Temporal Distance Map: A Warped Isochrone Map Depicting Accurate Travel Times

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Abstract - **The presented Temporal Distance Mapping tool creates a visual representation in which distance on the map represents travel time rather than physical distance. In the age of routing applications, most people are more concerned with the time it will take to reach a destination rather than its physical distance. A river, mountain, or even traffic can make nearby points on a map seem distant by comparison, while highways and fast public transportation lines can seem to bring distant physical locations together. Utilizing travel data, we can morph the shape of any mapped region to accurately depict travel time. First, a traditional static image map for a specific location of interest is overlaid with a grid of points. The travel time from the center point to each grid point is calculated. Each grid point is then shifted radially toward or away from the center point depending on calculated travel time. The rest of the map pixels are then shifted according to the new gridpoint locations using an affine transformation. In this way, the original map is warped to represent travel time relative to the center point. Although two destinations on a traditional map may have the same physical distance, the travel time may be orders of magnitude different due to barriers or access to public transportation. This map better represents access to the surrounding area, and also provides a compelling visual representation to understand the local community in the context of what matters most to them - their time.**

Keywords - euclidean; temporal distance; isochrone; metadata.

I. INTRODUCTION

Travel time is one of the main concerns people have when viewing a map, however, travel time is poorly represented on most physical maps. Transportation systems bring distant physical points in closer proximity in terms of time, while physical barriers can dramatically impact the travel time between closely located points on a map [1]. When faced with the prospect of visualizing travel time, most turn to the isochrone map [2][3]. An isochrone map uses contour lines to represent equivalent travel time from a single location [4]. The isochrone map is used in geographic [5][6], clinical [7], and astrophysical research [8]. Isochrone maps are widely used in research, however, they are also limited in public use [9]. Isochrone maps are not a common tool in the general populace given the complexity to reach them with overlaid contours. It would be more beneficial to have a map representation which directly depicts the travel time for the everyday user.

In the age of vehicle routing applications [10], drivers are much more interested in how long it takes to reach a location rather than the physical distance shown on most maps. Isochrones contours display these “temporal distances” but are only an overlay on a representation that is less directly relevant to a person’s experience of the world around them. The time it takes a person to reach a destination is far more important than the physical distance, particularly in cities and would best be represented directly in the underlying representation, rather than as an overlay on a less relevant depiction of physical distance.

We created a tool that uses the information present in a polar isochronic map [11] and morphs the static image to present travel time as the distances. Web mapping services [12] currently overlay alternate routes and travel time information onto a traditional map representation. This approach only provides information for travel time between two locations. A user may want to have a better understanding of their surrounding area to consider alternate destinations. Using current commercial mapping tools, if someone was interested in comparing travel times within an area, they would need to calculate the travel distance between every single point of interest [13]. We offer a tool that expedites this process while also offering visual clarity that will better allow a comparison of travel times at a glance.

The remainder of this paper is organized as follows: Section II explores our method for warping the images based on calculated travel time. Section III demonstrates application of the temporal distance map tool for a variety of locations. Finally, the paper concludes with Section IV.

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All information and documentation relevant to the research can be found on the github repository [14].

II. METHODS

As an overview, the method for generating the warped map begins with the creation of an overlaid and spaced rectangular grid of points. The travel time to the grid points is calculated, and the grid points are moved radially in proportion to travel time. The pixels of the original map are then transformed based on the new locations of the grid points. We will now step through the process in more detail.

Figure 1. Plot of 961 euclidean points overlaid the static image of the location. Arrows and times represent the travel time between each corresponding geographic coordinate and the center

To begin, we used Bing Maps API [14] calls to get a standard static image of the location. Then, on that image, we overlaid a mesh of 961 points. The corresponding latitude and longitude were mapped to a normalized coordinate system ranging from 0 to 1 along each dimension (Figure 1). For instance, (0.5, 0.5) is the center point on the map, and if the image depicted a latitude range of +56 to +60 (or 56 N to 60 N) and a longitude range of +40 to +44 (or 40 E to 44 E) then the central point would be the middle of each range or the geographic coordinate (58 N, 42 E).

Utilizing the Bing Maps Distance Matrix, we were able to efficiently find the travel time between every geographic coordinate and the central location (Figure 1). Then, we proceeded to remap the grid coordinates based on the calculated travel time. First, we calculated an estimate of one minute of travel time in the normalized coordinates by dividing the euclidean distance of the temporally furthest point on the map by its travel time. Using this estimate, we then calculated the new distance the grid point should be from the center. We maintained the same angle of the grid point relative to the center. This information provided a radius and angle from the center point for the new transformed coordinate. Effectively this shifted each grid point radially from the center point depending on calculated travel time.

