have you had any education in cartography?

Please choose only one of the following:

Yes
No
```

(Cartography is the study of the art and science of mapmaking.)

What is your English language skill level?

Please choose only one of the following:

Native
Fluent
Intermediate
Beginner
No answer

Do you have any uncorrected vision problems?
e.g., color blindness, vision loss in one or both eyes, glaucoma

Please choose only one of the following:

Yes
No
Unsure or Other

Make a comment on your choice here:

If you normally use glasses or contacts, please use them while taking the survey.

How familiar are you with cartograms?

Please choose only one of the following:

I've never heard of them
It sounds familiar but I don't know about them
I have seen them/used them before, but just a few times
I am very familiar with cartograms

Make a comment on your choice here:

If you have seen or heard of cartograms before, in what context did you have this experience?

Please choose all that apply:

School, university, or other academic lesson/exercise
On the internet, television, social media, etc.
Magazine, newspaper, or journal article
In a book, atlas, or collection of maps
Somewhere else
I have never seen a cartogram before

Bioproductivity Cartogram

Look at the following cartogram and use it to answer the following questions. You can refer back to the cartogram at any time while answering the questions.

Which of the following countries has higher bioproductivity than India?

Please choose all that apply:

Spain
Russia*
Brazil*
Turkey

Please note that there may be multiple correct answers.

Which country has a higher overall bioproductivity: Ireland or New Zealand?

Please choose only one of the following:

Ireland
New Zealand*
Unsure

Does Australia have relatively evenly or unevenly distributed bioproductivity?

Please choose only one of the following:

Evenly
Unevenly*
Unsure

Does Canada have a strong or weak change in bioproductivity depending on the season?

Please choose only one of the following:

Strong*
Weak
Unsure

Please give your overall impression of this cartogram.

Please choose the appropriate response for each item:

<< < - > >>

approximate–precise

authoritative–casual

generalized–specific

simple–detailed

exciting–calming

chaotic–organized

casual–formal

modern–traditional

lively–dull

Population Cartogram

Look at the following cartogram and use it to answer the following questions. You can refer back to the cartogram at any time while answering the questions.

Did Australia grow or shrink?

Please choose only one of the following:

Grew
Shrank*
Unsure

Which of the following countries has a higher population than the United States of America?

Please choose all that apply:

India*
Brazil
China*
Nigeria

Please note that there may be multiple correct answers.

Is population relatively evenly or unevenly distributed on the African continent?

Please choose only one of the following:

Evenly
Unevenly*
Unsure

Which has a larger population: India or Russia?

Please choose only one of the following:

India*
Russia
Unsure

Please give your overall impression of this cartogram.

Please choose the appropriate response for each item:

<< < - > >>

approximate–precise

authoritative–casual

generalized–specific

simple–detailed

exciting–calming

chaotic–organized

casual–formal

modern–traditional

lively–dull

Trees Cartogram

Look at the following cartogram and use it to answer the following questions. You can refer back to the cartogram at any time while answering the questions.

Which of the following countries has more trees than Australia?

Please choose all that apply:

Russia*
Mexico
United States of America*
India

Please note that there may be more than one correct answer.

Are trees relatively evenly or unevenly distributed on the North American continent?

Please choose only one of the following:

Evenly
Unevenly*
Unsure

Did Sweden grow or shrink?

Please choose only one of the following:

Grew*
Shrank
Unsure

Which has more trees: Canada or China?

Please choose only one of the following:

Canada*
China
Unsure

Please give your overall impression of this cartogram.

Please choose the appropriate response for each item:

<< < - > >>

approximate–precise

authoritative–casual

generalized–specific

simple–detailed

exciting–calming

chaotic–organized

casual–formal

modern–traditional

lively–dull

Onion Production Cartogram

Look at the following cartogram and use it to answer the following questions. You can refer back to the cartogram at any time while answering the questions. Use the slider button to transition from map to cartogram and back.

Is onion production relatively evenly or unevenly distributed on the South American continent?

Please choose only one of the following:

Evenly*
Unevenly
Unsure

Which country produced more onions: Turkey or Ireland?

Please choose only one of the following:

Turkey*
Ireland
Unsure

Did Germany grow or shrink?

Please choose only one of the following:

Grew
Shrank*
Unsure

Which of the following countries produced more onions than Spain?

Please choose all that apply:

India*
Japan*
Italy
South Africa

Please note that there may be multiple correct answers.

Please give your overall impression of this cartogram.

Please choose the appropriate response for each item:

<< < - > >>

approximate–precise

authoritative–casual

generalized–specific

simple–detailed

exciting–calming

chaotic–organized

casual–formal

modern–traditional

lively–dull

Please enter the number of transitions you used on the onion cartogram. The transition counter is located right above the cartogram.

Please write your answer here:

Tomato Production Cartogram

Look at the following cartogram and use it to answer the following questions. You can refer back to the cartogram at any time while answering the questions.

Did Turkey grow or shrink?

Please choose only one of the following:

Grew*
Shrank
Unsure

Which country produced more tomatoes: Egypt or France?

Please choose only one of the following:

Egypt*
France
Unsure

Is tomato production relatively evenly or unevenly distributed on the Asian continent?

Please choose only one of the following:

Evenly
Unevenly*
Unsure

Which of the following countries produced more tomatoes than Spain?

Please choose all that apply:

United States of America*
Germany
Australia
India*

Please note that there may be more than one correct answer.

Please give your overall impression of this cartogram.

Please choose the appropriate response for each item:

<< < - > >>

approximate–precise

authoritative–casual

generalized–specific

simple–detailed

exciting–calming

chaotic–organized

casual–formal

modern–traditional

lively–dull

The survey is almost done! Just a few more questions…

Did you have any difficulties completing the survey?

Yes

No

Make a comment on your choice here:

Do you have any other comments about the survey?

Submit your survey. Thank you for completing this survey.

ii Interactive animated cartogram code

index.html

```
<!DOCTYPE html>
<html>

<head>
    <title>Cartogram Survey: Onion Production, 2000</title>
    <meta charset="utf-8">
    <script src="https://d3js.org/d3.v3.min.js"></script>
    <script src="lib/colorbrewer.js"></script>
    <script src="lib/topojson.js"></script>
    <script src="cartogram.js"></script>
    <style type="text/css">
        body {
            font-family: "Helvetica Neue", Helvetica, Arial, sanscsv-serif;
            font-size: 14px;
            padding: 0;
            margin: 0;
        }

        #container {
            width: 800px;
            margin: 20px auto;
        }

        h1 {
            font-size: 140%;
            margin: 0 0 15px 0;
            text-align: center;
        }


        #map-container {
            width: 800px;
            height: 500px;
            text-align: center;
            position: relative;
            margin: 20px 0;
        }

        #map {
            display: block;
            position: absolute;
            background: #fff;
            width: 100%;
            height: 100%;
            margin: 0;
        }

        path.country {
            stroke: #666;
            stroke-width: .5;
        }
```

```
path.country:hover {
    stroke: #000;
}

select {
    font-size: inherit;
}

#credits {
    position: absolute;
    bottom: -71px;
    right: 1px;
    font-size: 0.8em;
    text-align: right;
}

.switch {
    position: relative;
    display: inline-block;
    width: 60px;
    height: 34px;
    float: right;
}

.switch input {
    opacity: 0;
    width: 0;
    height: 0;
}

.slider {
    position: absolute;
    cursor: pointer;
    top: 0;
    left: 0;
    right: 0;
    bottom: 0;
    background-color: #ccc;
    -webkit-transition: .4s;
    transition: .4s;
}

.slider:before {
    position: absolute;
    content: "";
    height: 26px;
    width: 26px;
    left: 4px;
    bottom: 4px;
    background-color: white;
    -webkit-transition: .4s;
    transition: .4s;
}

input:checked+.slider {
    background-color: #2196F3;
}
```

```
        input:focus+.slider {
            box-shadow: 0 0 1px #2196F3;
        }

        input:checked+.slider:before {
            -webkit-transform: translateX(26px);
            -ms-transform: translateX(26px);
            transform: translateX(26px);
        }

