# Animated Flow Maps for Visualizing Human Movement: Two Demonstrations with Air Traffic and Twitter Data*


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## ABSTRACT

We present a novel flow mapping method called Animated Flow Mapper. Conventional flow mapping uses the thickness of a flow line to differentiate the volume of a flow and arrows to represent the direction. These flow mapping methods have suffered from problems of occlusion especially for visualizing large volumes of data, and when many flows converge at--or diverge from--single points. The Animated Flow Mapper aims to circumvent these problems of occlusion and to provide a more effective visualization of the patterns of the flows. The method uses thin dashed lines of equal width, which are animated to represent the directions and volumes of flows of moving objects by repeatedly redrawing each dashed-line at different speeds. The case studies and results of a human subject opinion survey show the advantages of the Animated Flow Mapper are comparable to other flow mapping methods.



## KEYWORDS

flow map; animated map; air traffic; Twitter


## 1 INTRODUCTION[1]

Flow maps are cartographic representations of sets of linkages among pairs of point mapped locations. They include geo-dipole geographic data [1] that are connected by lines, with the line forming the thematic symbol. Flow maps have been widely used to visualize not only the movement of tangible objects such as human migration [2], commuting [3], air traffic flows [4], goods being traded (e.g., wine exports from France [5]), and subsurface flow in a watershed [6], but also the movement of intangible objects such as social media messages [7], disease spread and connections within social networks [8].

Research has identified the main challenge to flow mapping, that is, displaying a large number of connecting lines between a set of origins and destinations results in visual clutter [9-12], especially where the lines converge. One of the traditional flow mapping methods created by Tobler [2, 13] used variable thicknesses of lines to differentiate the amount of flow and arrows to represent the direction of flow. This method often creates flow maps where a few thick lines occupy considerable space and a large proportion of lines overlap with one another. This leads to visually cluttered or uninterpretable maps especially when the data size is big, or the flows are focused on single points, such as major cities.

Some scholars have reduced the visual clutter by merging and rerouting the flow lines. They have developed visualizations of flows that look like a tree – i.e., the flow has a few major branches coming from one origin, and small branches that have various widths coming from the major branches and reaching multiple destinations [14-17]. However, the cost to the viewer is that the arbitrary and winding flow lines of the tree-like flow maps are visually misleading and show incorrect information in terms of the volumes of the flows (see section 4.2 for details).




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We propose a new flow mapping method called Animated Flow Mapper. We focus not on developing an algorithm to generalize complex flow lines, but on the design of flow lines to improve the visual effectiveness of flow maps. The new design of flow lines was developed based on Tobler's flow mapping method [2], and aims to decrease the visual clutter and improve the understanding of movement patterns by animating the flow lines. We differentiate the volume of flows by varying the movement speed (frame rate) of flow lines. To remove the need for arrows, the direction is represented by repeatedly shifting the dashed flow lines to give the appearance of animated movement in the flow direction. In the demonstrations, the Animated Flow Mapper was used to visualize air traffic flows and movements of humans using geo-tagged Twitter messages. For comparison and human-subject testing, the same data were also visualized by two other flow mapping methods, Tobler's Flow Mapper [13] and Flow Map Layout [11]. In addition, we conducted n opinion survey to test the cognitive effectiveness of the animated flow maps in terms of differentiating the directions and volumes of flows. By the comparisons and the survey, we address the usefulness and effectiveness of the Animated Flow Mapper.

# 2 BACKGROUND

## 2.1 Two styles of distributive flow maps

Various types of flow maps have been developed. Parks [18] identified three types: distributive flow maps, network flow maps and radial flow maps. Later Slocum [19] identified two more different types, continuous flow maps, and telecommunications flow maps. Among them, the research presented here only considers distributive flow maps which describe "the movement of commodities, people, or ideas between geographic regions" [19]. Regarding the design of distributive flow maps, two principal styles have been developed: Tobler's flow map and the flow tree. The first consists of straight or arc-shaped flow lines that connect origins and destinations [e.g., 2, 20-23]. The other style of flow map is the flow tree [11, 12, 14-16, 24]. In this case, the flow lines are rarely straight and consist of winding or spiral link lines.

The maps that have straight or arc-shaped flow lines have methodological origins in Tobler's flow maps [2]. Tobler developed a software program to automatically draw flow lines on a digital map. In 2004, this software became available on Windows [13]. The software creates a straight line to connect origins and destinations, arrows to display the directions of flows, and various thicknesses of lines to represent the different volumes of flows – i.e., the thicker the line, the larger the flow. This flow mapping method can create lines from one origin to multiple destinations, from multiple origins to one destination, or from multiple origins to multiple destinations. Like other methods, Tobler's flow maps can produce over-plotted lines and arrow heads, especially for large volumes of data and for multiple flows that converge at--or diverge from--single points. Recently some maps have used curved lines instead of straight lines [e.g., 21, 23] and different color hues for better visual display [e.g., 23]. To simplify over-plotted lines, Zhu and Guo [25] developed a hierarchical clustering algorithm to cluster flow lines sharing geographically similar origins and destinations.

