Visualization of Spatio-temporal Data of Bus Trips

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***Abstract*— Bus is public means to travel in several cities. Traditional maps provide with the information of bus routes that passengers may use to design a travel from a place to another. It is difficult for them to obtain an appropriate route because of the lack of the information of time on the traditional maps. Some web sites enable passengers to take bus but they do not support passengers to have more diverse selections. In this paper, buses are considered as moving objects. Mathematically, movements of objects are the mappings (functions) from times to locations. In 3-D Cartesian coordinate systems, space-time cubes, which are called temporal maps in this paper, are models representing movements in spatio-temporal domain. A bus route on a traditional map is the curve connecting the spatial positions where the bus visits, from the departure station to the arrival. A bus trip is a bus route included time. It is represented on temporal maps. With the visualization of spatio-temporal data of bus trips on temporal maps, passengers may mark out bus trips for their more appropriate travels. This article implemented visualization tools for the design of bus travels on temporal maps.**

I. Introduction

Visualization enables humans to draw information implicit in massive data and analyze them according to the expectative targets. The visualization techniques represent data in mathematical models and display them as graphics. In digital computers, graphics are displayed flexibly with soft tools. With the available knowledge along with the diverse tools of computer engineering, humans can interact on computers to explore information implicit in data.

In geographic information science, since Hagerstrand's inclusion of the time dimension in geographical data [9],[17] and Peuquet's conceptual framework for the representation of temporal dynamics [12], a lot of scientists from diverse disciplines has been focusing on the methods representing and showing visually spatio-temporal data. They approach Cartesian coordinate systems to representing spatio-temporal data [10],[13],[14],[15],[16]. In this coordinate system, the two of three dimensions are used to represent spatial data and the other to represent the time. This 3-dimensional structure is considered as a space-time cube. Space-time cube represents spatio-temporal data and movement data to draw and analyze information.

Visualization contributes to the processes of visual analyses of data. The models of visual analysis include humans in the process analyzing data and everyone may become an analyst [3]. The visualization and visual analysis exploit the human distinct knowledge and computer's capacity to gain new information or knowledge according to various targets.

The visual analysis of spatio-temporal data enables humans to understand objects, locations, times and the relations between them. Viewing the data shown visually on the computer, humans analyze them according to their distinct needs, targets, and capacities. The visual analysis of movement data is currently levering the research of patterns visualizing movement data. The movement of objects is the change of their positions continuously in geographical space over time. Movement data refer to the data of positions changing over time of moving objects.

The main idea of this paper is to establish temporal maps of three dimensions to represent the movement of objects and illustrating it for the problem finding bus path. With the inclusion of time, the dynamic information of moving objects on temporal maps is shown more completely. Traditional maps can not enable to plan well an itinerary because of the lack of time information. Meanwhile, temporal maps offer humans not only the information of locations, but also times to plan routes more reasonably. Planning a travel with bus in a city is an application of temporal maps, which is presented in this paper.

Bus is public means to travel in several cities. The networks of bus routes of several cities are shown densely on static city maps. During the movement from the departure station to the arrival, buses visit several bus stops to pick up and drop off passengers. In order to travel from a place to another, humans may take one or more bus trips. By convention, they use bus maps to find suitable bus routes. However, it is difficult for passengers to mark out bus trips for their travel because bus maps do not show the time of bus trips. Passengers are impossible to control the departure and arrival time according to their distinct plans. In other words, passengers not only

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need the information of bus routes, but also bus trips with the time of departure, arrival, and visiting each bus stop to design their travel.

In this article, we integrate the time into bus maps to represent bus trips in space and time. The spatial data of a bus trip consists of the positions of the departure station, the arrival station, and bus stops of the route. The temporal data of a bus trip are the time moments when the bus departs from the departure station, visits bus stops, and reaches the arrival station. These data are represented in space-time cubes as temporal maps.

Finding an appropriate path to travel with bus in a city is a need of several people. It is easier for passengers if they are informed both routes and the time of each bus trip. We approach the method representing visually spatio-temporal data to show bus trips. Viewing the visual spatio-temporal data of bus trips, passengers may select convenient paths for traveling from a place to another with one bus trip or many bus trips linked at bus stops.

