Visualizing Space-Time Map for Bus

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Abstract. Current bus maps are created by tracing ground trajectories of bus routes on available base maps. These bus maps provide with the spatial information of ground trajectories and bus stops; some websites have associated departure time table with each ground trajectory on the map. It is considered that bus users need not only spatial but also temporal information. This paper integrates visualization with temporal geography to represent spatio-temporal data of bus network as a visualized-space-time bus map. The visualized-space-time bus map displays visually the movement data of bus as graphs of bus routes and bus trips on screen. The graphs are classified as visual classes according to their attributes. The visual features of the graphs are enhanced by integrating graph classes with retinal variables. The visualized-space-time bus map enables users to analyze visually the spatio-temporal data of bus network for their travels.

Keywords: Visual · Bus map · Spatio-temporal data · Space-time map

1 Introduction

Bus map of a city is means necessary for bus users, not only residents but also tourists. They utilize bus map to design the travels according to their individual demands. Almost current bus maps are created from tourist maps or road maps by tracing additionally bus trajectories, bus stops, and bus stations of routes. On the map, several bus trajectories are drawn densely along with several road segments. The visual features of the map are strongly reduced because of the weakness of selective and associative features with respect to viewers. Moreover, current bus maps do not display the time departing from or arriving at end stations, the time coming to or leaving from bus stops.

We proposed to apply the concept of space-time cube in temporal geography to represent bus network as a space-time map of bus network [1]. However, the limitation of screen on size and resolution makes it thick in displaying bus network. The space-time bus map is quite difficult to use because of its low visual features. In that, the difference between bus routes and each other as well as between bus route and bus trip is quite difficult to be perceived by human vision.

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The main idea of this paper is to enhance the visual features of space-time bus map by classifying visual graphs as visual classes according to each route to integrate them with retinal variables. Each visual class is composed of route graph (ground trajectory), trip graphs (space-time trajectories), and elements relating route such as the time axis, lines associating time with trip graphs. The visual classes are integrated with retinal variables to differentiate route graphs from each other and route graphs from trip graphs. The integration of visual graphs with retinal variables results in the significant enhancement of the utilization of space-time bus map in applications and analysis.

This paper is structured as follows. The next section refers to the capacity of human vision and visual features of maps in cognizing and understanding visualized maps. The Sect. 3 approaches temporal geography and space-time cube to making space-time bus map. In Sect. 4, visualized-space-time bus map is upgraded from space-time bus map, where only one normalized trip graph is displayed for a route to reduce the thickness of screen and all visual graphs are classified as visual classes according to each route to integrate them with retinal variables. The final section summarizes the results of the work.

2 Visual Features

2.1 The Capacity of Human Vision

The people perceive real world by collecting information through five senses, vision, hearing, touch, taste, and smell. Each sense has an organ to collect data, excite brain, and transmit information to mind. Vision stimulates strongly human perception as well as acquires fast and numerously information [2]. Human vision perceives an object in real world through light rays reflecting from the object to eyes which is an important organ of sight.

Human detects entities in real world by visional perception of light rays reflecting from the entities and focusing on the back of eyes. For two objects of the same size, closer one seems bigger. The visional perception of object size depends on visional angle which is formed by the pencil of light rays from the object to eye. For two objects of the same size, the closer one is perceived to be bigger because its visional angle is bigger. As a result, a smaller object is perceived to be further from eye. The visional resolution is the capacity of human eye for distinguishing two different points; it is also smallest visional angle to differentiate two points. The resolution depends on individual specification of biology of human eye and on the brightness, the luminance, and environment of objects.

The depth of an object perceived by human eye is due to the difference of lengths of light rays from the points on the object to eye. The distinction between the lengths of light rays coming to eye from points of different distance to eye results in the difference of phase of light rays at human eye. Accordingly, human vision can perceive the depth of the object. The specification enables painters to feel the depth in aerial perspective images on plane. The 3D orthogonal coordinate is used in visualization to makes feeling the depth on plane.

