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Pulsing Blood Vessels: A Figurative Approach to Traffic Visualization

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Designers often choose a personal approach to visualization. By using semantic figurative metaphors, the visualization designer invests in more figurative graphic representations. This approach seeks provocative perspectives on common topics, trying to invoke emotional responses while clearly communicating meaningful data stories.

Seeking more figurative metaphors in visualization thus involves adding nondata aspects to a visualization, which are often regarded as embellishments. From a purist point of view, this is not a recommended practice in visualization.[1] Often, adding embellishments is regarded as gratuitous and superfluous because it may introduce errors in the portrayal of information. In spite of this, Ellen Lupton provides a counterperspective:

> Tufte's purist point of view is profound and compelling, but it may be overly restrictive. Information graphics have a role to play in the realm of expressive and editorial graphics.... They can be clean and reductive or richly expressive, creating evocative pictures that reveal surprising relationships and impress the eye with the sublime density and grandeur of a body of data.[2]

Editors' Note

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A less restrictive approach to visualization can be justifiable in the context of communication and emotion. This article describes one approach, pointing out its strengths and necessary limitations, while illustrating it with a visualization of city traffic transformed into a system of blood vessels. These metaphorical renderings utilize the concept of the city as a living organism. In this light, the city is first portrayed as a minimal rendering of abstract clots in traffic, and it then evolves into a more figurative rendering of a system of pulsing blood vessels. The first experiments to show this dataset in light of these ideas were initially mentioned[3] and then technically described in earlier works.[4] In this article, we emphasize the graphic choices for the system while framing its evolution in the context of semantic figurative metaphors.

Semantic Figurative Metaphors

Andrew Vande Moere and Helen Purchase place visualization on three major axes: visualization studies, practice, and exploration.[5] The exploratory side of visualization emphasizes communication through emotional engagement with an audience. More specifically, the approach we describe here falls under the umbrella term *casual information visualization*.[6] Casual infovis targets a broad audience, including a wide spectrum of users, from experts to novices, whose usage patterns can be both momentary and contemplative. Additionally, the user's relationship with the data is more tightly coupled because the authors of casual information visualizations are not strictly interested in providing analytical insights, but instead are focused on providing awareness and social and reflective insights.

Visual metaphors are an intrinsic part of visualization. They are models used to bring data into

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the cognitive space and thus structure information; they are "a set of structural properties that provide a framework for meaning."[7] These structural metaphors can be simple models such as a pie chart that uses the metaphor of parts of a whole, a tree to depict hierarchy, a tree map to show containment,[7] or a simple line graph to portray a trend.[8] Donna Cox calls these structural metaphors *visaphors* and argues that they are so entrenched in our culture that we no longer recognize their metaphorical nature and thus interpret them as literal or conventional.[9] They are often generic and dependent on the structure of the data, but they can be highly figurative as well, such as Chernoff faces,[10] trees,[11] cartograms,[12] or flow layouts.[13]

Semantic figurative metaphors are more specialized metaphors added to these familiar structural models. They are not dependent on the data's structure, but allude to its content, and thus are the concretization of the visualizer's interpretation and message. For this, they have a semantic nature when the visualizer assumes the role of author. Furthermore, they are figurative in the sense that they are less abstract and give more concrete and emotional visual references to help connect with the audience. They are not embellishments without a purpose, but carry a well-founded metaphoric intent.

Radical examples of semantic figurative metaphors are Nigel Holmes' charts,[14] which are often simple graphs integrated into illustrations that are strongly figurative on the data topic. Edward Tufte describes them as chartjunk,[15] but Stephen Few considers them more of a well-executed and justifiable style of embellishment.[16] An opportunity arises to apply these semantic figurative metaphors in subtle ways to complex data.

Implementing semantic figurative metaphors encompasses two steps:

1. *Adapting the structural metaphor.* After an adequate visualization model is chosen, it is modified, namely by evading the model's rules of spatial arrangement, and making room to carry specific and new metaphors.
2. *Introducing visual cues.* Visual cues are added on top of the model that modify its graphical implantations, seeking to provide more figurative evidence of the new metaphors.

