Spatial Distortion Approach to Traffic Congestion Visualization
Capstone Research Progress Report

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Abstract. The field of traffic congestion visualization relies heavily on color-coded topographical maps; little work has been done, however, to examine the merits and possible weaknesses of this approach, and to evaluate its performance in comparison to alternative visualizations. This paper presents a design study of a new traffic visualization algorithm that uses spatial distortion instead of color to present the same information in a different way. A user study will be employed to empirically evaluate the ability of each algorithm to influence the users' routing decisions in a given network.

1 Introduction

According to Arnott and Small, "time spent ensnarled in traffic is not simply time wasted; for most of us, it is time miserably wasted." They offer a simple calculation to estimate the magnitude of the problem. About one third of all driving in metropolitan areas takes place in congested conditions, during which average speed decreases to half of the traffic segments' free flow value. Even without considering the cost of additional fuel, accidents, air pollution, and other issues due to congestion, the economic finding that drivers are willing to spend "about 1.33 USD to save 10 minutes [of] travel time" puts the annual cost of driving delays in the United States at 48 billion USD (446).

If it were possible to influence the traffic decisions of individual drivers, they could choose routes that are more efficient, based on the current traffic situation in the area. Thus, it is important to evaluate the degree to which each visualization of traffic congestion helps drivers make more optimal routing decisions in a variety of scenarios.

The field currently relies heavily on topographical maps with color overlays. However, little work has been done to objectively evaluate the merits of this visualization approach. At the same time, other techniques from the field of traffic visualization (e.g. Guo et al.; Lu, Boedihardjo and Zheng; Wang et al.) or other fields (e.g. Bruls, Huizing and van Wijk; Fitch and Margoliash; Johnson and Schneiderman; Oh et al.; Skog, Ljungblad and Holmquist) have not been examined.

This paper proposes spatial distortion as a novel approach to visualization of traffic congestion. The aim of the design study (Munzner, *Process* 4) is to make usability and complexity evaluations of this approach as opposed to the technique of color overlays, with a specific focus on the ability of each to influence the routing decisions of drivers. In doing so, this paper aims to help reduce the immense losses of time and money that could be spent more efficiently in most any other way.

2 Background

Visualization is, at its core, the science of representing problems and their solutions according to a logical structure that may or may not be immediately apparent. Visualization techniques seek to identify constituent elements of the problem, codify them as points in one or multiple data sets, and represent the data in a visual form that is intelligible for human readers (Munzner, *Visualization* 1).

The nature of this visual representation varies significantly depending on the identified relationships among data points. However, what matters is not the specific visual technique *per se*, but the nature of the information that may be gleaned by the observer from the presented data. The most successful visualizations are not those that merely illustrate the problem and/or its solution, but those that reveal information that might not have been accessible without the visual representation.

An important measure of the effectiveness of a visualization is whether it helps influence the reader's behavior. This is especially applicable in the field of traffic visualization and congestion prediction; a better visualization may allow users to avoid highly congested areas. The state of the art in traffic congestion visualization is the technique of overlaying topographical maps of traffic networks with color-coded lines to represent congestion. Importantly, this visualization approach allows the user to evaluate the state of the traffic network in terms of the traffic state of the constituent roads.

JamBayes, a traffic information and prediction system developed by Horvitz et al., uses a visual interface that assigns colors to road segments in a simplified map of the Seattle road network according to current traffic congestion (4), and can be seen in Figure 1.

The information is supplemented with clock illustrations to communicate expected time delay in more detail. Furthermore, exclamation marks are used to alert the user to potentially surprising traffic conditions, as predicted by the model.

This group also includes perhaps the most widely used system for traffic congestion visualization – Google Maps Traffic. The system combines the topographical map approach in tandem with a discrete colormap approach to overlay the current state of traffic at the main thoroughfares of supported cities and is presented in Figure 2.

The Google model presents innovations over the JamBayes model. To eliminate the need for introducing additional graphical elements to an already-busy map interface, the Google model abandons the advanced clock-icon features of Horvitz's model, and partially replaces them with an extension to the conventional colormap – which now includes the dark brown color to show traffic congestion that is even worse than that signified by the color red (Biersdorfer). Among other reasons, this qualifies Google Maps Traffic as a fair benchmark for the spatial distortion model for the purposes of evaluation in this user study.