        /* Rounded sliders */
        .slider.round {
            border-radius: 34px;
        }

        .slider.round:before {
            border-radius: 50%;
        }

        .counter {
            display: inline-block;
            height: 34px;

        }

        .counter span {

            vertical-align: middle;
            font-size: 18px;
        }

        #counts {
            font-weight: bold;
            font-size: 25px;
            margin-right: 21px;

        }
    </style>
</head>

<body>
    <div id="container">
        <h1>Onion Production, 2000</h1>

        <div id="map-container">
            <div class="counter">
                <span>Transition Counter: </span>
                <span id="counts">0</span>
            </div>
            <svg id="map"></svg>
            <label class="switch">
                <input id="myCheckbox" type="checkbox"
onclick="myFunction()">
                <span class="slider round"></span>
            </label>
```

```
            <div id="credits">Created by Sarah Palmer using <a
href="http://d3js.org">d3.js</a> and <a
href="https://github.com/shawnbot/d3-cartogram/">cartogram.js</a>. Data
from <a href="http://www.fao.org/faostat"> FAOSTAT</a>.
                <br>
                This work is licensed under a <a rel="license"
href="http://creativecommons.org/licenses/by-nc-sa/4.0/">Creative Commons
Attribution-NonCommercial-ShareAlike 4.0 International License</a>.
            </div>
        </div>

        <script>
            var counter = parseInt(d3.select("#counts").node().innerHTML);

            var fields = [{
                    key: "%d",
                }],
                fieldsById = d3.nest()
                .key(function(d) {
                    return d.id;
                })
                .rollup(function(d) {
                    return d[0];
                })
                .map(fields),
                field = fields[0],
                colors = colorbrewer.YlOrRd[4]
                .reverse()
                .map(function(rgb) {
                    return d3.hsl(rgb);
                });

            var body = d3.select("body"),
                stat = d3.select("#status");

            function myFunction() {

                var checkBox = document.getElementById("myCheckbox");

                if (checkBox.checked == true) {
                    year = "value";
                    d3.select("#counts").node().innerHTML = counter += 1
                    update();
                } else {
                    reset();
                }
            }

            d3.select("input[type=range]").on("change", function() {
                year = "value";
                update();
            });

            var map = d3.select("#map"),
                zoom = d3.behavior.zoom()
                .translate([-38, 32])
                .scale(.94)
```

```
            .scaleExtent([0.5, 10.0])
            .on("zoom", updateZoom),
            layer = map.append("g")
            .attr("id", "layer"),
            countries = layer.append("g")
            .attr("id", "countries")
            .selectAll("path");
        updateZoom();

        function updateZoom() {
            var scale = zoom.scale();
            layer.attr("transform",
                "translate(" + zoom.translate() + ") " +
                "scale(" + [scale, scale] + ")");
        }

        var proj = d3.geo.equirectangular(),
            topology,
            geometries,
            rawData,
            dataById = {},
            carto = d3.cartogram()
            .projection(proj)
            .properties(function(d) {
                if (d.id in dataById) {
                    return dataById[d.id];
                } else {
                    var tmp = d3.keys(dataById[d3.keys(dataById)[0]]);
                    var ret = {
                        "numcode": d.id
                    };
                    tmp.forEach(function(i) {
                        ret[i] = 0
                    });
                    return ret;
                }
            })
            .value(function(d) {
                return +d.properties[field];
            });


        var segmentized = location.search === "?segmentized",
            url = ["data",
                segmentized ? "world-segmentized.topojson" : "world-
110m.json"
            ].join("/");
        d3.json(url, function(topo) {
            topology = topo;
            geometries = topology.objects.countries.geometries;
            d3.csv("data/dry_onions_2000.csv", function(data) {
                rawData = data;
                dataById = d3.nest()
                    .key(function(d) {
                        return d.numcode;
                    })
                    .rollup(function(d) {
```

```
                return d[0];
            })
            .map(data);
        init();
    });
});

function init() {
    var features = carto.features(topology, geometries),
        path = d3.geo.path()
        .projection(proj);

    countries = countries.data(features)
        .enter()
        .append("path")
        .attr("class", "country")
        .attr("id", function(d) {
            return d.id;
        })
        .attr("name", function(d) {
            return d.properties.country;
        })
        .attr("fill", "#fafafa")
        .attr("d", path);

    countries.append("title");
}

function reset() {
    stat.text("");

    var features = carto.features(topology, geometries),
        path = d3.geo.path()
        .projection(proj);

    countries.data(features)
        .transition()
        .duration(750)
        .ease("linear")
        .attr("fill", "#fafafa")
        .attr("d", path);

    countries.select("title")
        .text(function(d) {
            return d.id;
        });
}

function update() {
    var start = Date.now();

    var key = field.key.replace("%d", year),
        fmt = (typeof field.format === "function") ?
        field.format :
        d3.format(field.format || ","),
        value = function(d) {
            return +d.properties[key];
```

```
                    },
                    values = countries.data()
                    .map(value)
                    .filter(function(n) {
                        return !isNaN(n);
                    })
                    .sort(d3.ascending),
                    lo = values[0],
                    hi = values[values.length - 1];

                var color = d3.scale.linear()
                    .range(colors)
                    .domain(lo < 0 ? [lo, 0, hi] : [lo, d3.mean(values),
hi]);

                // normalize the scale to positive numbers
                var scale = d3.scale.linear()
                    .domain([lo, hi])
                    .range([1, 1000]);

                // tell the cartogram to use the scaled values
                carto.value(function(d) {
                    return scale(value(d));
                });

                // generate the new features, pre-projected
                var features = carto(topology, geometries).features;

                // update the data
                countries.data(features)
                    .select("title")
                    .text(function(d) {
                        return [d.properties.country,
fmt(value(d))].join(": ");
                    });

                countries.transition()
                    .duration(750)
                    .ease("linear")
                    .attr("fill", function(d) {
                        return color(value(d));
                    })
                    .attr("d", carto.path);

            };
        </script>
</body>

</html>
```

cartogram.js

```
(function (exports) {

    /*
     * d3.cartogram is a d3-friendly implementation of An Algorithm to
Construct
     * Continuous Area Cartograms:
     *
     * <http://chrisman.scg.ulaval.ca/G360/dougenik.pdf>
     *
     * It requires topojson to decode TopoJSON-encoded topologies:
     *
     * <http://github.com/mbostock/topojson/>
     *
     * Usage:
     *
     * var cartogram = d3.cartogram()
     *  .projection(d3.geo.albersUsa())
     *  .value(function(d) {
     *    return Math.random() * 100;
     *  });
     * d3.json("path/to/topology.json", function(topology) {
     *  var features = cartogram(topology);
     *  d3.select("svg").selectAll("path")
     *    .data(features)
     *    .enter()
     *    .append("path")
     *      .attr("d", cartogram.path);
     * });
     */
    d3.cartogram = function () {

        function carto(topology, geometries) {
            // copy it first
            topology = copy(topology);

            // objects are projected into screen coordinates

            // project the arcs into screen space
            var tf = transformer(topology.transform), x, y, len1, i1, out1,
len2 = topology.arcs.length, i2 = 0, projectedArcs = new Array(len2);
            while (i2 < len2) {
                x = 0;
                y = 0;
                len1 = topology.arcs[i2].length;
                i1 = 0;
                out1 = new Array(len1);
                while (i1 < len1) {
                    topology.arcs[i2][i1][0] = (x += topology.arcs[i2][i1]
[0]);
                    topology.arcs[i2][i1][1] = (y += topology.arcs[i2][i1]
[1]);
                    out1[i1] = projection(tf(topology.arcs[i2][i1]));
                    i1++;
                }
                projectedArcs[i2++] = out1;
```