Metaphorical Mappings of City Traffic

The visualization in Figure 1 includes data for 1,534 vehicles circulating through the city of Lisbon during a one month period. The visualization compresses this data into a single virtual day (see https://vimeo.com/10198615 for a full video). The work started as a simple visualization of trajectories with blood-related tones and then acquired a highly figurative and dramatic tone, visualizing Lisbon as a system of pulsing blood vessels and using cartograms to emphasize traffic patterns.

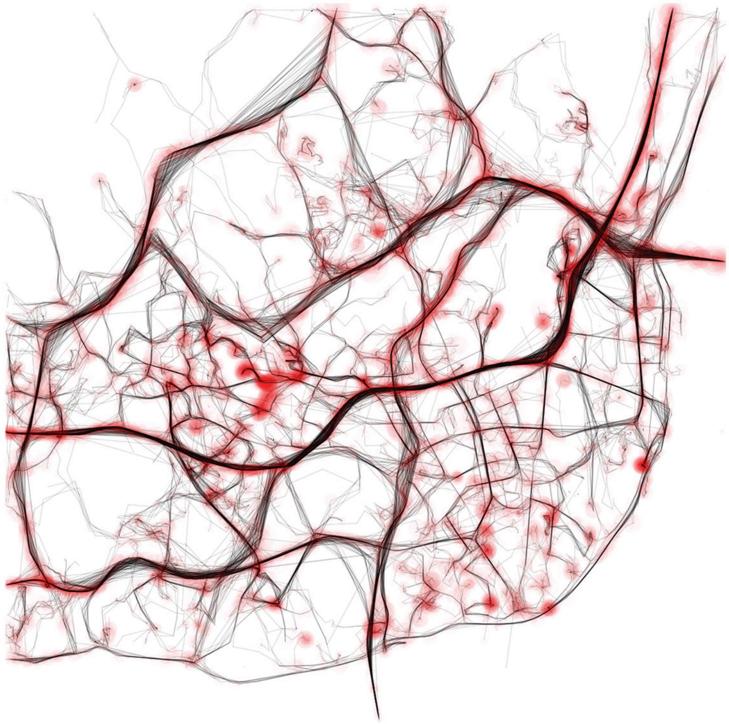


Figure 1. The visualization of clots in Lisbon's traffic. The full video is available https://vimeo.com/10198615.

Visualizing Trajectories and Clots

In a visualization of trajectories,[17] vehicles leave a dynamic trail of their last positions. Having such a quantity of trails creates a highly complex visualization, portraying the system with its own routines and patterns, that emerges from the collective behavior of individual agents. From this point of view, showing the city as a living organism can be a suitable metaphor for such complex systems.

The first step toward this idea was minimalistic from a graphic perspective. We began with a white canvas and then added semitransparent black traces and highlighted problematic areas using red. When a vehicle circulated at a low speed, it left a temporary trail of semitransparent red circles. This resulted in an animated composition of black and red on white, translating a minimalist rendering of the city with organic tones. In spite of using an inherently abstract language, this instantiation can have more figurative interpretations, with black arteries being painted over in red and white locations highlighted with masses