The spatial distortion traffic visualization discussed in this paper as the alternative to the Google model was conceived as a traffic-based response to the technique of the cartogram, elaborated upon significantly by Gastner and Newman (7502), and presented in Figure 3.

Cartograms begin with an ordinary map. However, the visualization algorithm then substitutes topographical accuracy for an illustration of values of a variable of interest – population density, for example. The map is distorted based on the visualized variable; the higher the value, the more prominent its position in the visualization. Conversely, if the value of the variable is relatively small in a given location, the corresponding area in the cartogram is shrunk proportionately.

As they encode information with position and area rather than color, cartograms prove more easily decipherable for their users than equivalent color-based visualizations (Cleveland and McGill 830). This comes with the qualification that the features of the original map must be discernible in the cartogram to supply visual clues to the reader (Card and Mackinlay 5).

3 Model

The spatial-distortion model uses traffic data to determine the degree to which a particular traffic segment should be emphasized. The more congested a traffic segment is, the more it distorts geography around itself; drivers are thus able to quickly identify the worst routes, and are able to opt instead for a detour through the least emphasized areas (Schleiffer).

While the technique of the cartogram is appealing on a very high level, implementation proved challenging. The question became, how can the input map be changed so that the output map reflects the traffic situation in an internally consistent, understandable, and intuitive way? It is important to remember that in order for them to be readable, cartograms still rely on visual cues on the boundaries of distorted areas to allow users to navigate the visualization. This process needed several iterations, in which the visualization algorithm was realigned several times.

3.1 Image Distortion Approach

The algorithm that would have been the least original would be the option to distort the map not on the level of the map data, but on the level of the output image. With a list of addresses of nodes, it could be possible to magnify/shrink areas of the image as needed by the traffic conditions. This option was quickly dismissed; it would be difficult to program an image-editing software to respond to changing input.

Therefore, it proved necessary to transform the input map of nodes and edges of the traffic network in terms of either changing the position of nodes or the lengths of nodes. This implies two possible approaches.

3.2 Traffic Edge Distortion Approach

The first is to change the lengths of edges depending on traffic congestion and adjust the position of nodes accordingly. This is the approach used in Spring Network simulations – each edge is interpreted as a spring, and the whole network is simulated in order to minimize the potential energy stored in each individual edge (Geipel 1538). Graphviz's Neato program is designed to provide Spring Network functionality for graph visualization, so it was examined for potential use as a space distortion algorithm (North). The desired length of each traffic segment was made to correspond to the product of the original length and traffic congestion, the shorter the segment, the heavier the traffic.

However, the spatial equalization property of spring networks proved problematic; higher-density neighborhoods with more roads proved to be more compressed than lower-density neighborhoods regardless of local traffic situation. This introduced undesirable bias in user perception of local traffic situation, as illustrated in Figure 4, and proved that an alternative approach was needed.

3.3 Traffic Node Distortion Approach

Therefore, the approach of distorting the network by moving traffic nodes to new positions depending on congestion was adopted – and the length of traffic edges depending on the movement of their endpoint nodes. This requires an assumption to be made about the way traffic congestion of nodes affects traffic congestion of the edges – in the end, the congestion of a node was determined as the average of traffic congestion of its incoming nodes.

To effect the distortion according to the traffic congestion of the nodes, another metaphor was brought in, this time from physics. It was recognized that the desired result of the map very much like the curvature of spacetime due to gravity in visualizations of physics, similar to Figure 5. The more traffic congestion there is at a node, the more mass it would have in the gravity model; and the more mass, the more distortion.

While the metaphor in this case would have been that of antigravity – repulsion of the surrounding matter depending on mass, this could be achieved with simply switching the sign of the gravity constant. In visual terms, instead of visualizing spatial distortion as observing the effects of the lines on a rubber sheet by looking from the top – converging – the lines would be observed from the bottom, as if bulging out around the heavy object.

Having settled on the technique of changing the positions of nodes in the network, it proved challenging to find the correct algorithm for spatial distortion. Multiple iterations of the algorithm were examined, drawing from different fields of physics that involve spatial distortion.