The second style of distributive flow map is the flow tree. A flow tree typically has a thick flow line (trunk), and this trunk is separated into multiple smaller lines (branches). The thickness of the flow lines is proportional to the volume of flows. One of the first flow tree maps was Charles Joseph Minard's map of French wine exports created in 1864 [5]. To improve the visual clutter of flow maps created by Tobler's method, Holten [14], Cui *et al* [16], Holten & Van Wijk [15], and Dijk [17] developed a hierarchical clustering algorithm to bundle together neighboring lines and so reduce the number of crossed lines. The bundled lines create lines that resemble the trunk and branches of a tree, hence the name. Phan *et al.* [11] presented another flow mapping method called Flow Map Layout. This method includes a hierarchical clustering algorithm that minimizes crossing lines and creates flow lines that also look like the trunk and branches of a tree. Based on this algorithm, they developed a software implementation that became available in 2005 [26]. This software has a graphical user interface where non-programmers can easily create flow trees from their own data. Verbeek *et al.* [24] presented an algorithm that creates crossing- free flow trees. The lines of their flow tree can be positioned to avoid particular areas on the map. In their case study, they presented a flow tree map of whiskey exports from Scotland in 2009, where the flow lines are routed along shipping routes crossing the oceans. This flow tree map is similar to the Minard map of French wine exports [5]. This old map was drawn by hand, whereas Verbeek *et al.*[24] developed an automated method.

A common limitation of flow tree maps is that the flow lines are arbitrary and winding, so they are visually misleading. Another limitation is that flow trees give a false impression in terms of quantities of flows. The width of each flow line within flow trees varies from an origin to a destination. However, in reality the volume of flow remains the same from origin to destination. For example, the number of passengers in an airplane remains the same during the entire flight. The limitations of flow trees are described in detail in section 4.2.

## 2.2 Animations for capturing spatiotemporal moving objects and visualizing flows

Animated maps have been used to visualize the movement of objects. An early example of a movie including animated flow maps is "*Victory Through Air Power*" [31]. In the movie, shipping or transportation routes were animated by repeatedly redrawing small iconographic symbols of ships, tanks, trains, and arrows along global shipping routes. These animations effectively visually describe the directions of the movements of each object in question, but do not describe the different volumes of the movements. A simple example of the same type of animation of the movement of humans is in the movie, "*Raiders of the Lost Ark*" [27]. This movie includes an image of an airplane moving along a long distance route ending in Nepal. The route was animated and overlain on the map to depict where the airplane moves. Peterson and Wendel [28] developed an Animated Flight Atlas, in which thousands of aircraft were animated to describe flight traffic over North America. Their animated map visualizes the minute-by-minute movement of each airplane over 24 hour periods. Such depictions are now common on the World Wide Web to show air and ship traffic. In addition, points were animated to visualize movements such as the slave trade [29] and global shipping [30].

The contemporary technologies of web mapping and Web-based GIS have enabled the development of animations visualizing moving objects combined with interactive maps. Sequeira [31] used Javascript-based libraries such as D3.js and Leaflet.js to develop a utility to visualize data with spatiotemporal trajectories. This utility provides not only the animated lines of moving objects but also an interactive user interface. As the user changes the specified time using the slider bar, trajectories of moving objects appear and disappear depending on the specified time. Another Web-based and user-interactive tool to visualize movements of objects is an open source library called Torque from CartoDB. By using this utility, the movements of 1 million movements of Royal Navy ships during WWI have been animated [32].

Conventional animated maps focus on where individuals or individual objects move over time. However, these maps do not show the overall patterns of volumes of movements, nor do they simultaneously differentiate the different volumes of movements during a specific period. In terms of the design of flow lines, the Animated Flow Mapper is similar to the animated flow maps in the movie "*Victory Through Air Power*" [31] where the direction of movements was depicted by movement. In addition, we differentiated the volume of flows by changing the animation speed of the dashed lines. The specific design of the Animated Flow Mapper is described in the section below.

# 3 Methodology

## 3.1 Design of Animated Flow Maps

Our map design was inspired by a bird eye's view of the movement of cars. When cars on a highway are viewed from the sky above, our eyes can easily detect the direction the cars are moving. Similar to the moving cars on the highway, on the map dashed lines are drawn between the origin and the destination, and animated to show directions and volumes of the flows (Figure 1). Blue dashed lines imitate cars on the road (Figure 1a and b). Uniformly spaced blue dashed lines were designed to resemble cars that are moving at equal intervals. Background grey lines resemble the road where cars are moving in the same direction. To make each car (i.e. each blue dash) appear to be moving on the road (i.e. background grey line) toward the left, a first dashed line was drawn (Figure 1b), then a second dashed line was redrawn in a slightly different position toward the left (Figure 2c), similarly the rest of each dashed line (Figure 1d, e and f) was repeatedly redrawn at equal intervals slightly further toward the left. By repeatedly redrawing these lines (Figure 1b to f) in the same position, the line was animated. As a result, the top line in Figure 2 appears to be moving toward the left.