```
            }

            // path with identity projection
            var path = d3.geo.path()
                .projection(null);

            var objects = object(projectedArcs, {
                    type: "GeometryCollection",
                    geometries: geometries
                })
                .geometries.map(function (geom) {
                    return {
                        type: "Feature",
                        id: geom.id,
                        properties: properties.call(null, geom, topology),
                        geometry: geom
                    };
                });

            var values = objects.map(value),
                totalValue = d3.sum(values);

            // no iterations; just return the features
            if (iterations <= 0) {
                return objects;
            }

            var i = 0;
            while (i++ < iterations) {
                var areas = objects.map(path.area);
                var totalArea = d3.sum(areas),
                    sizeErrorsTot = 0,
                    sizeErrorsNum = 0,
                    meta = objects.map(function (o, j) {
                        var area = Math.abs(areas[j]), // XXX: why do we
have negative areas?
                            v = +values[j],
                            desired = totalArea * v / totalValue,
                            radius = Math.sqrt(area / Math.PI),
                            mass = Math.sqrt(desired / Math.PI) - radius,
                            sizeError = Math.max(area, desired) /
Math.min(area, desired);
                        sizeErrorsTot += sizeError;
                        sizeErrorsNum++;
                        // console.log(o.id, "@", j, "area:", area,
"value:", v, "->", desired, radius, mass, sizeError);
                        return {
                            id: o.id,
                            area: area,
                            centroid: path.centroid(o),
                            value: v,
                            desired: desired,
                            radius: radius,
                            mass: mass,
                            sizeError: sizeError
                        };
```

```
                    });

                var sizeError = sizeErrorsTot / sizeErrorsNum,
                    forceReductionFactor = 1 / (1 + sizeError);

                // console.log("meta:", meta);
                // console.log("  total area:", totalArea);
                // console.log("  force reduction factor:",
forceReductionFactor, "mean error:", sizeError);

                var len1, i1, delta, len2 = projectedArcs.length,
                    i2 = 0,
                    delta, len3, i3, centroid, mass, radius, rSquared, dx,
dy, distSquared, dist, Fij;
                while (i2 < len2) {
                    len1 = projectedArcs[i2].length;
                    i1 = 0;
                    while (i1 < len1) {
                        // create an array of vectors: [x, y]
                        delta = [0, 0];
                        len3 = meta.length;
                        i3 = 0;
                        while (i3 < len3) {
                            centroid = meta[i3].centroid;
                            mass = meta[i3].mass;
                            radius = meta[i3].radius;
                            rSquared = (radius * radius);
                            dx = projectedArcs[i2][i1][0] - centroid[0];
                            dy = projectedArcs[i2][i1][1] - centroid[1];
                            distSquared = dx * dx + dy * dy;
                            dist = Math.sqrt(distSquared);
                            Fij = (dist > radius) ?
                                mass * radius / dist :
                                mass *
                                (distSquared / rSquared) *
                                (4 - 3 * dist / radius);
                            delta[0] += (Fij * cosArctan(dy, dx));
                            delta[1] += (Fij * sinArctan(dy, dx));
                            i3++;
                        }
                        projectedArcs[i2][i1][0] += (delta[0] *
forceReductionFactor);
                        projectedArcs[i2][i1][1] += (delta[1] *
forceReductionFactor);
                        i1++;
                    }
                    i2++;
                }

                // break if we hit the target size error
                if (sizeError <= 1) break;
            }

            return {
                features: objects,
                arcs: projectedArcs
            };
```

```
        }

        var iterations = 12,
            projection = d3.geo.albers(),
            properties = function (id) {
                return {};
            },
            value = function (d) {
                return 1;
            };

        // for convenience
        carto.path = d3.geo.path()
            .projection(null);

        carto.iterations = function (i) {
            if (arguments.length) {
                iterations = i;
                return carto;
            } else {
                return iterations;
            }
        };

        carto.value = function (v) {
            if (arguments.length) {
                value = d3.functor(v);
                return carto;
            } else {
                return value;
            }
        };

        carto.projection = function (p) {
            if (arguments.length) {
                projection = p;
                return carto;
            } else {
                return projection;
            }
        };

        carto.feature = function (topology, geom) {
            return {
                type: "Feature",
                id: geom.id,
                properties: properties.call(null, geom, topology),
                geometry: {
                    type: geom.type,
                    coordinates: topojson.object(topology,
geom).coordinates
                }
            };
        };

        carto.features = function (topo, geometries) {
            return geometries.map(function (f) {
```

```
            return carto.feature(topo, f);
        });
    };

    carto.properties = function (props) {
        if (arguments.length) {
            properties = d3.functor(props);
            return carto;
        } else {
            return properties;
        }
    };

    return carto;
};

var transformer = d3.cartogram.transformer = function (tf) {
    var kx = tf.scale[0],
        ky = tf.scale[1],
        dx = tf.translate[0],
        dy = tf.translate[1];

    function transform(c) {
        return [c[0] * kx + dx, c[1] * ky + dy];
    }

    transform.invert = function (c) {
        return [(c[0] - dx) / kx, (c[1] - dy) / ky];
    };

    return transform;
};

function angle(a, b) {
    return Math.atan2(b[1] - a[1], b[0] - a[0]);
}

function distance(a, b) {
    var dx = b[0] - a[0],
        dy = b[1] - a[1];
    return Math.sqrt(dx * dx + dy * dy);
}

function projector(proj) {
    var types = {
        Point: proj,
        LineString: function (coords) {
            return coords.map(proj);
        },
        MultiLineString: function (arcs) {
            return arcs.map(types.LineString);
        },
        Polygon: function (rings) {
            return rings.map(types.LineString);
        },
        MultiPolygon: function (rings) {
            return rings.map(types.Polygon);
```

```
            }
        };
        return function (geom) {
            return types[geom.type](geom.coordinates);
        };
    }

    function cosArctan(dx, dy) {
        var div = dx / dy;
        return (dy > 0) ?
            (1 / Math.sqrt(1 + (div * div))) :
            (-1 / Math.sqrt(1 + (div * div)));
    }

    function sinArctan(dx, dy) {
        var div = dx / dy;
        return (dy > 0) ?
            (div / Math.sqrt(1 + (div * div))) :
            (-div / Math.sqrt(1 + (div * div)));
    }

    function copy(o) {
        return (o instanceof Array) ?
            o.map(copy) :
            (typeof o === "string" || typeof o === "number") ?
            o :
            copyObject(o);
    }

    function copyObject(o) {
        var obj = {};
        for (var k in o) obj[k] = copy(o[k]);
        return obj;
    }

    function object(arcs, o) {
        function arc(i, points) {
            if (points.length) points.pop();
            for (var a = arcs[i < 0 ? ~i : i], k = 0, n = a.length; k < n;
++k) {
                points.push(a[k]);
            }
            if (i < 0) reverse(points, n);
        }

        function line(arcs) {
            var points = [];
            for (var i = 0, n = arcs.length; i < n; ++i) arc(arcs[i],
points);
            return points;
        }

        function polygon(arcs) {
            return arcs.map(line);
        }

        function geometry(o) {
```

```
            o = Object.create(o);
            o.coordinates = geometryType[o.type](o.arcs);
            return o;
        }
        var geometryType = {
            LineString: line,
            MultiLineString: polygon,
            Polygon: polygon,
            MultiPolygon: function (arcs) {
                return arcs.map(polygon);
            }
        };

        return o.type === "GeometryCollection" ?
            (o = Object.create(o), o.geometries =
o.geometries.map(geometry), o) :
            geometry(o);
    }

    function reverse(array, n) {
        var t, j = array.length,
            i = j - n;
        while (i < --j) t = array[i], array[i++] = array[j], array[j] = t;
    }