Human vision has capacity for perceiving different colors. The perception of color difference depends on brightness, luminance, environment, and biology specification of each person. In visualization, human capacity for distinguishing colors affects the selective feature as the color variable is utilized to represent visual graphs. Similarly, the brightness resolution refers to human capacity for detecting the distinction between different values as the brightness variable is used to represent values.

2.2 The Visual Features

The visual features result from studying the properties of human vision and the requirements of users in viewing visual graphs. In visual analysis, analysts have to answer various questions, elementary and synoptic [3], by their visional perception in viewing visual graphs representing data. The visual features applying for visual graphs enable human to extract information as well as answer questions as far as possible. Bertin proposed four following features to visualize a data set [4].

- *Selective feature:* The selective feature refers to the possibility of human vision distinguishing graphs representing different data variables or graphs representing different value intervals of one or more data variables.
- *Associative feature:* The associative feature refers to the possibility of human vision grouping variables or values of the same category or attribute.
- *Ordered feature:* The ordered feature refers to the possibility of human vision comparing data values of variables to differentiate between big one and small one or arranging them in order as an increasing or decreasing sequence.
- *Quantitative feature:* The quantitative feature refers to the possibility of human vision determining a quantitative value of data.

2.3 The Retinal Variables

Data visualization is a mapping of data onto graph representing visually data significance on planar screen. In that, a visual variable representing a data variable is displayed as an axis on screen, a visual variable representing tuples of relational data variables is shown as a coordinate system. The marks representing values of data or data-tuples constitute visual graphs at positions indicated on the axis or on the coordinate system. Retinal variables are used to enhance visual features of visual graphs. The works by Bertin discovered six retinal variables, shape, size, symbol, brightness, color, and direction (Table 1) [4, 5]. The development of graphic technique provides additionally with new retinal variables of frequency flicker and phase flicker [6].

3 Approaching Temporal Geography to Making Space-Time Bus Map

Since prehistoric period, maps have been created to record by drawing natural things, objects in real world [7]. Map depicts symbolically the natural surface of the globe,

Table 1. Retinal variables

Retinal Variables	Visual Marks
Shape ***S***	
Size ***Z***	
Symbol ***L***	
Brightness ***B***	
Color ***C***	
Direction ***D***	

indicates positions of entities on ground as well as represents the relationship between objects and their activities. In addition of drawings of real world, statistical graphs and data visualization are also utilized on maps to depict the relationship among things as well as between objects and nature. Cartography, statistics, and visualization have been relating to each other in their growth history [8]. The basic theory of cartography has strongly developed since 19th century, from the coordinate system indicating positions of objects to the symbols depicting entities and their relations. Besides that, cartographers classified different kinds of maps, general and thematic. For each type of map, there are common and individual codes to show and display things on map frame of two dimensions, where time is shown as a data table if necessary. The limitation of dimension of traditional map can not show time in the coordinate system.

3.1 Space-Time Map

Space-time map is an application of space-time cube [1, 9–12]. It is constituted by a 3D orthogonal coordinate system, where two axes serve as ground coordinate system indicating ground positions of objects, the rest is used to indicate time (Fig. 1). In that, the ground coordinate system is used to indicate the ground positions based on the geographic coordinate system or a geodetic coordinate system; the time unit suitable for data set is defined on the time axis. In other words, space-time map joins a 2D traditional map with a time axis perpendicular to the plane of the 2D map. With this structure, space-time map has also many types similar to 2D maps.

According to temporal GIS (Geographic Information Science), every object exists at a location on ground associating with a time point or a time interval [13]. A moving object has its ground position changing over time. In reality, each object moves on a continuous ground trajectory recorded by digital instruments as points on ground associating with time. Technically, the ground trajectory of a moving object is a polyline time-ordered connecting ground points recorded by positioning instruments. In that, the positions of moving object are recorded by following ways: time-based, location-based, change-based, event-based, combined [14].