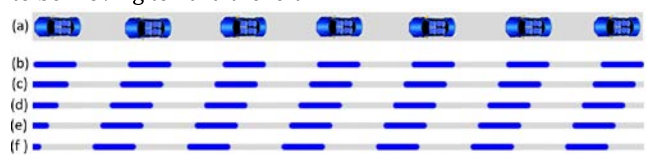


**Figure 1**: **The design of dashed lines and the process of making animated lines.**

**Figure 2. The animated lines. The animated version can be viewed at: http://vision.sdsu.edu/su42/Figure2**

The volumes of flows were differentiated not only by the different speed of moving dashed lines, but also by the gradient of colors (Figure 2). We used saturated colors and fast-moving lines to represent high flow volume. In contrast, the lighter-colored and slow-moving lines represent the smaller flows. Among the three blue lines differentiating the volume of moving objects, the first line represents the largest volume of flow, the second line represents a medium volume of flow, and the third line represents the smallest volume of flow. We also represent the different directions of moving objects by shifting the dashed lines towards the destination direction. The top line in Figure 2 appears to be moving towards the left. In contrast, the last line appears to move toward the right.

## 3.2 Technologies used for Animated Flow Mapper

Web-based geographic information system (GIS) technologies such as Leaflet were used to make the animated maps. The leaflet is an open-source javascript library for mobile-friendly interactive maps (Agafonkin). To make the animated lines, a Leaflet plug-in called Leaflet.PolylineDecorator was used (Becquet). In this paper, the core block of code is discussed, while the entire source code is available in the supplemental material.

The code below shows a core block of javascript programming code that draws an animation of dashed lines.

```
1   var background_line = L.polyline([[34.05, -118.24],
[40.73, -73.99]],
2   {
3       stroke: true,
4        color: "#FFFFFF" ,
5        weight: 4,
6        opacity: 0.7
7   }).addTo(map);
8   var dashed_line =
L.polylineDecorator(background_line).addTo(map);
9
10   var Offset_value = 0;
11   var animation = window.setInterval(function() {
12       dashed_line.setPatterns([{
13           offset: Offset_value+'%',
14           repeat:70,
15           symbol: L.Symbol.dash({pixelSize: 30,
16           pathOptions: {stroke: true, color:
"#FF3399",   weight: 4, opacity: 0.9}})}])
17       if(++Offset_value > 5){
18           Offset_value = 0;
19       }
20   },  speed);
```

The code in lines 1 to 8 is for drawing a solid line underneath a dashed line. A pair of coordinates, an origin and a destination are defined in the first line. In lines 3 to 6, the color, weight and opacity of the line is defined. The code in lines 10 to 20 is for drawing dashed line segments. *Offset_value* is the variable that enables repeated drawing of the dashed lines. Every time the loop in lines 11 to 20 is executed, the program increments *Offset_value* by one until it reaches its threshold. In this case, the threshold is 5 in line 17. The bigger this threshold, the further the dashed line is shifted. In lines 12 to 16, the style of the dashed line is defined. The value *repeat* represents the space between dashes. The bigger the value of *repeat* is, the wider the space between dashes. The bigger the value of *pixelSize*, the wider each dash is. Color, weight and opacity of dashes are defined in line 16. To differentiate the volume of flows, the various speeds of moving dashed lines were set to the variable, *speed* in line 20 in the code above. The smaller this number, the faster the dashed line appears to move.

Another plug-in called *Leaflet.Geodesic* was used to draw the shortest path between two locations as a great circle on world and continental-scale maps (Thasler). The code below shows some parts of the javascript programming code of *Leaflet.Geodesic*.

```
1 var Los_Angeles = new L.LatLng(34.05, -118.24);
2 var New_York = new L.LatLng(40.73, -73.99);
3
4 var Geodesic_line = L.geodesic([[Los_Angeles,
New_York]],
5 {
6    stroke: true,
7    color: "#FFFFFF" ,
8    weight: 4,
9    opacity: 0.7,
10   steps: 50
11 }).addTo(map);
```

In code lines 1 and 2, objects are created with a pair of coordinates of an origin and a destination, and the object that has each pair of coordinates is assigned in line 4. In this case, the origin is Los Angeles, and the destination is New York. After the whole block of code is executed, a line following the great circle between two places is drawn on the map. The code from lines 6 to 10 is for styling the line. The value of *steps* represents the discretization of the shortest path. The bigger the value, the closer the route is to the great circle, and the more computing time it requires.

# 4 CASE STUDY

## 4.1 Data

Air traffic data and geo-tagged Twitter data were used to test the Animated Flow Mapper. Air traffic data were collected from the Airline Origin and Destination Survey. The data are available from the website of the Bureau of Transportation and Statistics [36]. Twitter is an Internet-based social networking and microblogging service that allows registered users to receive and broadcast short text messages called Tweets. Tweets are limited to 140 characters in length. A streaming API allows us to download these geo-tagged tweets which include the longitude and latitude coordinates of each user's location. About 3.5 million Tweets were collected from the entire world for about three months from November 16, 2014 to February 17, 2015. Since the selected tweets were those that had the coordinates of the users, these coordinates can be used to identify where the users have moved.