Apart from the gravity simulation, this included simulation of refraction – the bending of light at the boundary of different transparent surfaces – as well as the logistic curve of population growth, the cosine curve, their combinations, and the linear curve. The linear curve proved to be the best.

It was discovered that the algorithm for spatial distortion represented the derivative of the curvature of the cross-section of spatial distortion. While the other algorithms produced curvatures of different shapes, the linear algorithm produced the desired semicircular cross-section, corresponding to a hemispherical distortion in the visualized space.

The results of the different visualization algorithms discussed in this section are presented in Figure 6. It can be seen that the refraction algorithm mimics the effect of using a magnifying glass of a constant radius centered at the congested node. Meanwhile, the gravity algorithm causes the visualized surface around the congested node to take a hyperboloidal, volcano-like shape, and the logistic curve elucidates a cylindrical shape. The cosine algorithm produces a nearly perfect hemispherical distortion effect, but there is a small amount of overlap at the edges; this overlap is finally eliminated with the linear algorithm.

Therefore, it was determined that the linear algorithm for spatial distortion was the most appropriate due to its visual properties. Several additional traffic networks are visualized with the linear algorithm and presented in Figure 7.

Note. *The following sections present an outline of parts of the Capstone research that will be finished next semester and are thus written in the future tense.*

4 Data

Both models will be supplied with the same traffic data. This will allow for a controlled evaluation of the effects of the visualization methods as such, rather than presenting artifacts of the data. SUMO, a free and open-source traffic network simulation program developed by German Institute of Traffic Research, was used throughout the project to handle traffic-model-specific issues while the algorithms was developed to work with the outputs of the simulation.

5 Evaluation

To evaluate the different visualization approaches, a user study will be performed. The user study participants will be presented with a Google visualization of traffic as well as the spatial-distortion model's interpretation of the same data.

The user study participants will be interviewed individually. The group of study subjects will be split into two groups; the difference will be which of the two visualizations they will be presented with first.

Each participant will be asked to answer 20 prompts in the form "Looking at the traffic situation presented in the visualization before you, identify the fastest route from point A to point B."

Before being presented with the first visualization of the traffic system, the subjects will be asked to answer the question as if there were no traffic congestion in the city, by drawing what they consider the best path in a supplied blind map of the roads in the traffic network.

Then, the subjects will be asked to answer the same question using the first visualization. After drawing out the answer with reference to traffic situation presented in the first visualization, they will be asked to answer the prompt with reference to the other visualization.

In the following question, the order in which the two visualizations are presented will be switched.

After collecting the data from test subjects, the ability of each visualization to influence the user's routing decision will be evaluated based on the difference of the perceived best route as compared to the free-flow best route. At the same time, the accuracy of the best-route estimates produced by each visualization will be evaluated in terms of the difference of the perceived best route and the empirically determined best route through the system (using the A* algorithm).

The evaluation will feature simulated traffic both in the traffic networks of real cities and in engineered test traffic networks that would examine the validity of the visualization in edge cases.

6 Hypothesis

It is expected that the Google model – currently the dominant method of traffic congestion visualization – will benefit from the effects of users' familiarity. These cases cannot simply be ignored in the analysis, either, because traffic networks of real cities would be the context in which the new spatial distortion model would eventually be applied.

Nevertheless, it is expected that the theorized superiority of the spatial-distortion system will make the visualization more successful in the engineered traffic networks – in networks where the Google model cannot use its familiarity to its advantage.