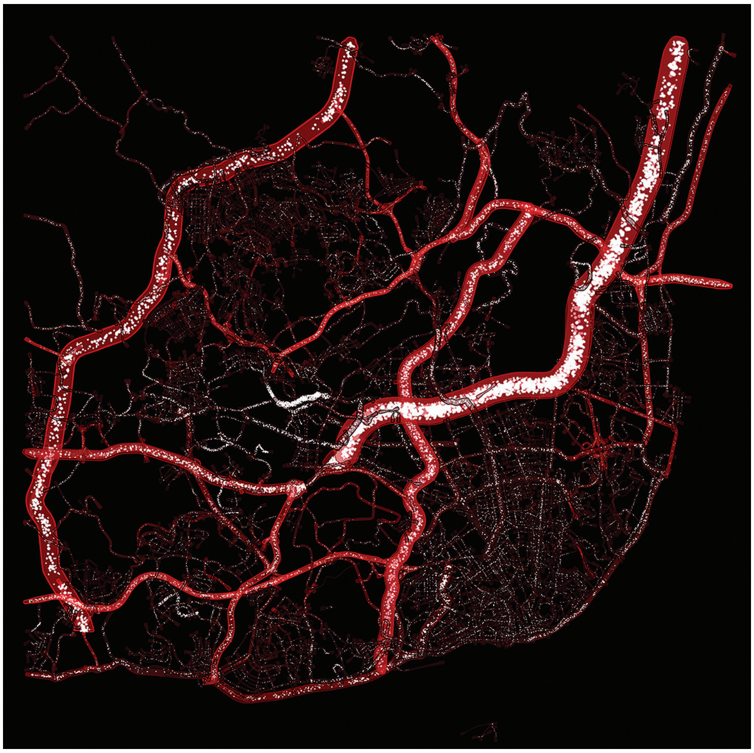


Figure 2. The visualization of Lisbon as a system of pulsing blood vessels. Thicker roads indicate more traffic and more circulating cells. The full video is available at https://vimeo.com/131835178.

of red dots, as if blood clots were halting traffic (see Figure 1).

This approach resulted in a short narrative for a typical day in Lisbon, showing a city that wakes up and acquires its form at dawn, pulses with movement and density during rush hours, and fades to white in the evening.

Blood Vessels

The initial visualization artifact eventually evolved into a more refined and complex system that displays the city as a set of pulsing blood vessels. If vessels are inside an organism, then the canvas is dark. Each road is mapped to a vessel, with a pulsing motion proportional to the velocities on that road. The vessels are red, but vessels with slower vehicles are darker, as in clotted blood. Thicker vessels signify more vehicles, and implanted in them are streams of white cells. These cells or particles also have a flowing motion proportional to the speed on the vessel and a density proportional to the number of vehicles in it. In this way, velocity is encoded in motion rather than in color, as it was before.

With these changes, the artifact has become more figurative and is now able to better emphasize high traffic volume on specific roads, as vessels get thicker and are populated by more white cells (see Figure 2).