The paper is structured as follows. The section II briefly summarizes the research related to the representation of spatio-temporal data, movement data in a space-time cube, including the positions of moving objects and their trajectories. The conventional needs using bus in a city are also described. The section III presents the representation of bus trips in space and time as temporal maps of buses. The section IV presents a process planning a bus itinerary with 1-trip mode, 2-trip mode, and 3-trip mode.

II. Conceptual Framework and Related Works

The movement of an object through space constitutes a trajectory, which is considered as a mapping from times t to positions p in geographic space, $T: t \rightarrow p$. The trajectory T trades times for positions of the moving object. In spatio-temporal domain, the trajectory T is the set of positions $p(t)$ of the moving object, $p(t) \equiv (x, y, t) \in T$. Each point on the trajectory is determined by its coordinates (x, y, t). In location domain, the spatial trajectory T_s is the set of positions $p = (x, y)$ where the moving object passes. Each point on the spatial trajectory is determined by its coordinates (x, y).

Technically, the movement data of moving objects are recorded separately based on time or location [6]. In the method of time-based recording, the positions of objects are recorded at the regularly spaced time moments or at the special time moments. Sampled at time moments t_i, where $i = 0,1,2,..$, these positions make up a sequence of the pairs (x_i, y_i) in location domain or a sequence of the tuples (x_i, y_i, t_i) in spatio-temporal domain. In the method of location-based recording, the time moments are recorded when the objects reach the indicated positions. In spatio-temporal domain of a movement, each sampled time moment matches with a position of the object to form a tuple (t_i, x_i, y_i). Because of $(t_i, x_i, y_i) \equiv (x_i, y_i, t_i)$, the positions sampled by the location-based recording may convert to time-based recording through the trajectory of the movement. The curve time-ordered connecting the points (x_i, y_i) in location domain quite matching the space trajectory is considered the digitized space trajectory or the space trajectory of the moving object. Similarly, the curve time-ordered connecting the points (x_i, y_i, t_i) in spatio-temporal domain quite matching the trajectory is considered the digitized trajectory or the trajectory of the moving object. Shorter is the sampling period, more equivalent are the digitized trajectories and the trajectories.

The inclusion of time in spatial data to represent the movement of objects in 3-D domain of the Cartesian coordinate system forms a space-time cube [9],[10],[13],[14],[17]. In a space-time cube, two of three axes constitute the space plane indicating the positions (x_i, y_i) of moving objects and another indicates the time t_i [10],[12],[13]. The positions of moving objects on temporal maps are indicated by their spatial positions over time. Each space-time position of a moving object is indicated on a temporal map by a tuple (x_i, y_i, t_i). The curve time-ordered connecting the space-time positions is the digitized trajectory of the moving object.

As an application, we consider on bus maps that bus routes are symbolized by colorful curves connecting the departure station to the arrival station, and passing several bus stops. Each bus route is coded with a number and a color. The maps do not provide with the information concerning the time of departure, arrival, and visiting bus stops.

In reality, there are several buses moving on a route everyday. Buses of the same route depart from the departure station of the route at different time moments and take the same time interval to reach the arrival station. The buses also visit the same bus stops on the route.

For the study of a bus movement, the space-time points are recorded with the location-based method. The departure time of a bus is recorded when it departs from the departure station. The arrival time of a bus is recorded when it reaches the arrival station. The stop times of a bus are recorded when it visits the bus stops.

On a bus route, several buses depart from the same departure station at different moments. A bus trip refers to the information of position and time of a bus from its departure station to arrival station. A bus trip is indicated by the position of the departure station and the departure time, the position of the arrival station and the arrival time, and the position of bus stops and the stop times. A bus trip can be determined by only its route and the departure time because buses take similar time intervals to move from the departure station to the arrival. In a day, there are many bus trips on a bus route and each bus trip is identified with departure-time-ordered numbering. The trip identifier is an integer indicating the order of a bus trip of a route in a day. On a route, each trip identifier corresponds with a departure time. Accordingly, the data of a bus trip include the trip identifier , the departure station and departure time, the bus stops and stop times, and the arrival station and arrival time.

The trip time refers to the duration which a bus takes to create its route. It is the time interval from the departure time to the arrival time of a bus moving on its route. The trip time of a bus trip also includes the stop times of the bus at bus stops. According to the regulations by bus managers, the trip times of buses on the same route are similar, approximately.