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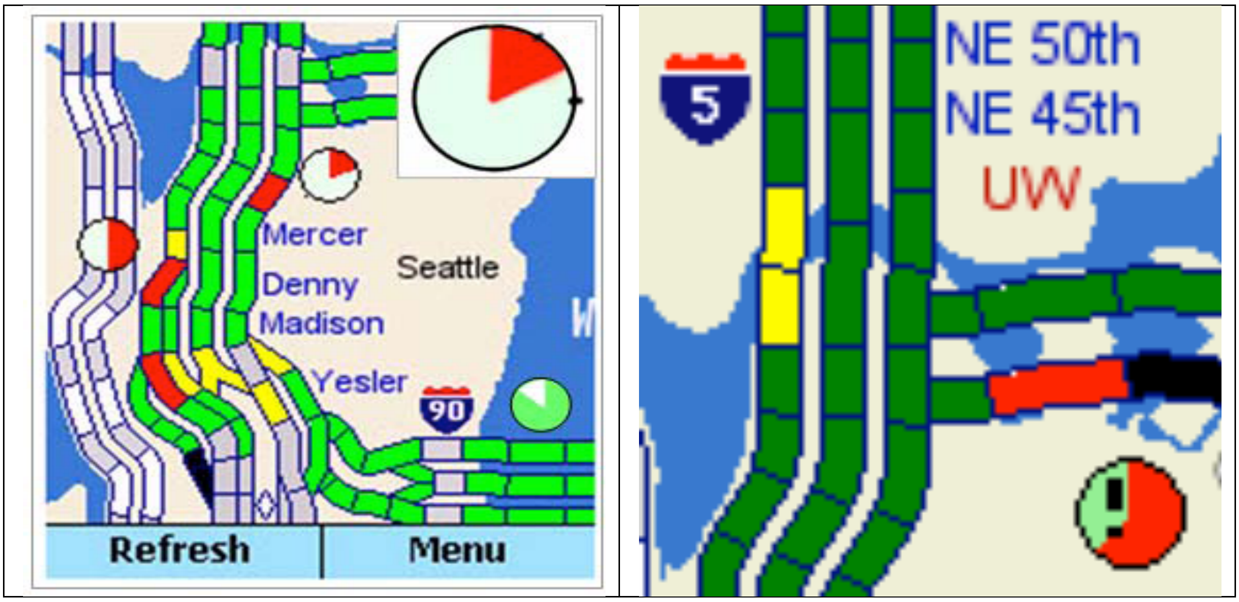


Figure 1. Map visualization approach used by Horvitz et al. (4), including the additional features.

Figure 2. The traffic congestion overlay model of Google Maps Traffic.