## 4.2 Flow maps visualizing air traffic flows and their comparison to the animated flow map

Air traffic flows were visualized by the Animated Flow Mapper, by Tobler's Flow Mapper [13] and by Flow Map Layout [26]. Each different flowmap was compared to the others in terms of the design of the flow lines. Figure 3 shows the visualizations of the top 75 air traffic flows coming to the Denver International Airport (DEN) during October, 2014. Flow lines in Figure 3(a) were created with Tobler's Flow Mapper. Figure 3(b) is similar to Figure 3(a), but Leaflet plugins were used [34, 35]. Figure 3(c) is a flow tree that was created by Flow Map Layout. Figure 3(d) is an animated flow map that was created by the Animated Flow Mapper. Tobler's Flow Mapper creates straight lines connecting origins and destinations (Figures 3(a)). On the other hand, curved lines were used to connect origins and destinations in Figures 3(b). These curved lines are the shortest routes from each origin to the destination. In the case of visualizing flow lines within the U.S., there is no big difference between the straight lines representing the Euclidean distances and the great circle distances. However, the difference becomes significant in the case of visualizing flow lines connecting two distant countries.

The issue of this difference is discussed in detail in the next case study.

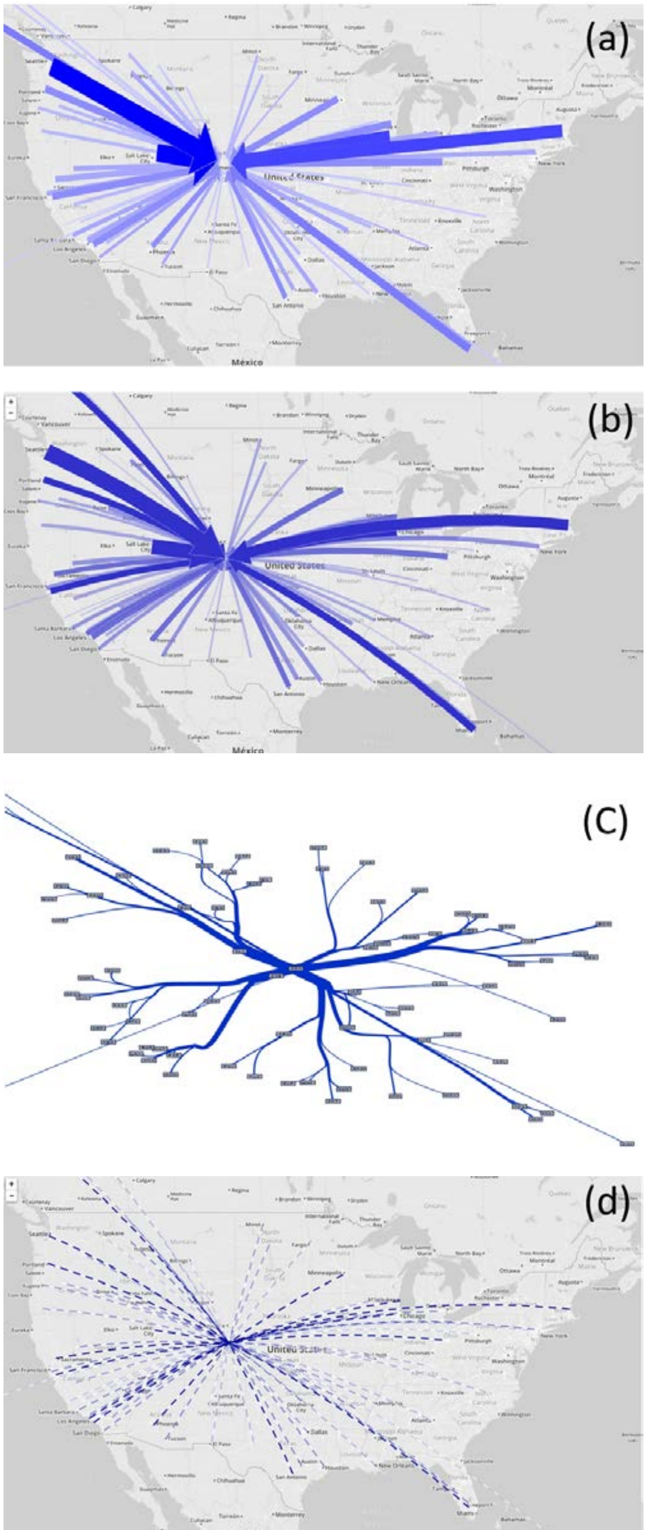


**Figure 3. Air traffic flows to the Denver airport during October, 2014 visualized by different flow mapping methods. (a) Tobler's Flow Mapper, (b) Leaflet plugins, (c) Flow Map Layout, (d) the Animated Flow Mapper: The animated version can be viewed at: http://vision.sdsu.edu/su42/Figure3d In maps (a) and (b), thick and dark colored lines represent large flow volumes; thin and light colored lines represent small. In map (c), thick lines represent the large flow volumes; thin lines represent small. In map (d), fast and dark colored lines represent the large flow volumes; slow and light colored line represent small**.