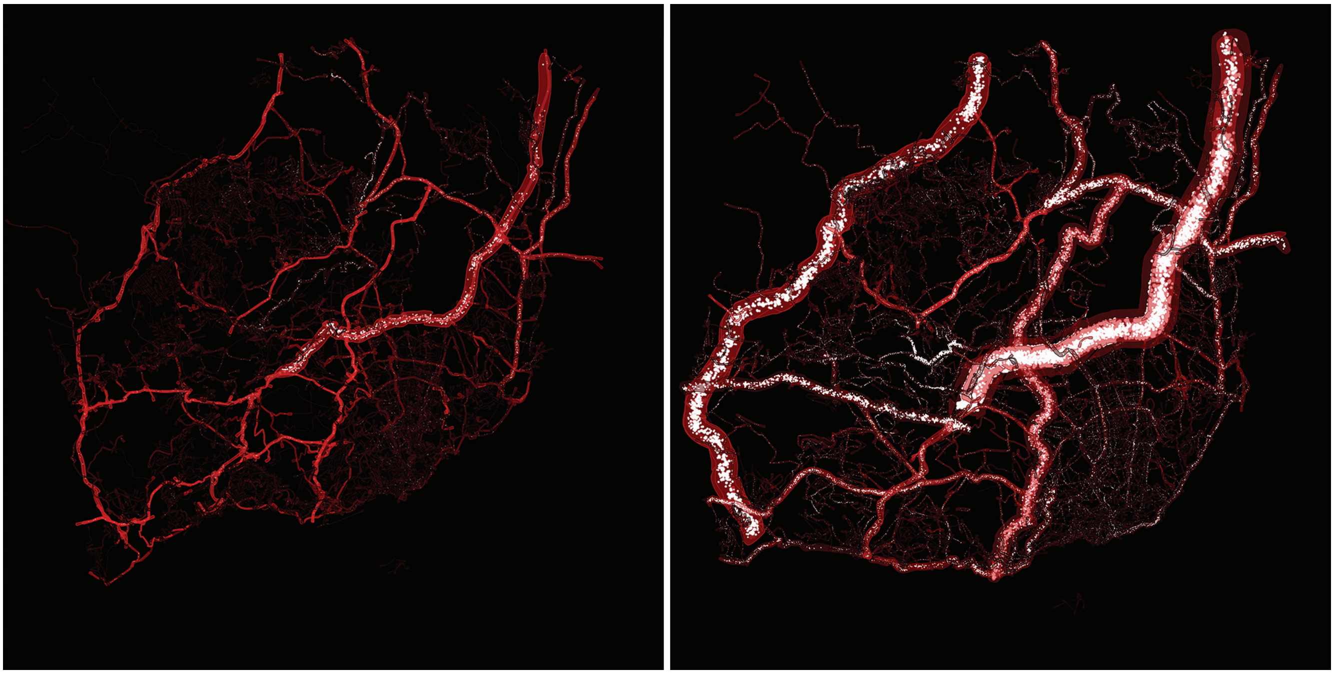
Dramatic Cartograms

In the context of the typical day in the traffic of Lisbon, two of the most significant aspects are the morning and evening rush hours. Thus, our goal was to build a visualization that emphasized this with a dramatic effect. To do so, the application resorted to cartograms, which are maps in which space is distorted in order to represent a statistical variable. The most common type of cartogram is the value-by-area cartogram—for example, countries on a world map can shrink and expand based on their population or GDP. Danny Dorling notes that cartograms distort reality and shock readers.[18] Cartograms have this dramatic effect because instead of using color, value, or shape to show information they manipulate position, which is systematically rated as the most accurate and strong visual variable to show quantitative, ordinal, and nominal information.[19–21] Furthermore, they do so by contrasting a distorted map to a mental reference of the undistorted map, confronting viewers with a new perspective on familiar maps.

For our specific dataset, the cartogram is not value-by-area but edge-based because we used the road map of Lisbon as the model to distort. Instead of manipulating areas, the lengths of Lisbon's roads are altered in order to show information. The velocities on a road are mapped to its length, using the following time-distance metaphor: if velocities are low, locations are perceived as being farther apart, and if velocities are high, they are perceived as closer. This way, a road shrinks if the velocities are high on it and expands if the velocities are low. This results in the whole city dramatically and organically expanding during rush hours because it seems as if everything is farther away during these periods. In the same way, the city appears to shrink in the evening when circulation is free of traffic constraints (see Figure 3).

The blood vessels metaphor works particularly well for Lisbon because it is delimited by the Tagus River, which resembles a human heart. The often-chaotic disposition of roads in a city is the main factor behind the organic expression of this visualization, and it can be applied to other cities as well. For example, Figure 4 shows a blood vessels visualization of London. In this case, the data for 141 vehicles during a one month period is condensed into one virtual day. For London, the system resembles an intricate tissue with clotting problems at its center rather than a specific organ.

Every cartogram yields an error in the depiction of information because it is generally impossible to accurately distort connected areas or edges while preserving their topology.[22] Therefore, compro-



(a) **(b)**

Figure 3. Snapshots with the visualization of blood vessels applied to the edge-based cartogram. The city (a) compresses at dawn and (b) then expands during the morning rush hour as a result of the increased traffic volume. The visualization is available at https://vimeo.com/88842273.

