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Exploratory visualisation of congestion evolutions on urban transport networks ☆

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ABSTRACT

Visualisation is an effective tool for studying traffic congestion using massive traffic datasets collected from traffic sensors. Existing techniques can reveal where/when congested areas are formed, developed, and moved on one or several highway roads, but it is still challenging to visualise the evolution of traffic congestion on the whole road network, especially on dense urban networks. To address this challenge, this paper proposes three 3D exploratory visualisation techniques: the isosurface, the constrained isosurface, and the wall map. These three techniques have different advantages and should be combined to leverage their respective strong points. We present our visualisation techniques with the case of link travel time data from Automatic Number Plate Recognition (ANPR) in London.

1. Introduction

Traffic congestion occurs where a given area (space) designated for movement is insufficient for the smooth and continuous flow of traffic, within an acceptable time or speed for most users (Lee et al., 2008). It is a major source of despair for road users, affecting individual commuters physically and mentally (Hennessy et al., 2000). It is also a substantial problem for the urban community, environmentally and economically (TTI, 2009). However, due to increasing mobility demands, traffic congestion is day-by-day becoming more acute in many big cities around the world. In order to alleviate congestion, we need to understand how traffic transforms itself on the road, and how congested areas form, develop, and spread in space and time simultaneously.

With advances in technology, various traffic sensors are now available, including traffic cameras, loop detectors, ramp metering systems, and GPS receivers on probe vehicles. These devices can provide us with an overwhelming amount of traffic data in the form of traffic parameters, e.g. velocity, travel time, and number of vehicles. There are many approaches to studying traffic congestion in space–time using these traffic data. Some use mathematical models to describe data such as traffic flow (Lighthill and Whitham, 1955; Jin and Zhang, 2003; Li, 2005). Others replicate traffic conditions using simulations (Helbing and Treiber, 1999; Helbing et al., 2001; Jiang et al., 2007).

Among other approaches, visualisation is an effective tool for studying traffic congestion, transforming non-visual data into 'readable' and 'recognisable' images (Shekhar et al., 2002; Kosara et al., 2008). We use the term exploratory visualisation to emphasise that visualisation techniques seek to be a part of data exploration that integrates human perceptual capabilities

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into the analysis process (Andrienko and Andrienko, 2005; Silva and Freire, 2008). It differs from other visualisation techniques that seek to summarise analytical findings. Exploratory visualisation presents data in visual form to enable data analysts to understand their data better. When analysts begin to understand the data, they can combine their flexibility, creativity, and knowledge of data analysis to form new hypotheses that will lead to further exploration and insight into the data (Keim, 2002).

A number of researchers have employed visualisation techniques to study traffic data. The Isoline (or contour line) is a visualisation method that has been employed to display many traffic parameters. The term isoline refers to a curve along which points of equal value are connected (Richard et al., 1996). An early example of an isoline is May (1962), who developed density contour maps to show the heterogeneity of traffic density of highway links over time. The density contour map can show the discontinuity of traffic flow, and consequently, it is possible to see the boundaries of congested areas. These enable us to measure the spatial extent and hotspots of congested areas (Cheng et al., 2010). Isolines have also been employed to present changes in speed. Marchand (1973), for example, presented isolines of average speeds between cities in Venezuela in 1936, 1941, 1950 and 1961, to reflect changes in the physical road conditions. A special type of isoline is an isochrone which connects points of equal travel time from a given origin (Brunsdon et al., 2007), which can be useful in making a decision to buy a property (Mysociety, 2007).

Distortions of real physical geometry have been employed to represent travel time. This technique is called a 'cartogram'. Weir (1975) illustrated the changes in travel time arising from a new bypass construction. He placed the nodes on the network within geographical space into time–space by using Multi-Dimensional Scaling (MDS), where distances between the nodes represented units of travel time rather than Euclidean distance. The corresponding nodes before and after the construction were connected, and the distance showed the degree of travel time change after the bypass was built. Another more recent example can be found at (Kaiser et al., 2010).

Q-Analysis has also been employed to show relative changes in travel times (Johnson, 1981; Gatrell, 1983). Q-Analysis is referred to as a language of structure. It was proposed to describe the linkage among components in a very complicated system, and the way they change (Legrand, 2002). Q-Analysis has been employed to describe and display how congestion moves through the road system (Johnson, 1981). The presentations of Q-Analysis are, however, difficult to understand.

The spatial treemap is another technique that has been employed to display traffic parameters, which was proposed by Wood and Dykes (2008) to represent hierarchical data. The spatial treemap consists of coloured rectangles. Each large rectangle is subdivided into small rectangles to represent a smaller group. Wood et al. (2008) used the spatial treemap to produce road maps of traffic speed and volume, obtained from GPS data. The spatial treemap represents the level of speed and volume by variations in brightness. Therefore, congested areas in the city can be seen as darker colours. When zooming into a specific area, small rectangles that represent the level of speed of each time interval can be distinguished. The spatial treemap provides information on how traffic parameters changed in each area within a day, and by vehicle type. Moreover, it can display multi-level data. For example, users can zoom into see hourly data inside a rectangle. However, the spatial treemap still does not provide information about the traffic congestion process, since the data in the smaller rectangles within a larger rectangle is static and isolated. It is, therefore, quite difficult to see how congestion propagates through the road network.

Although the visualisations mentioned above present traffic parameters in space or time, the movement and evolution of traffic congestion cannot be clearly distinguished except at individual roads. For example, Kerner and Rehborn (1996) and Bertini et al. (2004) employed line graphs to plot the velocity and flow at loop detector stations. The line graphs show abrupt changes in velocity and flow. Movement in congested areas can be seen when displaying the line graphs of several stations in series. They can also show information about the movement and displacement of congested areas when comparing data between adjacent stations. Coloured pixels, another technique of 2D space–time, is popularly used to study the evolution of traffic congestion in space–time by visualising the traffic speed of individual links obtained from loop detectors (Zhang and Rice, 1999). The space–time coloured pixels consists of two axes: a device position axis and a time axis. Each pixel represents the magnitude of a traffic parameter measured from a monitoring device at a particular time, in colours. Later, a 3D space–time coloured pixels technique was proposed (Treiber and Helbing, 2002; Schönhof and Helbing, 2007). Beyond the 2D, a third dimension is used to display the magnitude of a traffic parameter. Colours are still employed for the magnitude to give better contrast. The congested areas can be clearly seen in the 3D space–time coloured pixels since the boundaries between congested and free flow areas are quite distinct for individual roads. Since the display space is limited, congestion over a long time period cannot be displayed so an animation technique is employed to move the congestion information downwards with time (iTIS Holdings, 2011).

Existing techniques, however, normally only depict the spatial dimension along a single road or link. There is a failure to present the whole road network layout, and information is not available on how congestion spreads from one link to other contiguous links. Moreover, the study of congestion in space–time is normally applied to open highways, but not to roads in central city areas where the road network is very dense. There are a few exceptions in visualising congested areas within the city. Duan et al. (2009) and Zhang et al. (2004) presented the traffic state of the whole road network using a pseudo-colour and contour map. The evolution of traffic congestion over a wide area was shown by a series of maps (Zhang et al., 2004). These time series maps can inform the variability of traffic flow over space, but, in our opinion, they are still not able to present certain important aspects of changes over time due to the limitations of the snap-shot technique. For example, it is difficult to observe the change of the positions of congested areas unless maps of different time periods are compared.

In summary, despite many attempts to visualise traffic parameters in space–time, most existing works do not display the evolution of traffic congestion on the whole road network. And although many researchers focus on studying how congested