In terms of the visual aspect of flow lines, maps (a) and (b) in Figure 3 have many overlapping lines: a few thick lines occupy considerable space, so some of the flow lines are hidden beneath the thicker flow lines that overlap one another. The lines in the area near the Denver airport are overlapped significantly. This issue is particularly problematic in Figures 3(a) and (b): Arrows are intended to represent the direction of flows, but most of the medium to small size arrows are not visible. On the other hand, the flow tree in Figures 3(c) has much more generalized flow lines than the flow lines in maps (a) and (b) in Figures 3. Especially, the complex lines in the region near Denver in maps (a) and (b) in Figures 3 has been reduced to just a few lines in the flow trees in Figures 3(c). Flow trees consist of a few major thick lines and narrow flow lines coming from the thick lines; therefore, overlapping lines are much more reduced than the traditional flow maps in maps (a) and (b) in Figure 3.

The flow tree in Figures 3(c) has reduced the problem of overlapping lines; however, flow tree maps have a few downsides. First, the flow tree does not indicate the directions of the flows. Figure 3(c) is supposed to represent the flow lines coming to the Denver airport. However, the map in Figures 3(c) does not show in which direction the airplanes are heading. Furthermore, the flow tree map produces flow lines that are arbitrary and winding. For example, the line connecting the Denver airport (DEN) to the Phoenix airport (PHX) in Figure 3(c) is forced to be placed along one of the thick paths in the space near Denver, and it is turned at almost a ninety degree angle in the middle of the route. The arbitrary flow lines in Figures 3(c) are visually deceptive while the flow lines in maps (a), (b), and (d) of Figures are visually simple.

Another downside of the flow trees in Figure 3(c) is that they give incorrect information in terms of the volumes of flow. The flow trees have different line widths between the trunk (thick flow lines around Denver) and branches (thin flow lines toward the destination cities). In other words, the width of line is thin when it starts from the origin city and becomes gradually thicker as it reaches the destination city. For example, the line connecting San Antonio to Denver in Figure 3(c) becomes gradually thicker as it reaches its destination. As a result, the line describes a small volume of flow when it departs (San Antonio) and the volume becomes larger as it reaches the destination (Denver). However, the actual volumes of flows, such as the number of airplanes or passengers, remain constant through the entire travel from the origin to the destination. On the other hand, the Animated Flow Mapper describes the same amount of volumes of each flow from departing to arriving. To describe the downside of the flow tree, the Flow Map Layout (Figure 3(c)) was used as one of examples of flow mapping methods that produce a flow tree. In fact, the downside of the Flow Map Layout described here is common to all flow tree mapping methods [e.g., 11, 12, 14-16, 24].

The animated flow map in Figure 3(d) improves the problem of overlapping lines in Figure 3(a). The difference in the volumes of flows is represented by the various widths of flow lines in the maps as in (a) and (b) in Figure 3. Creating lines with various widths is the main reason that those flow maps suffer from the problems of occlusion. However, animated maps can use thin lines and still represent the different volumes of flows according to the apparent speed of the dashed lines. As a result, the flow lines in the animated maps have fewer overlapping and crossing lines than the lines in maps (a) and (b) in Figure 3. In terms of the flows directions, the animated map in Figure 3(d) represents the directions without arrows. In Figure 3(d) the flows look as if they are moving outward from the Denver airport. Representing directions without arrows is another factor that improves the problems of occlusion especially in the maps of Figure 3(a) and (b). The visual effectiveness of the animated flow maps against the conventional flow maps was tested through a human subject survey in section 4.4.

## 4.3 Animated Flow Mapper Use Case: Visualizing human movements using geo-tagged tweets

Animated Flow Mapper was also used to map international travel patterns as revealed by Twitter messages. The location of Twitter users can be identified when they post messages using GPS-enabled smartphones. The messages that have the coordinates of user locations are called geo-tagged tweets. Studies have found that geo-tagged tweets can be a proxy for human movements [37, 38]. If the same user sends tweets prior to and then after travel between cities and countries, we can surmise that travel has taken place by that user along that route. According to Hawelka et al. [37], geo-tagged tweets can be a proxy for human movements, especially at the level of country-to-country flows. However, this study does not contain the visualization of human flows. Such a visualization potentially can help comprehend the travel patterns at a single glance. Thus, this case study utilized Animated Flow Mapper to visualize human movement patterns between US cities and international countries, and aimed to demonstrate how different flow maps provide better or worse insight for the understanding of human flows.

To identify the origins and destinations of Twitter users, the same methods were adopted from previous work [37]. Tracking trajectories of Twitter users based on where and when they tweeted, we defined the city of residence as the city where the user had created most tweets during the three month period of data collection. Once the city of residence was identified, we examined in which cities each user had tweeted other than the city of residence to identify the user’s travel destination. For example, if a user whose city of residence is Los Angeles created tweets in New York, we considered that this user had travelled from Los Angeles to New York. To define the boundary of cities in the U.S. and other countries, the boundaries of the Census metropolitan and metropolitan statistical areas were used for the U.S. cities, and the global administrative areas were used for the countries outside of the U.S. The centroid of U.S cities and countries other than U.S. was used as a point for connecting the flow lines.