})(this);
```

dry_onions_2000.csv

regcode	numcode	country	value
17	4	Afghanistan	577910
8	8	Albania	30000
10	12	Algeria	315741
8	20	Andorra	0
12	24	Angola	0
3	28	Antigua and Barbuda	110
4	32	Argentina	545123
16	51	Armenia	31328
19	36	Australia	247067
6	40	Austria	95741
16	31	Azerbaijan	88770
3	44	Bahamas	695
16	48	Bahrain	1526
17	50	Bangladesh	134000
3	52	Barbados	320
7	112	Belarus	66100
6	56	Belgium	28329
2	84	Belize	0
11	204	Benin	12000
1	60	Bermuda	59
17	64	Bhutan	0
4	68	Bolivia	49300
8	70	Bosnia and Herzegovina	21624
9	72	Botswana	950
4	76	Brazil	1156332
20	96	Brunei Darussalam	0
7	100	Bulgaria	67981
11	854	Burkina Faso	0
13	108	Burundi	0
11	132	Cabo Verde	2700
20	116	Cambodia	0
12	120	Cameroon	67046
1	124	Canada	186120
12	140	Central African Republic	0

12	148	Chad	14860
4	152	Chile	282250
18	156	China, mainland	14070000
18	158	China, Taiwan Province of	34696
4	170	Colombia	745604
13	174	Comoros	0
12		Congo	500
21	184	Cook Islands	0
4	188	Costa Rica	15445
11	384	Côte d'Ivoire	0
8	191	Croatia	9613
3	192	Cuba	72859
8	196	Cyprus	7200
7	203	Czechia	76402
18	408	Democratic People's Republic of Korea	82639
12	180	Democratic Republic of the Congo	54819
5	208	Denmark	29107
13	262	Djibouti	0
3	212	Dominica	0
3	214	Dominican Republic	31629
2	218	Ecuador	0
10	818	Egypt	762993
2	222	El Salvador	400
12	226	Equatorial Guinea	0
13	232	Eritrea	0
5	233	Estonia	490
9	748	Eswatini	0
13	231	Ethiopia	114867
4	238	Falkland Islands (Malvinas)	0
21	242	Fiji	0
5	246	Finland	21700
6	250	France	418890
4	254	French Guiana	0
21	258	French Polynesia	0
12	266	Gabon	0
11	270	Gambia	0
16	268	Georgia	31000

6	276	Germany	316680
11	288	Ghana	38380
8	292	Gibraltar	0
8	300	Greece	212714
5	304	Greenland	0
3	308	Grenada	0
3		Guadeloupe	21
21		Guam	2
2	320	Guatemala	104780
11	324	Guinea	0
11	624	Guinea-Bissau	0
4	328	Guyana	4524
3	332	Haiti	6000
8	336	Holy See	0
2	340	Honduras	10547
7	348	Hungary	117393
5	352	Iceland	0
17	356	India	4721100
20	360	Indonesia	772818
17	364	Iran (Islamic Republic of)	1343588
16	368	Iraq	139000
5	372	Ireland	7800
16	376	Israel	110000
8	380	Italy	439618
3	388	Jamaica	1219
18	392	Japan	1247000
16	400	Jordan	47263
15	398	Kazakhstan	256490
13	404	Kenya	57391
21	296	Kiribati	0
16	414	Kuwait	6591
15	417	Kyrgyzstan	147447
20	418	Lao People's Democratic Republic	0
5	428	Latvia	8280
16	422	Lebanon	157600
9	426	Lesotho	0
11	430	Liberia	0

10	434	Libya	178000
6	438	Liechtenstein	0
5	440	Lithuania	20232
6	442	Luxembourg	72
13	450	Madagascar	5800
13	454	Malawi	30000
20	458	Malaysia	0
17	462	Maldives	77
11	466	Mali	20291
8	470	Malta	5554
3	474	Martinique	0
11	478	Mauritania	0
13	480	Mauritius	11134
2	484	Mexico	905452
21	583	Micronesia (Federated States of)	0
6	492	Monaco	0
18	496	Mongolia	1100
8		Montenegro	0
3		Montserrat	56
10	504	Morocco	348270
13	508	Mozambique	2565
20		Myanmar	583500
9	516	Namibia	3000
21	520	Nauru	0
17	524	Nepal	0
6	528	Netherlands	821022
19	554	New Zealand	0
2	558	Nicaragua	5500
11	562	Niger	356184
11	566	Nigeria	593008
21	570	Niue	0
5	578	Norway	0
16		Palestine	25649
16	512	Oman	13932
17	586	Pakistan	1647991
21	585	Palau	0
2	591	Panama	5404

21	598	Papua New Guinea	0
4	600	Paraguay	34000
4	604	Peru	383495
20	608	Philippines	84216
7	616	Poland	720345
8	620	Portugal	110000
16	634	Qatar	3700
18	410	Republic of Korea	877514
7	498	Republic of Moldova	53661
13		Réunion	1030
7	642	Romania	296297
14	643	Russian Federation	1133753
13	646	Rwanda	1000
3	659	Saint Kitts and Nevis	59
3	662	Saint Lucia	0
3	670	Saint Vincent and the Grenadines	0
21	882	Samoa	0
8	674	San Marino	0
12	678	Sao Tome and Principe	0
16	682	Saudi Arabia	94651
11	686	Senegal	79736
8		Serbia	0
8		Serbia and Montenegro	130931
13	690	Seychelles	0
11	694	Sierra Leone	0
20	702	Singapore	0
7	703	Slovakia	26262
8	705	Slovenia	6260
21	90	Solomon Islands	0
13	706	Somalia	11552
9	710	South Africa	329000
8	724	Spain	959731
17	144	Sri Lanka	79060
10	736	Sudan (former)	168000
4	740	Suriname	0
5	752	Sweden	39523
6	756	Switzerland	25589

16	760	Syrian Arab Republic	71917
15	762	Tajikistan	113000
20	764	Thailand	90341
8	807	North Macedonia	36336
11	768	Togo	0
21	776	Tonga	0
3	780	Trinidad and Tobago	0
10	788	Tunisia	133000
16	792	Turkey	2200000
15	795	Turkmenistan	60900
21	798	Tuvalu	0
13	800	Uganda	137286
7	804	Ukraine	563000
16		United Arab Emirates	0
5	826	United Kingdom	392700
13	834	United Republic of Tanzania	36188
1	840	United States of America	3253190
4	858	Uruguay	20000
15	860	Uzbekistan	431300
21	548	Vanuatu	0
4	862	Venezuela (Bolivarian Republic of)	175228
20	704	Viet Nam	210000
21	876	Wallis and Futuna Islands	0
10	732	Western Sahara	0
16	887	Yemen	74606
13	894	Zambia	27000
13	716	Zimbabwe	2400

world-110m.json