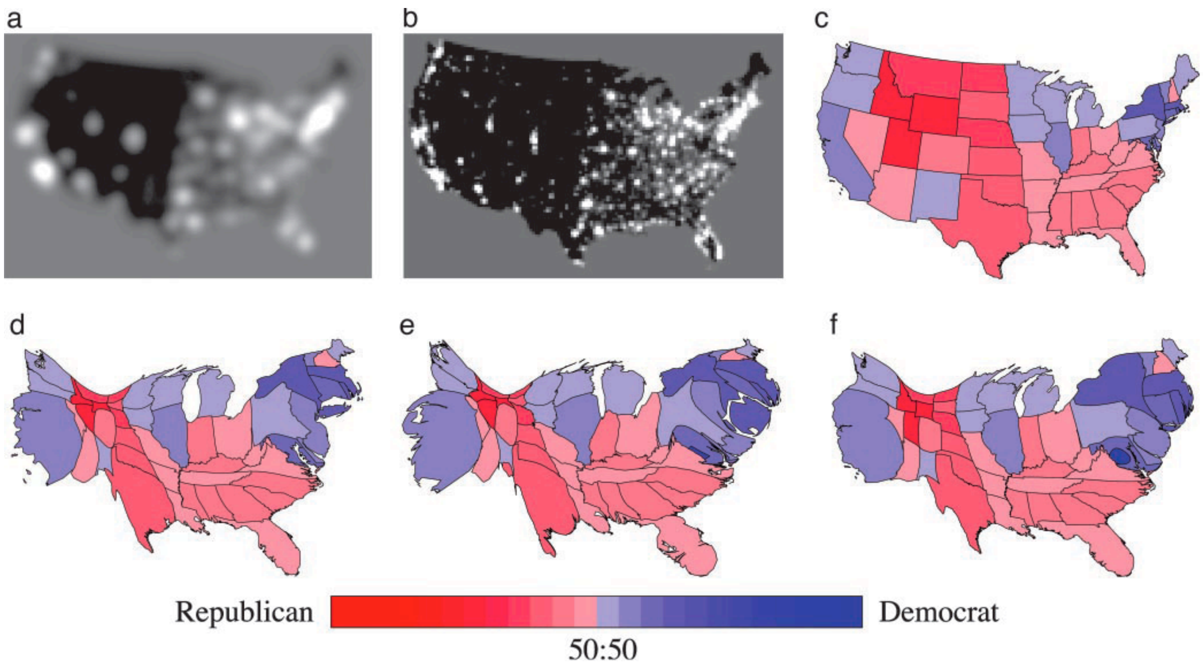


Figure 3. Cartograms illustrating the results of the 2000 US presidential election, from Gastner and Newman (7502). A map of the continental United States (c) is distorted according to population distribution data at two different levels of granularity (d, e), and according to the distribution of electors in the US Electoral College (f).

Figure 4. An illustration of the problems with the Spring Network approach. Although both streams of the highway – pictured at the bottom edge of the network – are experiencing the same amount of traffic, the stream that is attached to the dense traffic network is dragged along and significantly shortened. This produces a false impression that traffic on the affected stream is much heavier than it should be.

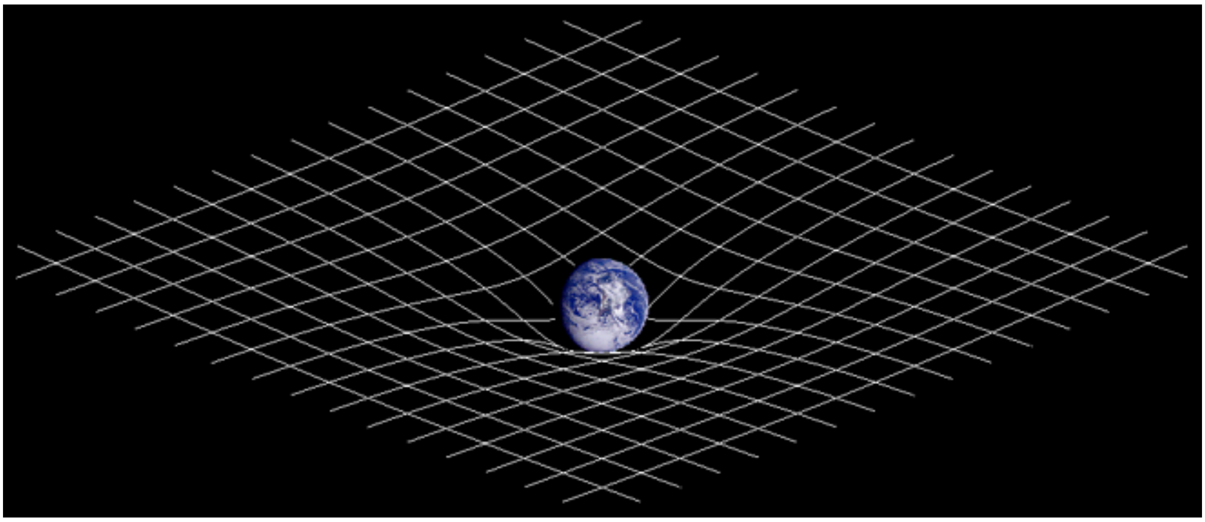


Figure 5. A gravity visualization. A gridded rubber sheet is pushed down by a heavy object. Seen from above, the lines would seem to converge due to the object's mass; seen from below, the lines would seem to bulge out around the object.