Animated Flow Mapper has several advantages in terms of visualizing human movement patterns compared to more traditional flow mapping methods. All maps in Figure 4 visualize the volumes of travel to Los Angeles County. Figure 4(a) was created by Tobler’s Flow Mapper, in which wide lines are visualized on top of narrow lines. In this case, many narrow lines representing the small volumes of flows are hidden underneath the thick lines representing the large volumes. Therefore, Figure 4(a) lost the details of individual flow lines. Figure 4(b) was also created by Tobler’s Flow Mapper, in which narrow lines are positioned on the top of the thick lines. In the case of Figure 4(b), the narrow lines can be seen in more detail than the case of Figure 4(a), whereas the large volumes of flows represented by the thick lines are hidden. Therefore, Figure 4(b) does not capture the patterns of large volumes of flows. Next, we used the Leaflet plugins [35] in Figure 4(c) to create the flow lines along the great circle paths. The use of the great circle path helps to reveal more details of the flow lines than the use of Euclidean distance in Figures 4(a) and (b). The reason is that Figure 4(c) has the flows coming from every direction, while Figures 4(a) and (b) have mostly flows that are connected to the east. In addition, humans are likely to move along the shortest route, that is the great circle route. From this reason, the use of great circles is more effective to describe human movement than the Euclidean distance although the purpose of flow maps is not describing the trajectories of moving objects.

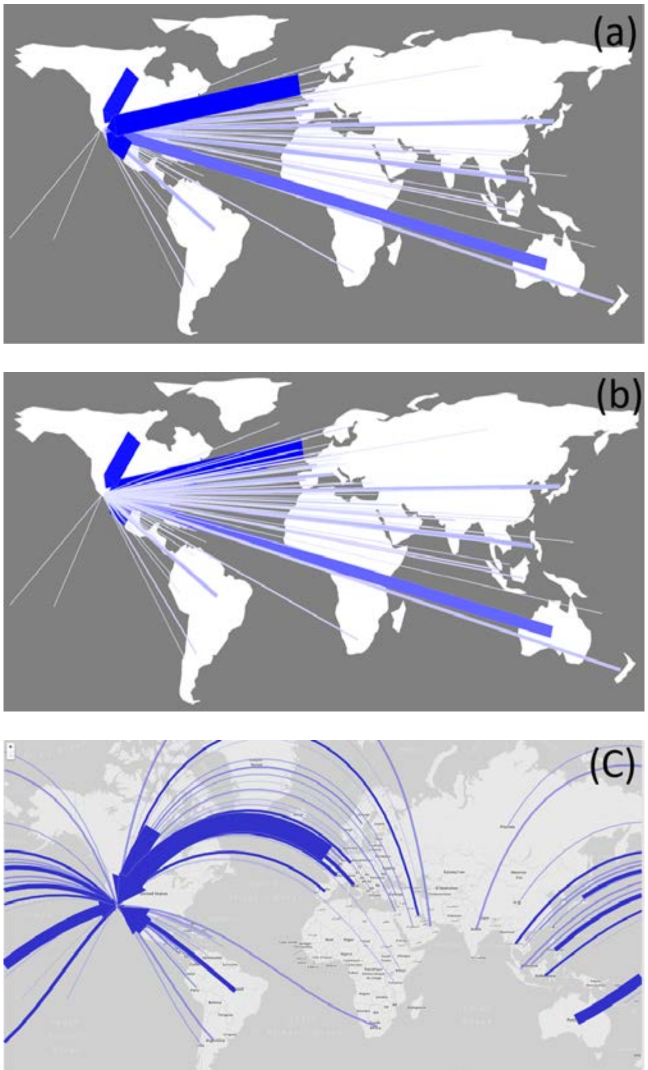


**Figure 4. Flows of Twitter users from international countries to Los Angeles County. Maps (a) and (b) are visualized by Tobler's Flow Mapper, (c) is created using Leaflet Plugins. The centroid of each country was used for the point of origin and destination of each county.**

Figure 5 has thin lines and no arrows to minimize overlapping flow lines, while Figure 4(c) has many overlapping lines and arrows. Figure 5 was designed to avoid hiding lines that were inevitable due to wide lines in Figure 4(c).

**Figure 5. Flow of Twitter users from international countries to Los Angeles County from Nov. 15, 2014 to Feb. 17, 2015. This map is visualized by the Animated Flow Mapper. The map represents the movements of Twitter users from international countries to Los Angeles County. The animated version can be viewed at: http://vision.sdsu.edu/su42/Figure5aThe animation representing the movements of Twitter users from Los Angeles County to international countries can be viewed at: http://vision.sdsu.edu/su42/Figure5bThe centroid of each country was used for the point of origin and destination of each county. Fast and dark colored lines represent the movement of a large number of Twitter users; slow and light colored lines represent the movement of a small number of Twitter users.**