```
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176],[244,-217],[172,-596],[104,-254],[97,-363],[103,-579],[483,-189],
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[-2,1],[-434,98]],[[48727,82186],[413,-54],[1,0]],[[49181,82475],[-186,364],[-4,8]],[[61098,76242],[34,70],[235,-101],[409,-96],[378,-283],[48,-110],[169,93],[259,-124],[85,-242],[175,-137]],[[62106,74858],[-268,290],[-296,-28]],[[50006,57090],[-20,-184],[116,-305],[-1,-429],[27,-466],[69,-215],[-61,-532],[22,-294],[74,-375],[62,-207]],[[47655,55121],[-78,15],[-57,-238],[-78,3],[-55,126],[19,237],[-116,362],[-73,-67],[-59,-13]],[[47158,55546],[-77,-34],[3,217],[-44,155],[9,171],[-60,249],[-78,211],[-222,1],[-65,-112],[-76,-13],[-48,-128],[-32,-163],[-148,-260]],[[45797,57103],[123,288],[84,-11],[73,99],[61,1],[44,78],[-24,196],[31,62],[5,200]],[[46194,58016],[134,-6],[200,-144],[61,13],[21,66],[151,-47],[40,33]],[[46801,57931],[16,-216],[44,1],[73,78],[46,-19],[77,-150],[119,-48],[76,128],[90,79],[67,83],[55,-15],[62,-130],[33,-163],[114,-248],[-57,-152],[-11,-192],[59,58],[35,-69],[-15,-176],[85,-170]],[[45357,58612],[302,17],[63,140],[88,9],[110,-145],[86,-3],[92,99],[56,-170],[-120,-133],[-121,11],[-119,124],[-103,-136],[-50,-5],[-67,-83],[-253,13]],[[45367,57897],[147,96],[92,-19],[75,67],[513,-25]],[[56638,74190],[-154,-1],[-147,305]],[[56486,73734],[-105,-129],[155,-273]],[[56431,72099],[-184,-8],[-228,257],[-104,473]],[[55838,74710],[182,53],[106,129],[150,-12],[46,103],[53,20]],[[57254,75292],[135,-157],[-86,-369],[-66,-67]],[[24381,59170],[7,172],[32,138],[-39,111],[133,481],[357,2],[7,201],[-45,36],[-31,128],[-103,136],[-103,198],[125,1],[1,333],[259,1],[257,-7]],[[25493,59872],[-127,-225],[-131,-166],[-20,-113],[22,-116],[-58,-150]],[[25179,59102],[-65,-37],[15,-69],[-52,-66],[-95,-149],[-9,-86]],[[34125,54109],[-44,-532],[-169,-154],[15,-139],[-51,-305],[123,-429],[89,-1],[37,-333],[169,-514]],[[33129,53652],[-188,448],[75,163],[-5,273],[171,95],[69,110],[-95,220],[24,215],[220,347]],[[25697,58436],[-84,51]],[[25613,58487],[19,237],[-38,64],[-57,42],[-122,-70],[-10,79],[-84,95],[-60,118],[-82,50]],[[25860,59889],[128,15],[90,66]],[[26903,59440],[-95,12],[-38,-81],[-97,-77],[-70,0],[-61,-76],[-56,27],[-47,90],[-29,-17],[-36,-141],[-27,5],[-4,-121],[-97,-163],[-51,-70],[-29,-74],[-82,120],[-60,-158],[-58,4],[-65,-14],[6,-290],[-41,-5],[-35,-135],[-86,-25]],[[55230,77704],[67,-229],[89,-169],[-107,-222]],[[55155,75778],[-31,-100]],[[54448,76285],[-233,434],[56,45]],[[53809,77462],[194,-20],[51,100],[94,-97],[109,-11],[-1,165],[97,60],[27,239],[221,157]],[[54601,78055],[88,-73],[208,-253],[229,-114],[104,89]],[[54716,79012],[141,-151],[103,-65],[233,73],[22,118],[111,18],[135,92],[30,-38],[130,74],[66,139],[91,36],[297,-180],[59,61]],[[56134,79189],[155,-161],[19,-159]],[[56308,78869],[-170,-123],[-131,-401],[-168,-401],[-223,-111]],[[55616,77833],[-173,26],[-213,-155]],[[54601,78055],[-54,200],[-47,6]],[[84713,45326],[28,-117],[5,-179]],[[89166,49043],[5,-1925],[4,-1925]],[[80461,51765],[47,-395],[190,-334],[179,121],[177,-43],[162,299],[133,52],[263,-166],[226,126],[143,822],[107,205],[96,672],[319,0],[241,-100]],[[72530,68413],[-176,-268],[-108,-553],[269,-224],[262,-289],[362,-332],[381,-76],[160,-301],[215,-56],[334,-138],[231,10],[32,234],[-36,375],[21,255]],[[77035,67277],[20,-224],[-97,-108],[23,-364],[-199,107],[-359,-408],[8,-338],[-153,-496],[-14,-288],[-124,-487],[-217,135],[-11,-612],[-63,-201],[30,-251],[-137,-140]],[[73107,61020],[-276,-387],[-1,-271]],[[72692,60216],[-251,-212],[-129,-31]],[[71996,56025],[-253,-168],[-93,-401]],[[68937,64577],[185,395],[612,-2],[-56,507],[-156,300],[-31,455],[-182,265],[306,619],[323,-45],[290,620],[174,599],[270,593],[-4,421],[236,342],[-224,292],[-96,400],[-99,517],[137,255],[421,-144],[310,88],[268,496]],[[64978,72558],[244,114],[197,338],[186,-17],[122,110],[197,-55],[308,-299],[221,-65],[318,-523],[207,-21],[24,-498]],[[66909,68203],[137,-310],[112,-357],[266,-260],[7,-520],[133,-96],[23,-272],[-400,-305],[-105,-687]],[[66559,65575],[-303,136],[-313,76]],[[63594,68492],[-104,-231]],[[63490,68261],[-153,311],[-3,314],[-89,0],[46,428],[-143,449],[-340,324],[-193,562],[65,461],[139,204],[-21,345],[-182,177],[-180,705]],[[62436,72541],[-152,473],

[55,183],[-87,678],[190,168]],[[63490,68261],[-164,29]],[[63326,68290],[-187,49],[-204,-567]],[[62935,67772],[-516,47],[-784,1188],[-413,414],[-335,160]],[[60887,69581],[-112,720]],[[60775,70301],[615,614],[105,715],[-26,431],[152,146],[142,369]],[[61763,72576],[119,92],[324,-77],[97,-150],[133,100]],[[59922,69905],[-49,-186]],[[59873,69719],[-100,82],[-58,-394],[69,-66],[-71,-81],[-12,-156],[131,80]],[[59832,69184],[7,-230],[-139,-944]],[[59757,70130],[93,-1],[25,104],[75,8]],[[59950,70241],[4,-242],[-38,-90],[6,-4]],[[53835,78058],[-31,-291],[67,-251]],[[54413,75123],[249,-214],[204,-178]],[[53108,75604],[-189,340],[-86,585]],[[59922,69905],[309,-234],[544,630]],[[60887,69581],[-53,-89],[-556,-296],[277,-591],[-92,-101],[-46,-197],[-212,-82],[-66,-213],[-120,-182],[-310,94]],[[59832,69184],[41,173],[0,362]],[[69711,75551],[-159,-109],[-367,-412],[-121,-422],[-104,-4],[-76,280],[-353,19],[-57,484],[-135,4],[21,593],[-333,431],[-476,-46],[-326,-86],[-265,533],[-227,223],[-431,423],[-52,51],[-715,-349],[11,-2178]],[[65546,74986],[-142,-29],[-195,463],[-188,166],[-315,-123],[-123,-197]],[[63639,77993],[-142,96],[29,304],[-177,395],[-207,-17],[-235,401],[160,448],[-81,120],[222,649],[285,-342],[35,431],[573,643],[434,15],[612,-409],[329,-239],[295,249],[440,12],[356,-306],[80,175],[391,-25],[69,280],[-450,406],[267,288],[-52,161],[266,153],[-200,405],[127,202],[1039,205],[136,146],[695,218],[250,245],[499,-127],[88,-612],[290,144],[356,-202],[-23,-322],[267,33],[696,558],[-102,-185],[355,-457],[620,-1500],[148,309],[383,-340],[399,151],[154,-106],[133,-341],[194,-115],[119,-251],[358,79],[147,-361]],[[72294,75601],[-171,87],[-140,212],[-412,62],[-461,16],[-100,-65],[-396,248],[-158,-122],[-43,-349],[-457,204],[-183,-84],[-62,-259]],[[60889,47817],[-399,590],[-19,343],[-1007,1203],[-47,65]],[[59417,50018],[-3,627],[80,239],[137,391],[101,431],[-123,678],[-32,296],[-132,411]],[[59445,53091],[171,352],[188,390]],[[61626,52895],[-243,-670],[3,-2152],[165,-488]],[[70465,73876],[-526,-89],[-343,192],[-301,-46],[26,340],[303,-98],[101,182]],[[69725,74357],[212,-58],[355,425],[-329,311],[-198,-147],[-205,223],[234,382],[-83,58]],[[78495,57780],[-66,713],[178,492],[359,112],[261,-84]],[[79227,59013],[229,-232],[126,407],[246,-217]],[[79828,58971],[64,-394],[-34,-708],[-467,-455],[122,-358],[-292,-43],[-240,-238]],[[85103,71220],[51,443],[-122,615]],[[85048,72883],[17,54],[124,-21],[108,266],[197,29],[118,39],[40,143]],[[55575,75742],[52,132]],[[55627,75874],[66,43],[38,196],[50,33],[40,-84],[52,-36],[36,-94],[46,-28],[54,-110],[39,4],[-31,-144],[-33,-71],[9,-44]],[[55993,75539],[-62,-23],[-164,-91],[-13,-121],[-35,5]],[[63448,67449],[-196,-16],[-69,282],[-248,57]],[[79227,59013],[90,266],[12,500],[-224,515],[-18,583],[-211,480],[-210,40],[-56,-205],[-163,-17],[-83,104],[-293,-353],[-6,530],[68,623],[-188,27],[-16,355],[-120,182]],[[77809,62643],[59,218],[237,384]],[[78380,63852],[162,-466],[125,-537],[342,-5],[108,-515],[-178,-155],[-80,-212],[333,-353],[231,-699],[175,-520],[210,-411],[70,-418],[-50,-590]],[[59999,71049],[125,-31],[45,-231],[-151,-223],[-68,-323]],[[47498,53435],[-252,449],[-237,324]],[[46822,54589],[66,189],[15,172],[126,320],[129,276]],[[54125,64088],[-197,-220],[-156,324],[-439,255]],[[52633,68486],[136,137],[24,250],[-30,244],[191,228],[86,189],[135,170],[16,454]],[[56646,69496],[276,-70],[68,-195]],[[56944,63578],[0,-1180],[-320,-2],[-3,-248]],[[56621,62148],[-1108,1131],[-1108,1132],[-280,-323]],[[58049,33472],[96,-178],[-85,-288],[-47,-192],[-155,-93],[-51,-188],[-99,-59],[-209,454],[148,374],[151,232],[130,120],[121,-182]],[[56314,82678],[-23,150],[30,162],[-123,94],[-291,103]],[[55848,83684],[318,181],[466,-38],[273,59],[39,-123],[148,-38],[267,-287]],[[56523,82432],[-67,182],[-142,64]],[[57579,84537],[134,-136],[24,-287],[89,-348]],[[47592,66920],[-42,0],[7,-317],[-172,-19],[-90,-134],[-126,0],[-100,76],[-234,-63],[-91,-460],[-86,-44],[-131,-745],[-386,-637],[-92,-816],[-114,-265],[-33,-213],[-625,-48],[-5,1]],[[46350,66910],[5,8],[139,227]],[[46494,67145],[259,65],