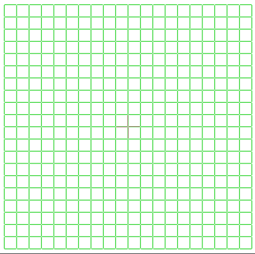
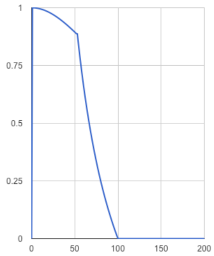
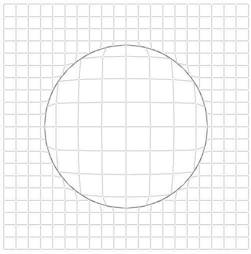
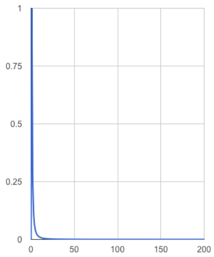
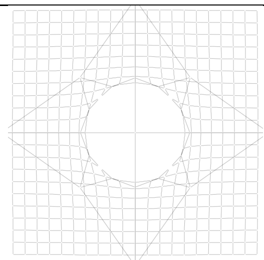
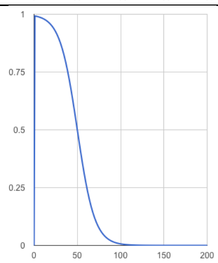
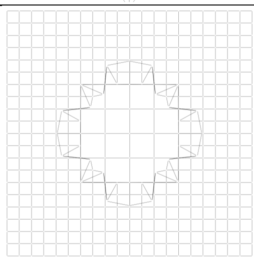
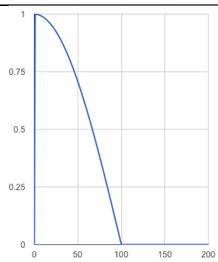
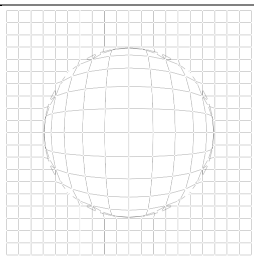
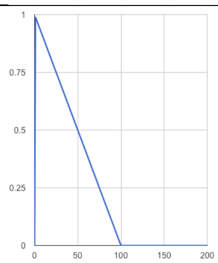
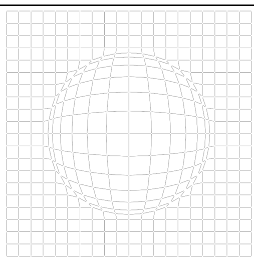
Algorithm	Graph of Algorithm	Visualization	Problems
Google			Difficult to identify traffic congestion.
Refraction			The edges of the visualization are overlapping in one curve.
Gravity			Overlapping at the center of the visualization.
Logistic			Overlapping in the middle of the visualization.
Cosine			Overlapping at the edges of the visualization.
Linear			

Figure 6. The evolution of the algorithm for the spatial distortion model. The effects of each algorithm on the spatial distortion of a simple engineered traffic network are presented in terms of: The graph of the function used; the top-down view of the distorted traffic map; and the cross-sectional view of the spatial distortion. Visual problems associated with each visualization are identified. The first row presents the traffic situation in the network in terms of the corresponding Google Maps Traffic visualization.

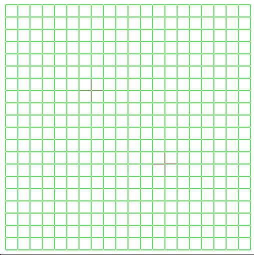
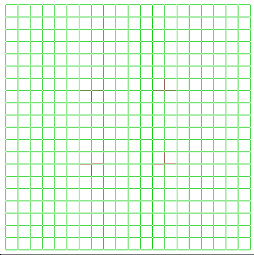
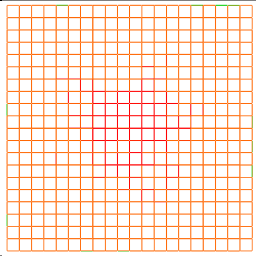
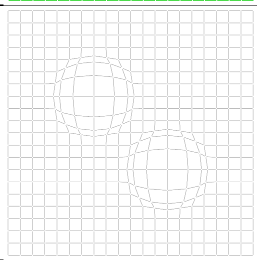
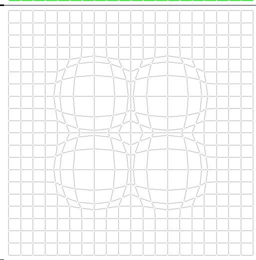
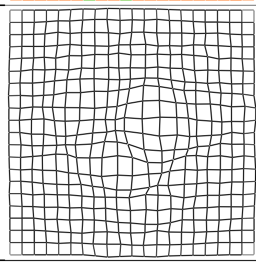
Google			
Spatial Distortion			

Figure 7. A visualization of three additional traffic networks with the spatial distortion model using the linear algorithm.