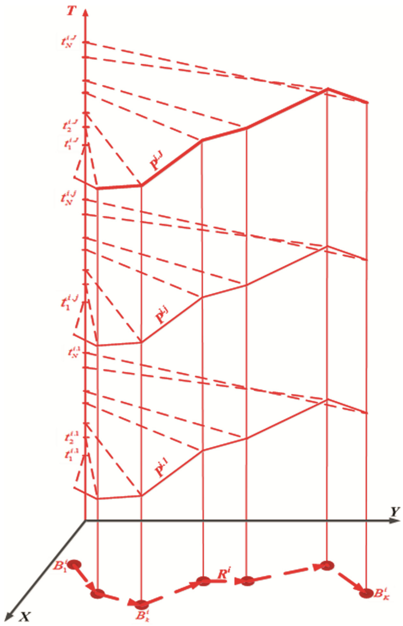

Fig. 1. Space-time bus map for the route *i* consists of a route graph R^i (ground trajectory) joining bus stops and several trip graphs $P^{i,j}$ of the route *i*.

3.2 Space-Time Map for Representing Bus Network

Bus network of a city is composed of several routes. Hochiminh city has over 150 bus routes, each of which connects end stations, one is departure and another is arrival, and is coded by a natural number, titled by the names of two end stations. Bus stops along the route are the locations to pick up and drop out passengers. The information of network is shown on 2D map. Traditionally, bus network is shown on maps of street. A lot of digital bus maps are supplied on website by different institutions with various features. Ground trajectories of bus routes are traced along streets of the city base map, where all bus stops from departure to arrival station are joined with trajectories. On the base map, user may select a bus route by clicking at the name or the code of a route on the route table of bus network (http://xe-buyt.com/ban-do-xe-buyt). Another bus map provides user with soft tool to find bus route for an individual travel from departure to arrival location. Some of cases, this bus map can not display any bus route for a selected travel (http://bando24h.com/FindBus.aspxv).

This study proposes to represent bus network on space-time map, where each bus route is shown on the base map of 2D coordinate system indicating ground locations as a ground trajectory of all buses moving on the route. The ground trajectory may be drawn along roads where all busses of the route move, or be simulated as a polyline connecting straight bus stops to each other and to bus stations, called route graph. Hundreds busses move on a route in a day, the movement of a bus is represented as a space-time trajectory on space-time map, called bus trip. The space-time trajectories are simulated as polylines time-ordered connecting straight spatio-temporal points which are the spatial positions of bus stops associated with time instants when the bus of the trip comes to or leaves from the stops or the stations. A polyline simulating space-time trajectories is called trip graphs.

Route graphs are mathematically represented by the visual variable $X \times Y$ that is a geographic or geodesy coordinate system indicating ground locations. Data of route graphs are tuples <*i*, *x*, *y*>, where $i|i = 1, 2, \ldots, I$ is route code, $(x_n^i, y_n^i) \in X \times Y | n = 1, 2, \ldots, N$ is the ground locations of the bus stop *n* of the route *i*, $B_n^i | n = 1, 2, \ldots, N$ is the title of the bus stop at $(x_n^i, y_n^i) \in X \times Y$. Trip graphs are mathematically represented by visual variable $X \times Y \times T$, where $X \times Y$ indicates ground locations and *T* indicates time. Data of a trip graph are tuples <*i*, *j*, *x*, *y*, *t*>, where $i|i = 1, 2, \ldots, I$ is route code, $j|j = 1, 2, \ldots, J$ is trip code, $(x_n^{i,j}, y_n^{i,j}, t_n^{i,j}) \in X \times Y \times T | n = 1, 2, \ldots, N$ is the space-time location of the trip *j* of the route *i* at the of bus stop B_n^i, and $t_n^{i,j}$ is the time when the bus of the trip *j* of the route *i* calls at the stop $B_n^i(x_n^i, y_n^i)$.

4 Approaching Temporal Geography and Visualization to Creating Visualized-Space-Time Bus Map

For visualization, the visual features of space-time map of bus network may be improved by reducing the thickness of screen as displaying route and trip graphs and enhancing the visual features of graphs of different categories. In subsequent discussion, let:

R^i: Route graph of the route $i|i = 1, 2, \ldots, I$;
$P^{i,j}$: Trip graph $j|i = 1, 2, \ldots, J$ of the route *i*;
Q^i: Normalized trip graph of the route *i*;
T^i: The time axis applying for the route *i*.