III. REPRESENTING BUS TRIPS ON TEMPORAL MAP

In a space-time cube, a bus is considered as a moving object. The movement of buses is specified by their routes and trips. Bus routes are shown on traditional maps with a code for each route. On temporal maps, a bus route is represented by a space trajectory on the location plane. It provides with the information of the positions of the departure station, the arrival station, and the bus stops. A bus trip is depicted as a temporal bus route, i.e. a bus trip is a bus route integrated time. On temporal maps, bus trips are represented by trajectories, which show the positions of departure stations, arrival stations, and bus stops along with the times of departures, arrivals, and stops (figure 1).

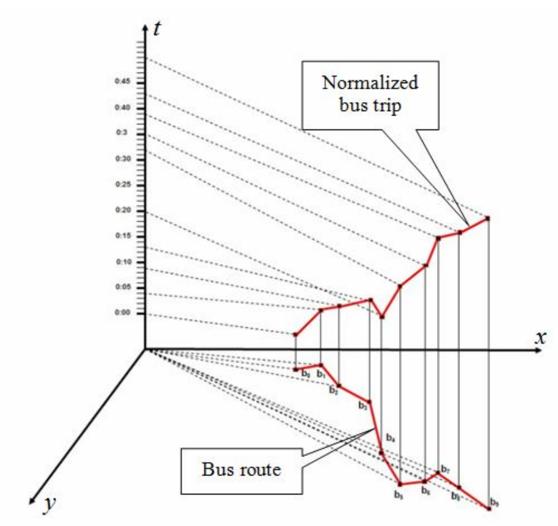

Figure 1. Bus route and bus trip in a space-time cube

Everyday, there are several buses traveling on a route. The representation of massive data of bus trips is a challenge to the design of a travel with bus based on visual method. We consider that the trip times of all bus trips are similar and their average velocity on the same route is equivalent. Hence, the trajectories of buses on a route are similar in shape.

We apply the method of data abstraction to represent bus trips [1],[2]. The shape-based abstraction of bus trips aggregates all bus trips of a route in a bus trip, called the normalized bus trip. Every bus trip is inferred from the normalized bus trip and its trip identifier. On a temporal map, displacing the normalized bus trip along the time axis or displacing the time axis along itself, passenger obtains a bus trip of the identifier corresponding with the departure time on the time axis.

Each bus trip of a route is represented by the tuple <trip identifier, the departure time> and the tuples of the normalized trips <the identifiers of positions on the route, the coordinates (x, y) of the positions, the times t when the bus visits the positions>, where:

- The identifiers of positions of the route consist of the identifiers of the departure station, the arrival station, and bus stops.
- The coordinates (x, y) of the positions indicate the positions of the departure station, the arrival station, and the bus stops.
- The times t indicate the moments when the bus departs from the departure station, reaches the arrival station, and visits the bus stops.

IV. FINDING AN APPROPRIATE BUS TRAVEL

In order to travel from a place to another, a passenger may apply a part bus trip or several part bus trips of different routes. By convention, passengers prefer to get a bus travel of the shortest path connecting their departure with arrival place. In some cases, passengers can not find any bus trip connecting directly the departure bus stop to the arrival. Accordingly, they must connect the departure stop to the arrival with two or more trips of different routes. Sometimes, some local tourists like to visit around by connecting many bus trips.

In several cities, passengers may travel from a place to another with bus. Much software enables them to find a travel with a bus trip or a combination of two or more bus trips. However, the tools do not support the passengers' selection.

In this article, we apply the method of data visualization to enable passengers to select bus trips appropriate for their diversified individual needs. We study that some people like to select a path of short time to travel, some tourists like to select a longer path for their sightseeing, and most people do not like to be taken a long time to wait for the next bus at a crossing stop of two different routes.

The visualization of spatio-temporal data enables passengers to find by themselves the bus trips appropriate for their individual demands. The visualization method represents the spatio-temporal data of bus trips on temporal maps. The tools of visualization techniques enable passengers to find one or some bus trips connecting their departure place to their arrival.