[218,404],[140,158]],[[57394,79070],[66,87],[185,58],[204,-184],[115,-22],[125,-159],[-20,-200],[101,-97],[40,-247],[97,-150],[-19,-88],[52,-60],[-74,-44],[-164,18],[-27,81],[-58,-47],[20,-106],[-76,-188],[-49,-203],[-70,-64]],[[57842,77455],[-50,270],[30,252],[-9,259],[-160,352],[-89,249],[-86,175],[-84,58]],[[23016,65864],[-107,-518]],[[24067,59806],[-144,191],[-226,155]],[[19641,66203],[-142,138],[-164,287]],[[18570,68996],[-201,234],[-93,-25]],[[19362,64423],[-181,337],[-201,286]],[[17464,69802],[316,46],[353,64],[-26,-116],[419,-287],[634,-416],[552,4],[221,0],[0,244],[481,0],[102,-210],[142,-186],[165,-260],[92,-309],[69,-325],[144,-178],[230,-177],[175,467],[227,11],[196,-236],[139,-404],[96,-346],[164,-337],[61,-414],[78,-277],[217,-184],[197,-130],[108,18]],[[55993,75539],[95,35],[128,9]],[[46619,59216],[93,107],[47,348],[88,14],[194,-165],[157,117],[107,-39],[42,131],[1114,9],[62,414],[-48,73],[-134,2550],[-134,2550],[425,10]],[[51185,61897],[1,-1361],[-152,-394],[-24,-364],[-247,-94],[-379,-51],[-102,-210],[-178,-23]],[[46801,57931],[13,184],[-24,229],[-104,166],[-54,338],[-13,368]],[[77809,62643],[-159,-137],[-162,-256],[-196,-26],[-127,-639],[-117,-107],[134,-519],[177,-431],[113,-390],[-101,-514],[-96,-109],[66,-296],[185,-470],[32,-330],[-4,-274],[108,-539],[-152,-551],[-135,-607]],[[55380,75322],[-58,46]],[[55338,76294],[74,-101],[40,-82],[91,-63],[106,-123],[-22,-51]],[[74375,79706],[292,102],[530,509],[423,278],[242,-182],[289,-8],[186,-276],[277,-22],[402,-148],[270,411],[-113,348],[288,612],[311,-244],[252,-69],[327,-152],[53,-443],[394,-248],[263,109],[351,78],[279,-78],[272,-284],[168,-302],[258,6],[350,-96],[255,146],[366,98],[407,416],[166,-63],[146,-198],[331,49]],[[59599,43773],[209,48],[334,-166],[73,74],[193,16],[99,177],[167,-10],[303,230],[221,342]],[[59870,36949],[-45,-275],[65,-101]],[[59890,36573],[-41,-245],[-116,-211]],[[59119,34780],[-211,5]],[[58908,34785],[-24,261],[-41,265]],[[58843,35311],[-23,212],[49,659],[-72,419],[-133,832]],[[58664,37433],[292,671],[74,426],[42,53],[31,348],[-45,175],[12,442],[54,409],[0,748],[-145,190],[-132,43],[-60,146],[-128,125],[-232,-12],[-18,220]],[[58409,41417],[-26,421],[843,487]],[[59226,42325],[159,-284],[77,54],[110,-149],[16,-237],[-59,-274],[21,-417],[181,-365],[85,410],[120,124],[-24,760],[-116,427],[-100,191],[-97,-9],[-77,768],[77,449]],[[46619,59216],[-184,405],[-168,435],[-184,157],[-133,173],[-155,-6],[-135,-129],[-138,51],[-96,-189]],[[45260,62987],[60,197],[1088,-4],[-53,853],[68,304],[261,53],[-9,1512],[911,-31],[1,895]],[[59226,42325],[-147,153],[85,549],[87,205],[-53,490],[56,479],[47,160],[-71,501],[-131,264]],[[59099,45126],[273,-110],[55,-164],[95,-275],[77,-804]],[[77801,54399],[48,105],[227,-258],[22,-304],[183,71],[91,243]],[[56448,40227],[228,134],[180,-34],[109,-133],[2,-49]],[[55526,35946],[0,-2182],[-248,-302],[-149,-43],[-175,112],[-125,43],[-47,252],[-109,162],[-133,-292]],[[54125,64088],[68,-919],[104,-153],[4,-188],[116,-203],[-60,-254],[-107,-1199],[-15,-769],[-354,-557],[-120,-778],[115,-219],[0,-380],[178,-13],[-28,-279]],[[53939,57955],[-52,-13],[-188,647],[-65,24],[-217,-331],[-215,173],[-150,34],[-80,-83],[-163,18],[-164,-252],[-141,-14],[-337,305],[-131,-145],[-142,10],[-104,223],[-279,221],[-298,-70],[-72,-128],[-39,-340],[-80,-238],[-19,-527]],[[52072,53186],[-105,31],[-107,-132]],[[51398,53895],[-197,389],[-209,-7]],[[25647,58207],[31,91],[46,-88]],[[51063,81078],[244,869],[380,248]],[[58639,91676],[-473,-237],[-224,-54]],[[55734,91409],[-172,-24],[-41,-389],[-523,95],[-74,-329],[-267,2],[-183,-421],[-278,-655],[-431,-831],[101,-202],[-97,-234],[-275,10],[-180,-554],[17,-784],[177,-300],[-92,-694],[-231,-405],[-122,-341]],[[52328,85032],[-371,-138],[-384,301]],[[51474,85830],[-88,1363],[256,381]],[[65352,60997],[1,-238],[-134,-165]],[[64880,60451],[-128,-34]],[[64752,60417],[-91,413],[-217,975]],[[64444,61805],[833,591],[185,1182],[-127,418]],[[65945,64688],[203,-78],[165,-107]],[[68734,64727],[-83,424],[-215,450]],[[28212,55535],[-52,196],[-138,164]],[[27170,56020],[-6,-126],[111,-26]],[[55461,82736],[342,-67],