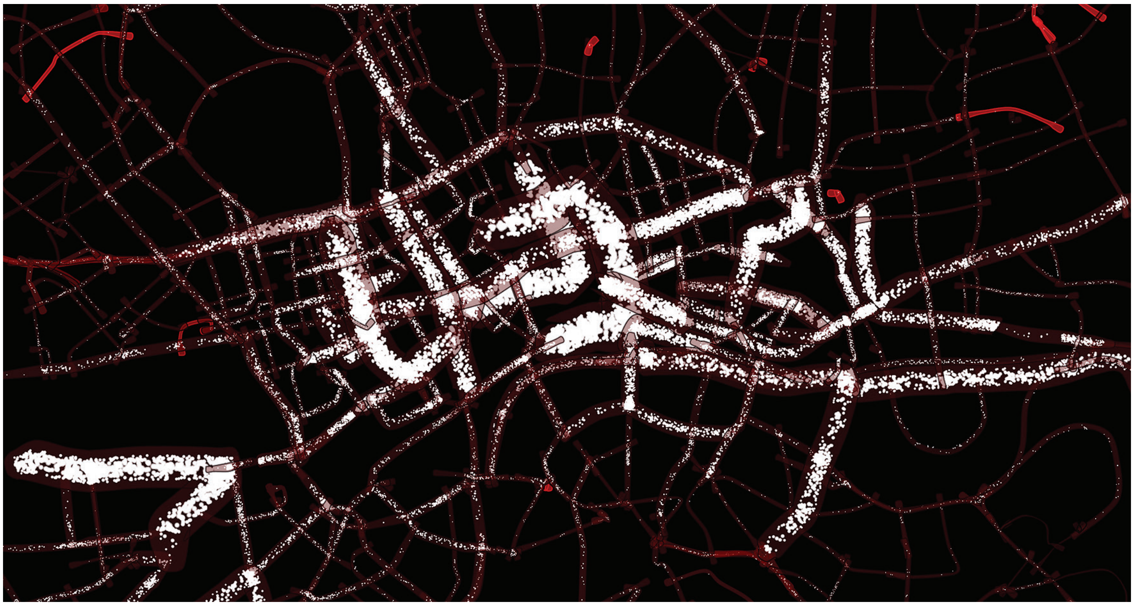


Figure 4. The blood vessels metaphor applied to the city of London. The full visualization is available at https://vimeo.com/135803141, and an animated cartogram is available at https://vimeo.com/135803140.

mises are made that try to minimize this error. Like all semantic figurative metaphors, at their very core, cartograms modify the structural metaphor of geographical maps in an attempt to shock viewers by distorting their spatial awareness at the expense of inducing slight informational errors.

This specific visualization is a rendering of a semantic figurative metaphor at its fullest. Its metaphorical component not only uses the time-distance metaphor in a data-related manner, but it also offers a new language when portraying traffic. The result is a figurative portrayal (an organ or tissue) that has semantic meaning tightly coupled with the data—the city is a living organism, but it behaves in accord with the data, with varying thicknesses, cell densities and speeds, pulsing motions, and overall expansions and contractions. Furthermore, it also encompasses the two steps suggested for semantic figurative metaphors: modifying the structural metaphor, which is the projected map of the city through the use of edge-based cartograms, and bringing new visual cues that embody the figurative component of the artifact. The motion of the vessels and the streams of the cells, together with the expansions and contractions of the cartogram, add visual behaviors that are unrelated to the data and potentially reach the limits of eccentricity when working with figurative metaphors in visualization.

Strengths and Limitations

Semantic figurative metaphors carry the weight of subjective authorial intent in visualization. They explicitly add nondata elements to visualizations in order to augment their metaphorical value. Adding nondata aspects to visualization comes at the expense of data accuracy and may cause confusion for viewers when they attempt to quantify editorial embellishment in data representation. The use of semantic figurative metaphors should be handled soberly and with restraint. Designers should make as clear as possible their intended message and the parts of the visualization that reflect their interpretation. The addition of nondata ink contradicts the economy principle in visualization, but the adequacy of the addition is highly debated: "Embellishments that represent data, even metaphorically, can themselves qualify as data ink,"[16] given their functional value for communication.

Semantic figurative metaphors can be used in the context of casual visualization, where communicating with large audiences is favored over more utilitarian purposes. Such representations aim for contemplative and momentary uses, trying to provoke awareness and reflective insights. They humanize visualizations because they are less abstract and more figurative, connecting more emotionally with the audience. They are not models, but an approach to visualization. Each nondata metaphorical aspect should be tailored specifically to a dataset, for a structural model and for a message, and thus it is rarely generalizable.

Nonetheless, this approach does not advocate for or encourage the production of chartjunk. The use of semantic figurative metaphors should have a well-defined authorial communicative purpose that is implemented as part of the design process from its inception. For example, modifications of the structural model should be connected with the addition of visual cues, in light of the same metaphors. Moreover, the figurative aspect should not be extreme, but gentle, so as not to distract from the familiar and abstract graphical languages that visualizers use to depict data. The goal should be to produce clear, subtle, and more figurative visual cues.

The application of blood vessels on a dynamic cartogram is graphically strong and is figuratively close to its metaphorical domain. Nonetheless, it also distances itself from the elegance of simplicity, where the authorial intent superimposes the functionality of data portrayal. Although permissible, there is a point where the beauty of complexity might turn into visual confusion. Thus, each work that implements visual semantic metaphors can have intense and elaborate expressions for the sake of authorial intent, but it should be restrained to moderate visual cues.