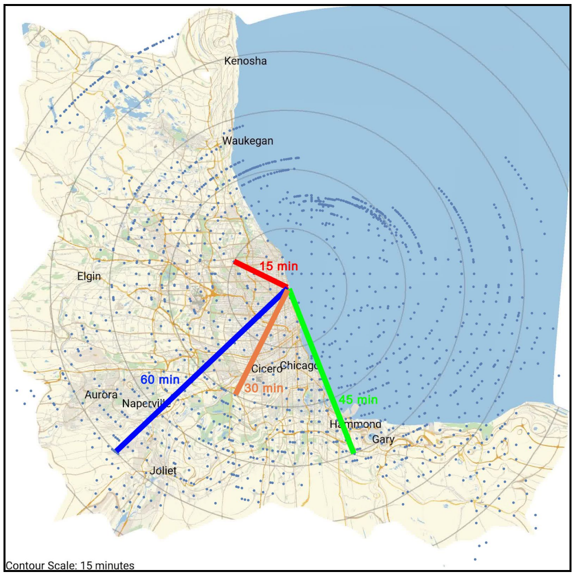

Figure 2. The plot of 961 euclidean points post-transformation based on travel time. The points now form concentric circles around the center and the travel time is now properly represented and uniform around the image.

Each grid point now has original coordinates and transformed coordinates; however, they were spaced out significantly given the computational resources necessary to calculate travel time between all grid points and the center point. In order to visualize the new coordinates, the pixel coordinates of the original map also had to be transformed. Each pixel of the original image was converted to normalized coordinates, and an affine transformation based on the surrounding grid points was performed to transform the original, normalized pixel coordinates into the new map coordinates (Figure 2).

Additionally, this coordinate transform was also used to create an animation to more readily observe the effects of warping due to travel time. The old and new coordinates were then linearly interpolated from time t=0 at the original coordinates to t=1 for the new transformed coordinates.

III. RESULTS AND DISCUSSION

In this section, we display several applications of the Temporal Distance Map to observe and discuss the effect. The demonstrations are for Pennsport, Pennsylvania; Miami, Florida; and Kansas City, Kansas. In these map transformations, notable changes can be seen due to distinct geographic features and infrastructure.

A. Transformation of Pennsport and the Delaware River

The Delaware River acts as a natural boundary between Pennsylvania and New Jersey. Pennsport, a city on the edge of the river with close proximity to both the Walt Whitman and Benjamin Franklin Bridges, is depicted in Figures 3 and 4.

Figure 3. Static image of Pennsport from the Bing Maps API.

Figure 4. Morphed version of Pennsport. The location is transformed based upon travel time from the central(red) point.

After transforming the image, the area immediately around Pennsport begins to stretch relative to other areas outside the first 15 minute contour. This is due to the availability of ways to cross the river. Someone situated in the heart of Pennsport needs to drive either North or South to one of the bridges in order to reach New Jersey on the opposite side; therefore, increasing the relative travel time. Notice how once the river is crossed (generally around the 15 minute contour) other areas begin to squeeze together due to the availability of roads once they cross the bridge.

B. Transformation of Miami Bay, Key Biscayne, and the Everglades/Francis Wildlife Management Area

The Eastern Coast of Miami has a variety of islands, harbours, and keys. Key Biscayne is located to the South-East of Downtown Miami and is used as the center in Figure 5. Notably, Miami travel is more efficient along the coast given the geographic barriers to travel. Given these geographic barriers, the North-West and South-East corners of the map both stretch due to how long travel takes compared to travel along the coastal highways. The North-West corner is faced with a journey across the management area of both the Everglades National Park and the Big Cypress National Preserve, both of which have limited vehicle infrastructure. The South-East corner is blocked by Key Biscayne, any traveler that wants to reach that corner of the map will need to choose to drive around Key Biscayne on a boat or drive along Key Biscayne in its entirety, increasing travel time when compared to other regions on the map. There is, notably, a direct path through a gap in Key Biscayne that would allow a boater to travel to the South-East corner uninterrupted, thus resulting in the large uninterrupted zone of generally constant contour rings.

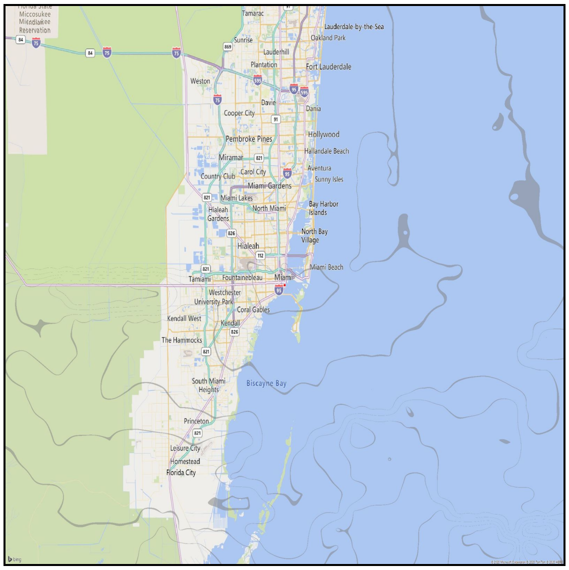

Figure 5. Static image of Miami, Florida from the Bing Maps API.