[511,9]],[[56535,81053],[139,-515],[-29,-166],[-138,-69],[-252,-491],[71,-266],[-60,35]],[[56266,79581],[-264,227],[-200,-84],[-131,61],[-165,-127],[-140,210],[-114,-81],[-16,36]],[[86288,75628],[39,-104]],[[86221,75560],[-120,-200],[-83,-202]],[[85048,72883],[-135,112],[-34,-111]],[[84641,73095],[76,260],[66,69]],[[84829,73851],[-18,96],[-163,65]],[[64246,66009],[84,-185],[5,-346]],[[64274,65130],[-77,-42],[-84,117]],[[56308,78869],[120,127],[172,-65],[178,-3],[129,-144],[95,91],[205,56],[69,139],[118,0]],[[57842,77455],[124,-109],[131,95],[126,-101]],[[56293,76715],[-51,103],[65,99],[-69,74],[-87,-133],[-162,172],[-22,244],[-169,139],[-31,188],[-151,232]],[[81143,94175],[251,112],[141,-379]],[[84237,94144],[590,-104],[443,4]],[[97224,91732],[123,262],[886,-165]],[[96192,85904],[-126,219],[-268,-253]],[[95032,82989],[-486,-302],[-96,-674]],[[93543,84472],[14,276],[432,132]],[[95182,86999],[-705,-649],[-227,727]],[[90412,85637],[-914,-175],[-899,-1153]],[[88378,82339],[178,295],[305,-38]],[[89262,81946],[9,-503],[-217,-590]],[[60617,78409],[9,262],[143,165],[269,43],[44,197],[-62,326],[113,310],[-3,173],[-410,192],[-162,-6],[-172,277],[-213,-94],[-352,208],[6,116],[-99,256],[-222,29],[-23,183],[70,120],[-178,334],[-288,-57],[-84,30],[-70,-134],[-104,23]],[[59670,89515],[18,-274],[18,-604]],[[60317,88590],[-168,254],[177,224]],[[60998,88700],[233,144],[-186,433]],[[62654,90499],[1,-328],[219,-203]],[[63371,90473],[580,282],[970,507]],[[69038,93080],[183,537],[206,116]],[[69427,93733],[736,-156],[57,-328]],[[70444,91717],[222,593],[-361,482]],[[72363,94093],[483,119],[669,-26]],[[58449,49909],[110,-333],[-16,-348],[-80,-74]],[[58216,49787],[67,-60],[166,182]],[[61883,60238],[-37,252],[-83,178]],[[60335,65400],[-77,306],[-81,132]],[[63741,66597],[190,-249],[16,-243]],[[64444,61805],[-801,-226],[-259,-266],[-199,-620],[-130,-99],[-70,197],[-106,-30],[-269,60],[-50,59],[-321,-14],[-75,-53],[-114,153],[-74,-290],[28,-249],[-121,-189]],[[59434,56171],[-39,12],[5,294],[-33,203],[-143,233],[-34,426],[34,436],[-129,41],[-19,-132],[-167,-30],[67,-173],[23,-355],[-152,-324],[-138,-426],[-144,-61],[-233,345],[-105,-122],[-29,-172],[-143,-112],[-9,-122],[-277,0],[-38,122],[-200,20],[-100,-101],[-77,51],[-143,344],[-48,163],[-200,-81],[-76,-274],[-72,-528],[-95,-111],[-85,-65]],[[56635,55672],[-23,28]],[[56351,57163],[3,143],[-102,174],[-3,343],[-58,228],[-98,-34],[28,217],[72,246],[-32,245],[92,181],[-58,138],[73,365],[127,435],[240,-41],[-14,2345]],[[59433,56242],[1,-71]],[[59434,56171],[3,-460]],[[59445,53091],[-171,-272],[-195,1],[-224,-138],[-176,132],[-115,-161]],[[56824,55442],[-189,230]],[[25613,58487],[-31,-139]],[[62075,57243],[54,-245],[125,-247]],[[63596,57321],[-2,-9],[-1,-244],[0,-596],[0,-308],[-125,-363],[-194,-493]],[[34889,53069],[109,-351],[-49,-254],[-24,-270],[-71,-248]],[[56266,79581],[-77,-154],[-55,-238]],[[58908,34785],[-56,-263],[-163,-63],[-166,320],[-2,204],[76,222],[26,172],[80,42],[140,-108]],[[60041,71744],[74,129],[75,130],[15,329],[91,-115],[306,165],[147,-112],[229,2],[320,222],[149,-10],[316,92]],[[68841,72526],[156,598],[-60,440],[-204,140],[72,261],[232,-28],[132,326],[89,380],[371,137],[-58,-274],[40,-164],[114,15]],[[65546,74986],[313,8],[-45,297],[237,204],[234,343],[374,-312],[30,-471],[106,-121],[301,27],[93,-108],[137,-609],[317,-408],[181,-278],[291,-289],[369,-253],[-7,-362]],[[53083,72381],[-139,-290],[-2,-273]],[[58441,72005],[-192,-70],[-268,314]],[[57981,72249],[-303,-11],[-165,588]],[[59768,75418],[485,-417],[399,-228]],[[57321,74302],[-87,276],[3,121]],[[59099,45126],[-157,177],[-177,100],[-111,99],[-116,150]],[[58388,46397],[-161,331],[-55,342]],[[58449,49909],[98,71],[304,-7],[566,45]],[[30523,76389],[-147,-351],[-47,-133]],[[30377,75084],[-133,11],[-205,-103]],[[29172,73738],[-61,30],[-91,148]],[[29077,73598],[69,-105],[5,-223]],[[28966,72994],[-142,225],[-33,491]],[[28797,73080],[-183,93],[191,-191]],[[27672,65472],[-83,-75],[-137,72]],[[27408,65728],[-105,136],[-148,508]],[[26747,68267],[-108,90],[-281,-268]],[[26309,68119],[-135,275],[-174,147]],[[25227,68491],[-114,-92],[50,-157]],[[24755,67801],[-

207,312],[-242,-73]],[[16564,70932],[-71,95],[-33,324]],[[15516,76404],
[34,536],[33,536]],[[15948,78405],[69,156],[-45,484],[-94,485]],
[[10396,86079],[-385,-51],[-546,272]],[[8164,85656],[-308,-126],[-39,348]],
[[7158,84934],[-299,-248],[-278,-180]],[[4985,85596],[50,216],[-179,211]],
[[4541,89915],[-38,-296],[586,23]],[[4864,90008],[-342,225],[-197,296]],
[[30102,56752],[-123,-344],[105,-468]],[[31762,56607],[213,-74],[155,185]],
[[64752,60417],[-201,-158]],[[63521,58853],[-122,-33],[-83,35]],
[[63153,58610],[-177,-114],[-233,-30]],[[62539,58233],[-43,-150],[-
137,13]],[[57838,31217],[-210,-269],[-290,-229]],[[58175,37528],[113,-7],
[134,-100],[94,71],[148,-59]],[[58409,41417],[-210,-81],[-159,-235],[-33,-
205],[-100,-46],[-241,-486],[-154,-383],[-94,-13],[-90,68],[-
311,65]]],"transform":{"scale":
[0.0036000360003600037,0.0016925586033320111],"translate":[-180,-
85.60903777459777]}}