4.1 Reducing the Thickness of Screen

A bus network is constituted to depict hundreds of routes, each of which consists of hundreds of trips. It is impossible to display a lot of graphs on a screen of limited size and resolution. The following reasoning aims at reducing the number of trip graphs of a route. Studying the time table of all bus routes, we discover that all trip graphs of a route are similar; they have the same projection on ground, which is just the graph of the route. Indeed, the trip graphs of a route coincide with each other as they are moved according to the direction of the time axis. The study represents only one trip graph for a route, which is called normalized trip graph of the route.

All trip graphs of a route may be generated from the normalized trip graph of the route. The generation of trip graphs of a route is created according to two ways. First, in order to generate a trip graph at an indicated departure time, user moves the normalized trip graph along the direction of the time axis so that its departure point associates with the departure time of the trip on the time axis. Second, user moves the time axis along itself so that the departure time on the time axis associates with the departure point of the normalized trip graph. In the second way, each route associates with an individual time axis to make trip graphs and only one trip graph displays for a route at a moment.

The approach of the normalized trip graph reduces significantly the thickness of screen. The number of route graphs does not change but the number of trip graphs reduces from hundreds to one graph for a route. The approach of the normalization of trip graph results in the significant improvement in displaying space-time map of bus network, where there are only two graphs for a route, one for route graph and another for normalized trip graph (Fig. 2).

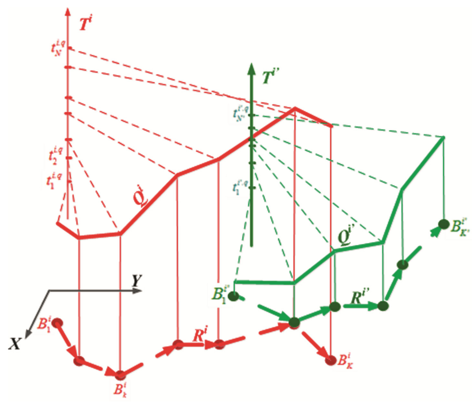

Fig. 2. Visualized-space-time bus map is created with the visual class of the route i and the visual class of the route i'. The visual class of red color represents data of the route i, the visual class of green color represents data of the route i'. The bold dashes are route graphs and thin lines are normalized trip graphs. The round points symbolize bus stops. (Color figure online)

4.2 Creating Visualized-Space-Time Bus Map

Integrating the concept of space-time cube in temporal GIS [9, 13, 15] with visualization for analysis, we constitute visualized-space-time bus map. For a space-time bus map, data relating to bus and its activities are organized on a base map [1]. For a visualized-space-time map, data of bus network are classified according to each route as visual classes, each of which is composed of graphs representing data concerning a route of bus network. Visualized-space-time map is the integration of visual classes of routes with base map. Each visual class comprises (Fig. 2):

- A polyline approximating ground trajectory connects bus stops (including two end stations) located on base map, called route graph.
- A normalized trip graph is space-time trajectory of some bus travelling on the route according to the regulated time table.
- Bus stops and two end stations of the route, commonly called bus stops, are also located on base map.
- Time axis marked linear-time points can be moved along the direction perpendicular to the base map to convert the normalized trip graph to a convenient trip graph.
- The lines associate the time axis with the points on trip graphs

Based on the base map, visual classes may be joined each other by graphic soft tools. For applications of visual analysis of spatio-temporal data of bus, users may show visual classes necessary for their problems of visual analysis according to flexible ways.

4.3 Improving Visual Features of Visualized-Space-Time Bus Map

The approach of visualization is applied for space-time bus map to strengthen the capacity of human vision for perceiving visual graphs and processing bus data. The improvement is studied according to the visual features including selective, associative, ordered, and quantitative. For a route of space-time bus map, route graph, trip graphs and normalized trip graph, and time axis are considered as the elements of the visual class of the route i, $G^i = R^i \cup Q^i \cup T^i$.