## 4.4 Cognitive acceptance of the Animated Flow Maps

A human subjects survey was conducted to evaluate the cognitive acceptability and effectiveness of the Animated Flow Mapper. The survey questionnaire was coded in javascript and HTML, and took the form of a web site that could be entered from a URL. Emails requesting participation in this survey were sent to people affiliated to any of following organizations: (1) the Department of Geography at San Diego State University, (2) the Department of Geography at the University of California, Santa Barbara, (3) the Cartography and Geographic Information Society (CaGIS), and (4) the Cognitive Visualization Commission (CogVis) of the International Cartographic Association (ICA). A total of 156 people voluntarily filled out the survey. During the survey, participants were asked to view several different visualizations of flow maps representing air traffic flow. Every participant answered all questions. Table 1 to 9 represents the percentage of people who picked each of options. They were first asked to rate their respective level of experience with maps, and 41% of participants responded that they had much experience with maps (Table 1).

**Table 1: Participants' level of experience with maps. The higher the number, the more experience the participants had with maps.**

| | Level of experience with maps |
|---|---|
| 1 (none) | 1.9 % |
| 2 | 3.8% |
| 3 | 22.4% |
| 4 | 28.2% |
| 5 (much) | 41% |
| no response | 2.6 % |

The survey consisted of three parts. In each part, the participants were asked to compare two maps side by side. In the first part, they were asked to examine the two maps in Figure 6(a) and then the questions in Table 2 were asked. These questions were intended to explore whether users could distinguish the direction of air traffic flows from the animated dashed lines. About 83% of participants recognized the direction of air traffic flows from Denver to other cities in Map -1B in Figure 6(a). About 85% of participants recognized the direction of air traffic flows from other cities to Denver in Map-1A in Figure 6(a). In other words, most of participants were able to differentiate the inflow versus outflow of the animated flow maps.

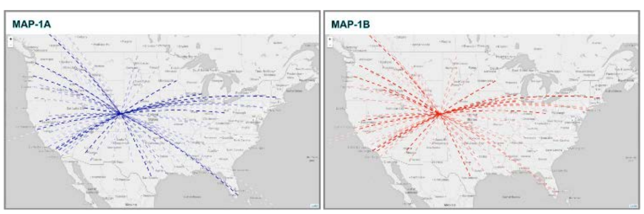


**Figure 6(a) Maps that were shown in the survey. The animated version is available at: http://vision.sdsu.edu/su42/survey/q1.html**

**Table 2: Two questions and their responses in the first section of the survey. These questions were followed by Figure 6(a).**

| | 1.1 Which map do you think best shows air traffic flows from Denver to other cities? | 1.2 Which map do you think best shows air traffic flows from other cities to Denver? |
|---|---|---|
| Map-1A | 7.1 % | 85.3 % |
| Map-1B | 82.7 % | 3.2 % |
| I don't know | 10.3 % | 11.5 % |

In the second section of the survey, the participants were asked to examine the two maps in Figure 6(b), and then answer the questions in Tables 3 and 4. In terms of differentiating the flow directions, the static map on the left in Figure 6(b) uses an arrow at the end of each line, which is the traditional way of representing the direction in the flow map. Since all lines converge at one point, placing the arrow at the end of each line results in an aggregation of arrows. In contrast, the moving dashed lines of the animated map represent the direction of flows without arrows. In terms of visualizing the different volumes of flows, the static map on the left used only the gradient colors while the animated map on the right used both gradient colors and different speeds of the dashed lines.

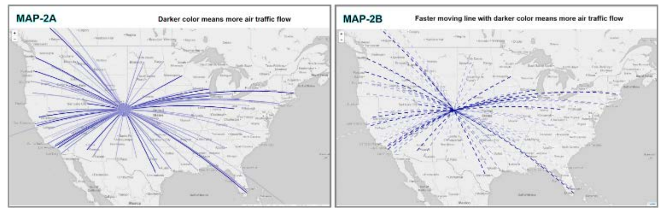


**Figure 6(b) Maps that were shown in the survey. The animated version is available at: http://vision.sdsu.edu/su42/survey/q2.html**

The questions in the second section of the survey were intended to see if the animated flow map with thin dashed lines was more acceptable than the static maps with thin solid lines in terms of differentiating the direction and volume of flows. The response to question 2.1 (Table 3) shows that most participants could not identify the direction of air traffic flow on the static map (Map-2A). In contrast, responses to question 1.1 and 1.2 (Table 2) show that most participants could differentiate the direction of flow in the animated flow maps. One question shown in Table 4 was intended to see if the animated flow map differentiated the volume of flows with two variables (i.e., color and speed) performs better than the static map with only one variable (i.e., color) in order to depict the volume of flows. The result in Table 4 shows that more than half of the participants responded that the animated map (Map -2B) works better in differentiating the volume of air traffic flows than the static map (Map -2A).