Using cartograms necessarily introduces errors in information portrayal. We would also agree that using texture together with thickness to show traffic volume is redundant and displaying velocity through motion is not particularly orthodox. However, all this is a consequence of implementing certain semantic figurative metaphors that, at the expense of data accuracy, try to intensify the communication with the audience. This exploratory side of visualization should be handled with care and with a mindful goal of maximizing the value of metaphor while minimizing quantifiable distortion.

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References

1. E.R. Tufte, *The Visual Display of Quantitative Information*, Graphics Press, 1983.
2. E. Lupton and J.C. Phillips, *Graphic Design: The New Basics*, Princeton Architectural Press, 2008, p. 199.
3. P. Cruz and P. Machado, "Visualizing the Circulatory Problems of Lisbon," *ACM SIGGRAPH 2011 Posters*, 2011, article no. 92.
4. P. Cruz, A. Cruz, and P. Machado, "Contiguous Animated Edge-Based Cartograms for Traffic Visualization," *IEEE Computer Graphics and Applications*, vol. 35, no. 5, 2015, pp. 76–83.
5. A. Vande Moere and H. Purchase, "On the Role of

Design in Information Visualization," *Information Visualization*, vol. 10, no. 4, 2011, pp. 356–371.
6. Z. Pousman, J.T. Stasko, and M. Mateas, "Casual Information Visualization: Depictions of Data in Everyday Life," *IEEE Trans. Visualization and Computer Graphics*, vol. 13, no. 6, 2007, pp. 1145–1152.
7. C. Ziemkiewicz and R. Kosara, "The Shaping of Information by Visual Metaphors," *IEEE Trans. Visualization and Computer Graphics*, vol. 14, no. 6, 2008, pp. 1269–1276.
8. J. Zacks and B. Tversky, "Bars and Lines: A Study of Graphic Communication," *Memory and Cognition*, vol. 27, no. 6, 1999, pp. 1073–1079.
9. D. Cox, "Metaphoric Mappings: The Art of Visualization," *Aesthetic Computing*, MIT Press, 2006, pp. 89–114.
10. H. Chernoff, "The Use of Faces to Represent Points in *k*-Dimensional Space Graphically," *J. Am. Statistical Assoc.*, vol. 68, no. 342, 1973, pp. 361–368.
11. M. Lima, *The Book of Trees*, Princeton Architectural Press, 2014.
12. W.R. Tobler, "Thirty-Five Years of Computer Cartograms," *Annals of the Assoc. Am. Geographers*, vol. 94, no. 1, 2004, pp. 58–73.
13. S. Havre, B. Hetzler, and L. Nowell, "ThemeRiver: Visualizing Theme Changes over Time," *Proc. IEEE Symp. Information Visualization* (InfoVis), 2000, pp. 115–123.
14. N. Holmes, *Designer's Guide to Creating Charts and Diagrams*, Watson-Guptill Publications, 1984.
15. E.R. Tufte, *Envisioning Information*, Graphic Press, 1990, pp. 34–35.
16. S. Few, "The Chartjunk Debate: A Close Examination of Recent Findings," *Visual Business Intelligence*, June 2011; www.perceptualedge.com/articles/visual_business_intelligence/the_chartjunk_debate.pdf.
17. N. Andrienko and G. Andrienko, "Visual Analytics of Movement: An Overview of Methods, Tools and Procedures," *Information Visualization*, vol. 12, no. 1, 2013, pp. 3–24.
18. D. Dorling, *Area Cartograms: Their Use and Creation*, vol. 59, Concepts and Techniques in Modern Geography series, 1996; www.dannydorling.org/wp-content/files/dannydorling_publication_id1448.pdf.
19. J. Bertin, *Semiology of Graphics: Diagrams, Networks, Maps*, Esri Press, 2010, p. 6.
20. J. Mackinlay, "Automating the Design of Graphical Presentations of Relational Information," *ACM Trans. Graphics*, vol. 5, no. 2, 1986, pp. 110–141.
21. W.S. Cleveland and R. McGill, "Graphical Perception: Theory, Experimentation, and Application to the Development of Graphical Methods," *J. Am. Statistical Assoc.*, vol. 79, no. 387, 1984, pp. 531–554.
22. D.A. Keim, S.C. North, and C. Panse, "CartoDraw: A Fast Algorithm for Generating Contiguous Cartograms," *IEEE Trans. Visualization and Computer Graphics*, vol. 10, no. 1, 2004, pp. 95–110.

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