Selective feature: The feature of visual selection of visualized-space-time bus map refers to the difference between a graph class and others as well as between route graph and trip graphs of a route. The feature may be enhanced by integrating retinal variables into the graphs, for example:

- For distinguishing between a visual class and others, the color variable is integrated into graph classes. The product is defined as follows.

$$C \times G^i = \{(c_1, G^1), (c_2, G^2), \ldots, (c_I, G^I)\}$$

$$C \times G^i = \{(c_1, R^1), \ldots, (c_I, R^I)\} \cup \{(c_1, Q^1), \ldots, (c_I, Q^I)\} \cup \{(c_1, T^1), \ldots, (c_I, T^I)\}$$

where $C = \{c_1, c_2, \ldots, c_I\}$ is the color variable, e.g. $C = \{red, green, blue, pink, \ldots\}$.

Technically, the number of colors is limited and the human capacity for distinguishing different colors is also limited. The limitation is made good by only selecting graph classes necessary for application to display simultaneously.

- For distinguishing between route graph, normalized trip graph, and time axis of a route, the symbol variable is integrated into graph class. The product is defined as follows.

$$L \times G^i = \{l_1, l_2, l_3\} \times \{G^1, G^2, \ldots, G^I\}$$

$$L \times G^i = \{l_1, l_2, l_2\} \times \{R^1, R^2, \ldots, R^I\} \cup \{Q^1, Q^2, \ldots, Q^I\} \cup \{T^1, T^2, \ldots, T^I\}$$

$$L \times G^i = \{(l_1, R^1), \ldots, (l_1, R^I)\} \cup \{(l_2, Q^1), \ldots, (l_2, Q^I)\} \cup \{(l_3, T^1), \ldots, (l_3, T^I)\}$$

where $L = \{l_1, l_2, l_3\}$ is the symbol variable, and l_1, l_2, l_3 are symbols, e.g. l_1 is dashes, l_2 is thin lines, l_3 is arrows.

The marks of bus stops are visually distinguished from route graph by the difference of symbols according to the concepts of GIS, where bus stops are represented as objects of point meanwhile route graphs as objects of lines.

Associative feature: The feature of visual association refers to the visual similarity of the graphs of the same category. In above examples, the graphs of a route including route and trip graphs are visually associative by the display of the same color; the route or trip graphs of different routes are visually associative by the display of the same symbol such as line, dashes or arrow (Fig. 2). The marks of bus stops are visually associated with route graph by the color of the graph. In other words, the color of bus stops of a route is similar to the color of its route.

Ordered feature: The feature of visual order refers to the order of trip graphs and bus stops. The order of trip graphs of a route is visually perceived by associating each trip graph with time axis (Fig. 1). The order of bus stops which all busses of a trip call at is cognized by the arrows representing the direction of route graph.

Quantitative feature: The feature of visual quantity refers to the locations of bus stops and the time associating with trip graphs. The quantitative values relating to a bus stop are cognized by lines associating its location with coordinate axes. The quantitative values relating to trip graph are cognized by lines associating trip graph with time axis and route graph.

5 Conclusion

Space-time bus map is formed by the combination of visual variables representing bus data with a base map. The map provides visually with not only ground data such as ground trajectories and bus stops of different routes but also regulated temporal data of bus trips. The map enables to solve the problem of visual analysis of spatio-temporal data concerning bus network in a city, e.g. the approach to visualization method to finding bus routes and trips for a travel with given data of departure and arrival location, and arrival time.

Visualized-space-time bus map is upgraded from space-time bus map by replacing hundreds of trip graphs for a route with only one normalized trip graph and integrating retinal variables into space-time bus map to enhance the visual features of the map. Visualized-space-time bus map is structured with separated graph classes. Each class represents data of a route, including a route graph, a normalized trip graph, bus stops, a time axis, and lines associating time with normalized trip graph. This structure is suitable for storing as well as displaying fast and analyzing flexibly bus data or finding bus travels. The proposed visualized-space-time map may apply for the systems of transportation of regular routes such as metro, train, and so on.

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