**Table 3: The first question in the second section of survey. The question follows Figure 6(b)**

| | 2.1. Can you differentiate the direction of air traffic flows (i.e., inflow or outflow) in map-2A? |
|---|---|
| Yes | 13.5 % |
| No | 86.5 % |

**Table 4: The second question in the second section of survey. The question follows Figure 6(b).**

| | 2.2. Which map do you think works better in differentiating the volume of air traffic flows? |
|---|---|
| Map-2A | 30.1 % |
| Map-2B | 60.3 % |
| Hard to tell | 9.6 % |

The use of thin lines in both the static map on the left and the animated map on the right in Figure 6(b) produced less overlapping lines than the flow map with various width lines in the left of Figure 6(c). Therefore, the problem of overlapping lines has been eliminated in both maps in Figure 6(b). In this case, some people might think that the static map on the left in Figure 6(b) might be enough to differentiate the direction and volume of flows. However, the survey result in Table 3 and 4 shows that the animated flow map on the right in Figure 6(b) performs better in terms of differentiating both the direction and the volume of flows.

In the third section of the survey, the participants were asked to examine the two maps in Figure 6(c), and then answer the questions in Tables 5,6,7,8 and 9. The questions were intended to test the visual effectiveness of the animated map on the right in Figure 6(c) versus the traditional flow map on the left in Figure 6(c). Table 5 shows that the traditional flow map works well in representing the direction of flows. In terms of the effectiveness of differentiating the direction of air traffic flow, it is hard to tell which one works better (Table 6). On the other hand, about 54% of participants responded that the traditional flow map works better in differentiating the volume of flow (Table 7). Regarding the question in Table 8, however, more than 80% of participants responded that they can differentiate the volume of air traffic flow on the animated flow map. The last question in Table 9 was intended to test if the participants recognize the reduced overlapping lines of the animated flow map compared to the traditional flow map. The result shows that 80% of them could recognize less overlap and hidden flows of the animated flow map better than the traditional flow map.

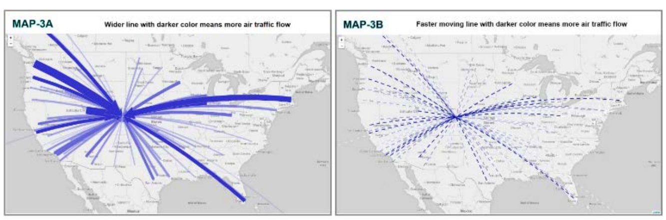


**Figure 6(c) Maps that were shown in the survey. The animated version is available at: http://vision.sdsu.edu/su42/survey/q3.html**

**Table 5: The first question in the third section of survey. The question follows Figure 6(c).**

| | 3.1. Do you think that Map-3A shows flows toward Denver? |
|---|---|
| Yes | 92.9 % |
| No | 7.1 % |

**Table 6: The second question in the third section of survey. The question follows Figure 6(c).**

| | 3.2. Which map do you think works better in differentiating the direction of air traffic flows? |
|---|---|
| Map-3A | 29.5 % |
| Map-3B | 30.8 % |
| Both work | 25.6 % |
| Neither map works | 14.1 % |

**Table 7: The third question in the third section of survey. The question follows Figure 6(c).**

| | 3.3. Which map do you think better differentiates the volume of air traffic flows? |
|---|---|
| Map-3A | 54.5 % |
| Map-3B | 37.8 % |
| I don't know | 7.7 % |

**Table 8: The fourth question in the third section of survey. The question follows Figure 6(c).**

| | 3.4. Can you differentiate the volume of air traffic flows in map-3B? |
|---|---|
| Yes | 81.4 % |
| No | 15.2 % |
| I don't know | 3.4 % |

**Table 9: The last question in the third section of survey. The question follows Figure 6(c)**

| | 3.5. Which map do you think has less overlapping and hidden flows? |
|---|---|
| Map-3A | 8.3 % |
| Map-3B | 80.7 % |
| I don't know | 11.0 % |

## 5 CONCLUSION

In summary, the cognitive efficiency of the animated flow map is comparable to the traditional flow map in terms of differentiating the directions and volumes of flows (Table 5,6,7,8 and 9). However, one big merit of the animated flow map is that the animated flow maps do not use thick lines or arrows, but nevertheless remain capable of differentiating the volumes and directions of flows (Table 3,5, and 8). Using thin lines for the animated flow map considerably reduces the overlapping and hidden lines of the traditional flow map, so the animated flow map has improved the problems of the occlusion of the conventional flow mapping method. Without the thick lines and arrows, the use of thin dashed lines helps to save space on the map. Therefore, visualizing thin dashed lines without arrows reveals more flow lines than visualizing with various width of lines with arrows. In other words, the animated flow maps help the users to explore more details of the flow lines by reducing overlapping lines compared to the flow maps that have various widths of line with arrows (Table 9). Another merit of the Animated Flow Mapper is that it works better than the static map in terms of differentiating the direction of flows, especially when many arrows are overlapping (Table 3 and 5).

The results of the case studies show that the animated flow map has advantages over the flow tree. The straighter flow lines of the Animated Flow Mapper are simpler than the arbitrary and winding flow lines of the flow tree. The common downside of the design of the flow tree is that it describes unrealistic volume of flows; the volume of each flow increases or decreases between an origin and a destination. However, the Animated Flow Mapper describes the constant volume of flow between an origin and a destination. Therefore, the Animated Flow Mapper describes more realistic quantities of flows than the flow trees.

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