Viewing a temporal map displaying visually movement data from the database of buses, passengers may choose flexibly the bus trips to travel from a place to another according to the following process:

- Step 1. *To mark the arrival location*: Mark the point of the arrival location on the location plane based on its coordinates or the passenger's estimation.
- Step 2. *To mark the departure location*: Mark the point of the departure location on the location plane based on its coordinates or the passenger's estimation.
- Step 3. *To select the arrival bus stop:* Displace the cursor to the arrival location. When the arrival location is indicated, all bus stops near the location are shown. Displace the cursor to a bus stop, the bus routes visiting this stop are displayed on the location plane. If there are one or more routes reaching near by the departure location, mark out this stop for the arrival bus stop. Hide other stops. Continue the step 4. If there is no route reaching near by the departure location, repeat the step 3 to indicate another stop until a route reaching a stop near the departure location is available. Mark out the stop for the arrival bus stop. Hide other stops. Continue the step 4. If there is still no route reaching a stop near the departure location, mark out a stop for the arrival bus stop, estimably. Hide other stops. Skip to the step 5.
- Step 4. *To select the departure stop and the bus travel*: Displace the cursor to the arrival bus stop. Select the route visiting a bus stop near the departure location. Hide other routes. Select the departure stop. Show the normalized bus trip of the route. Displace the normalized trip along the time axis to uncover the most appropriate bus trip. Mark out this trip for the bus travel from the departure location to the arrival (figure 2). The 1-trip bus travel shows the departure stop and time, the arrival stop and time. Skip to the step 16.

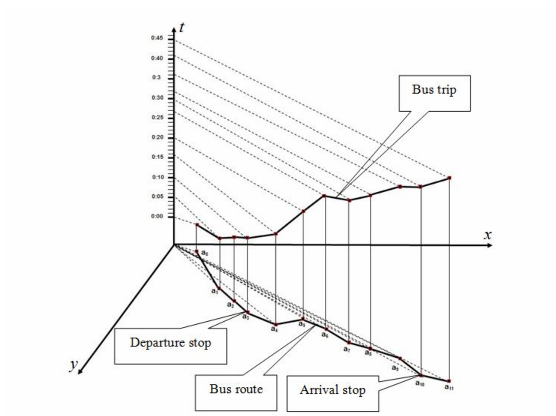

Figure 2. 1-trip bus travel from the departure stop to the arrival

- Step 5. *To select the arrival bus route*: Displace the cursor to the arrival bus stop, all bus routes visiting the stop are shown. Mark out a route for the arrival route, estimably. Hide other routes.
- Step 6. *To select the departure bus stop*: Displace the cursor to the departure location. When the departure location is indicated, all bus stops near the location are shown. Mark out a stop for the departure stop, estimably. Hide other stops.
- Step 7. *To select the departure bus route*: Displace the cursor to the departure stop, the bus routes visiting this stop are displayed on the location plane. If there are one or more routes crossing the arrival route at a common stop, mark out a route crossing the arrival route for the departure route. Hide other routes. Go to the step 8. If it is impossible to find any route crossing the arrival route, repeat the step 6 to indicate another departure bus stop until a route crossing the arrival route is available. Mark out the route for the departure bus route. Hide other routes. Go to the step 8. If it is still impossible to find any route crossing the arrival route, go back the step 3 to indicate another arrival bus stop. If it is still impossible to find out any pair of routes crossing each other in all routes visiting stops near the arrival station and all routes visiting stops near the departure station, mark out a route visiting the stop near the arrival station for the arrival route and some route visiting the stop near the departure station for the departure route, estimably. Skip to the step 11.
- Step 8. *To select the arrival bus trip*: Displace the cursor to the arrival bus route to show the normalized bus trip. Displace the normalized bus trip along the time axis to mark out the trip appropriate for the expected arrival time for the arrival trip.
- Step 9. *To select the departure bus trip*: Displace the cursor to the departure bus route to show the normalized bus trip. Displace the normalized bus trip along the time axis to find out the trip crossing the arrival trip at the common stop. Mark out this trip for the departure bus trip.
- Step 10. *To build the bus travel*: Connect the arrival bus trip with the departure bus trip for the bus travel (figure 3). The 2-trip bus travel shows the departure stop and time, the arrival stop and time, and the crossing bus stop and time. Skip to the step 16.