topojson.js

```
topojson = (function() {

  function merge(topology, arcs) {
    var arcsByEnd = {},
        fragmentByStart = {},
        fragmentByEnd = {};

    arcs.forEach(function(i) {
      var e = ends(i);
      (arcsByEnd[e[0]] || (arcsByEnd[e[0]] = [])).push(i);
      (arcsByEnd[e[1]] || (arcsByEnd[e[1]] = [])).push(~i);
    });

    arcs.forEach(function(i) {
      var e = ends(i),
          start = e[0],
          end = e[1],
          f, g;

      if (f = fragmentByEnd[start]) {
        delete fragmentByEnd[f.end];
        f.push(i);
        f.end = end;
        if (g = fragmentByStart[end]) {
          delete fragmentByStart[g.start];
          var fg = g === f ? f : f.concat(g);
          fragmentByStart[fg.start = f.start] = fragmentByEnd[fg.end =
g.end] = fg;
        } else if (g = fragmentByEnd[end]) {
          delete fragmentByStart[g.start];
          delete fragmentByEnd[g.end];
          var fg = f.concat(g.map(function(i) { return ~i; }).reverse());
          fragmentByStart[fg.start = f.start] = fragmentByEnd[fg.end =
g.start] = fg;
        } else {
          fragmentByStart[f.start] = fragmentByEnd[f.end] = f;
        }
      } else if (f = fragmentByStart[end]) {
        delete fragmentByStart[f.start];
        f.unshift(i);
        f.start = start;
        if (g = fragmentByEnd[start]) {
          delete fragmentByEnd[g.end];
          var gf = g === f ? f : g.concat(f);
          fragmentByStart[gf.start = g.start] = fragmentByEnd[gf.end =
f.end] = gf;
        } else if (g = fragmentByStart[start]) {
          delete fragmentByStart[g.start];
          delete fragmentByEnd[g.end];
          var gf = g.map(function(i) { return ~i; }).reverse().concat(f);
          fragmentByStart[gf.start = g.end] = fragmentByEnd[gf.end = f.end]
= gf;
        } else {
          fragmentByStart[f.start] = fragmentByEnd[f.end] = f;
        }
```

```
      } else if (f = fragmentByStart[start]) {
        delete fragmentByStart[f.start];
        f.unshift(~i);
        f.start = end;
        if (g = fragmentByEnd[end]) {
          delete fragmentByEnd[g.end];
          var gf = g === f ? f : g.concat(f);
          fragmentByStart[gf.start = g.start] = fragmentByEnd[gf.end =
f.end] = gf;
        } else if (g = fragmentByStart[end]) {
          delete fragmentByStart[g.start];
          delete fragmentByEnd[g.end];
          var gf = g.map(function(i) { return ~i; }).reverse().concat(f);
          fragmentByStart[gf.start = g.end] = fragmentByEnd[gf.end = f.end]
= gf;
        } else {
          fragmentByStart[f.start] = fragmentByEnd[f.end] = f;
        }
      } else if (f = fragmentByEnd[end]) {
        delete fragmentByEnd[f.end];
        f.push(~i);
        f.end = start;
        if (g = fragmentByEnd[start]) {
          delete fragmentByStart[g.start];
          var fg = g === f ? f : f.concat(g);
          fragmentByStart[fg.start = f.start] = fragmentByEnd[fg.end =
g.end] = fg;
        } else if (g = fragmentByStart[start]) {
          delete fragmentByStart[g.start];
          delete fragmentByEnd[g.end];
          var fg = f.concat(g.map(function(i) { return ~i; }).reverse());
          fragmentByStart[fg.start = f.start] = fragmentByEnd[fg.end =
g.start] = fg;
        } else {
          fragmentByStart[f.start] = fragmentByEnd[f.end] = f;
        }
      } else {
        f = [i];
        fragmentByStart[f.start = start] = fragmentByEnd[f.end = end] = f;
      }
    });

    function ends(i) {
      var arc = topology.arcs[i], p0 = arc[0], p1 = [0, 0];
      arc.forEach(function(dp) { p1[0] += dp[0], p1[1] += dp[1]; });
      return [p0, p1];
    }

    var fragments = [];
    for (var k in fragmentByEnd) fragments.push(fragmentByEnd[k]);
    return fragments;
  }

  function mesh(topology, o, filter) {
    var arcs = [];

    if (arguments.length > 1) {
```

```
      var geomsByArc = [],
          geom;

      function arc(i) {
        if (i < 0) i = ~i;
        (geomsByArc[i] || (geomsByArc[i] = [])).push(geom);
      }

      function line(arcs) {
        arcs.forEach(arc);
      }

      function polygon(arcs) {
        arcs.forEach(line);
      }

      function geometry(o) {
        geom = o;
        geometryType[o.type](o.arcs);
      }

      var geometryType = {
        LineString: line,
        MultiLineString: polygon,
        Polygon: polygon,
        MultiPolygon: function(arcs) { arcs.forEach(polygon); }
      };

      o.type === "GeometryCollection"
          ? o.geometries.forEach(geometry)
          : geometry(o);

      if (arguments.length < 3) for (var i in geomsByArc) arcs.push([i]);
      else for (var i in geomsByArc) if (filter((geom = geomsByArc[i])[0],
geom[geom.length - 1])) arcs.push([i]);
    } else {
      for (var i = 0, n = topology.arcs.length; i < n; ++i) arcs.push([i]);
    }

    return object(topology, {type: "MultiLineString", arcs: merge(topology,
arcs)});
  }

  function object(topology, o) {
    var tf = topology.transform,
        kx = tf.scale[0],
        ky = tf.scale[1],
        dx = tf.translate[0],
        dy = tf.translate[1],
        arcs = topology.arcs;

    function arc(i, points) {
      if (points.length) points.pop();
      for (var a = arcs[i < 0 ? ~i : i], k = 0, n = a.length, x = 0, y = 0,
p; k < n; ++k) points.push([
        (x += (p = a[k])[0]) * kx + dx,
        (y += p[1]) * ky + dy
```

```
      ]);
      if (i < 0) reverse(points, n);
    }

    function line(arcs) {
      var points = [];
      for (var i = 0, n = arcs.length; i < n; ++i) arc(arcs[i], points);
      return points;
    }

    function polygon(arcs) {
      return arcs.map(line);
    }

    function geometry(o) {
      o = Object.create(o);
      o.coordinates = geometryType[o.type](o.arcs);
      return o;
    }

    var geometryType = {
      LineString: line,
      MultiLineString: polygon,
      Polygon: polygon,
      MultiPolygon: function(arcs) { return arcs.map(polygon); }
    };

    return o.type === "GeometryCollection"
        ? (o = Object.create(o), o.geometries = o.geometries.map(geometry),
o)
        : geometry(o);
  }

  function reverse(array, n) {
    var t, j = array.length, i = j - n; while (i < --j) t = array[i],
array[i++] = array[j], array[j] = t;
  }

  return {
    version: "0.0.3",
    mesh: mesh,
    object: object
  };
})();
```

color codes.csv

1	North America
2	Central America
3	Caribbean
4	South America
5	Northern Europe
6	Central Europe
7	Eastern Europe
8	Southern Europe
9	Southern Africa
10	Northern Africa
11	Western Africa
12	Central Africa
13	Eastern Africa
14	Russia
15	Central Asia
16	Western Asia
17	Southern Asia
18	Eastern Asia
19	Australia and New Zealand
20	Southeastern Asia
21	Pacific Oceania

iii Statistical test: Repeated Measures ANOVA

	Detect Change	Compare	Summarize	Filter	Means	Squared Deviations (Raw Scores - Means)			
Bioproductivity	22	24	19	4	17.25	22.56	45.56	3.06	175.56
Onions	9	22	17	9	14.25	27.56	60.06	7.56	27.56
Tomatoes	23	21	24	13	20.25	7.56	0.56	14.06	52.56
Population	25	22	16	21	21	16.00	1.00	25.00	0.00
Trees	17	21	21	19	19.5	6.25	2.25	2.25	0.25
Means	19.2	22	19.4	13.2	18.45				497.25
Squared Deviations Variable Means - Grand Mean	5.625	126.025	9.024999999	275.625	416.3				
	SS	DF	MS	F	P				
SS Within Subjects	497.3	15							
SS Model	416.3	3	138.77	20.57	0.000051				
SS Error	81.0	12	6.75						