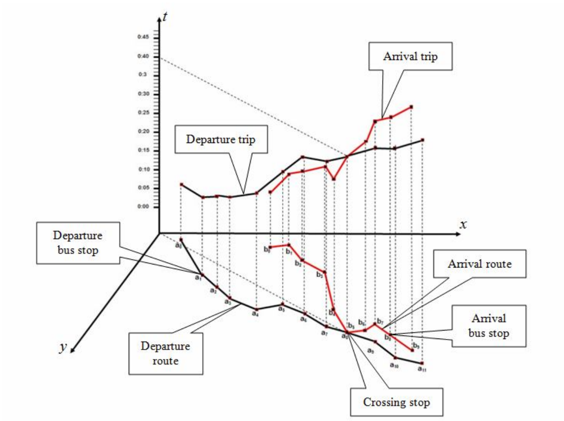

Figure 3. 2-trip bus travel from the departure stop to the arrival

- Step 11. *To select the near-departure bus stop*: Mark out another bus stop on the departure bus route, quite near the departure location, for the near-departure bus stop.
- Step 12. *To select the near-departure bus route*: Displace the cursor to the near-departure bus stop, the bus routes visiting this stop are displayed on the space plane. If there are one or more routes crossing the arrival route at a common stop, mark out a route for the near-departure bus route and go to the step 13. Hide other stops and routes. If else, go back the step 11 to select another near-departure bus stop.
- Step 13. *To select the arrival bus trip and the near-departure bus trip*: Displace the cursor to the arrival route to show the arrival normalized bus trip. Displace the normalized trip along the time axis to find out the trip appropriate for the passenger's demand. Mark out the trip for the arrival bus trip. Displace the cursor to the near-departure bus route to show its normalized trip. Displace the normalized trip along the time axis to find out a trip crossing the arrival bus trip at the common stop. Mark out this trip for the near-departure bus trip.
- Step 14. *To select the departure bus trip*: Displace the normalized trip of the departure bus route to find out the cross between the departure bus trip and the near-departure bus trip. Mark out the trip for the departure bus trip.
- Step 15. *To build the bus travel*: Combine the departure trip, the near-departure trip and the arrival trip to form the bus travel. The 3-trip bus travel shows the departure station and time, the arrival station and time, and the two crossing bus stops and times. Go to the step 16.
- Step 16. *To end the process.*

The process presents three modes planning a bus travel. The 1-trip mode from the step 1 to step 4 provides passengers with the travel taking 1 bus trip, without connecting trips. The 2-trip mode from the step 1 to step 10 provides passengers with the travel taking 2 bus trips connecting at one bus stop. The 3-trip mode from the step 1 to step 15 provides passengers with the travel taking 3 bus trips connecting at two bus stops. The selection of trip modes depends on the passenger's needs and the capacity constraint of the bus system.

V. CONCLUSION

The paper proposed to use 3-dimensional Cartesian coordinate systems to represent moving objects as temporal maps. The approach depicts completely the data of positions changing over time. With visualization tools on computer, temporal maps enable humans to analyze data according to their distinct needs. The illustration of the idea is an application of a temporal map for finding reasonable bus paths.

In reality, the method showing bus routes on traditional maps is difficult for passengers to design a bus travel because of the lack of the time information. Accordingly, it is necessary to include time in bus routes to form bus trips. Under the view of space and time, buses are considered as moving objects, the bus routes as space trajectories, and the bus trips as trajectories. All these data are represented on a temporal map.

Because there are a lot of bus trips on a route everyday, their massive data are shown on a temporal map. The shape-based abstraction of bus trip data aggregates all bus trips in the normalized bus trip of a route. Consequently, all bus trips of a route are inferred from the normalized bus trip.

Viewing bus routes and trips on temporal maps, passengers may design bus travels from a place to another for their diversified individual needs. The complexity of the problem finding bus paths depends on the capacity of the network of bus routes responding the passengers' demands. The process designing a bus travel consists of three cases, 1-trip bus travel, 2-trip bus travel, and 3-trip bus travel. Each case offers passengers the departure bus stop and time, the arrival bus stop and time, and crossing bus stops and times.

The soft tools have been implemented experimentally at the Information System Laboratory of the University of Information Technology. They demonstrate that the visual representation of bus networks in space and time enable passengers to design flexibly bus travels appropriate for their diversified individual needs.

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