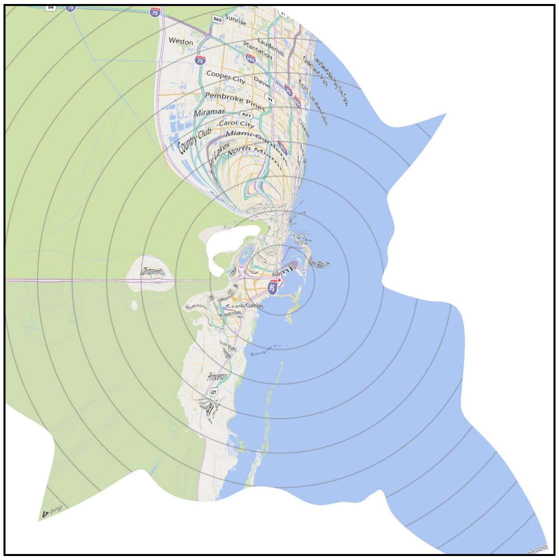

Figure 6. Morphed version of Miami, notice the warping of the ocean surrounding the Key Biscayne.

Notably, the acceptable methods of travel would alter the representations, so by altering the route options available (e.g., allowing use of tolls, ferries, etc.) the resulting representation would change.

C. Transformation of Kansas City and Road Infrastructure

Kansas City was chosen due to its transportation infrastructure. The city is completely covered by infrastructure, like highways and public transport systems, all of which influence the transformation depicted in Figure 5.

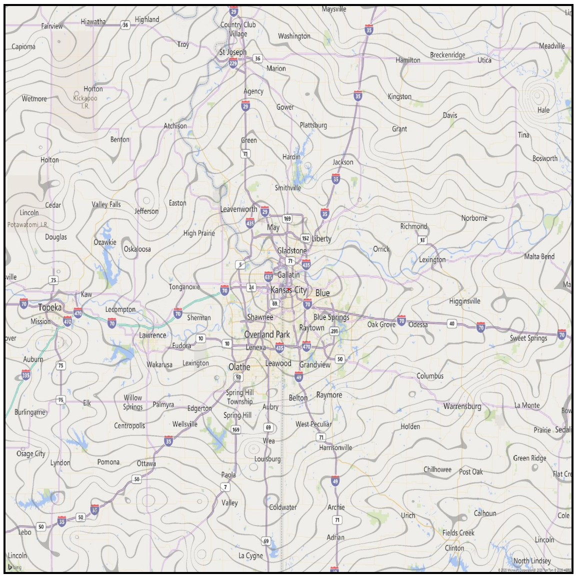

Figure 7. Static image of Kansas City, Kansas from the Bing Maps API.

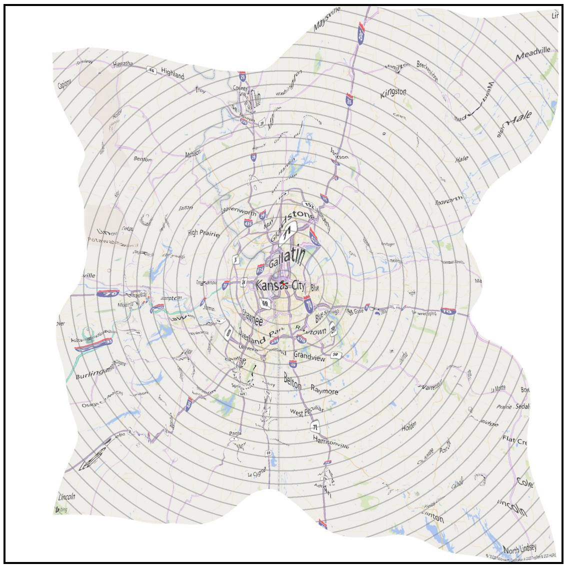

Figure 8. Morphed version of Kansas City, notice how the abundance of highways morph the region.

For the transformation in Figure 7, the contours reflect 5 minute intervals instead of the typical 15 minutes in other figures. This way, it is readily apparent how highways begin to shift the image of the map. First, highways allow a driver to cover a large distance in a relatively short period of time. Thus, the warped image contracts along highways, a pattern that is visible in any of the projections featuring a major roadway Additionally, while Kansas City is known for its widespread road infrastructure, the top right corner of the map is less connected with the city center. Therefore, during the transformation the map contracts everywhere except the top right corner, which is unreachable along a highway.

These examples represent a cross-section of geographic impacts on travel time. The river of Pennsport, the ocean and everglades of Miami, and the road infrastructure of Kansas City all warp the map in ways that are consistent with a local understanding of travel time, but depict that information visually in a way that is more direct to a casual observer.

IV. CONCLUSION AND FUTURE WORK

This project was prompted by a desire to visualize access to nearby locations in a way that is more relevant to personal experience - travel time rather than physical distance. We created an application that allows a user to enter a geographic location and returns a transformed map of the region in a way that depicts travel time by distance on the map.

The transformations more directly represent the impact of geographic and infrastructure features on a person’s experience navigating the local area. This new way of representing distance can be used to inform personal travel decisions by providing a more direct comparison between travel time and distance.

The new projection would be most useful for travelling in areas with unique geography that is unfamiliar to the traveller. By being able to readily compare alternate destinations relative to one's current location, travel time can be more intuitively used in selecting among the alternate destinations. The implementation uses readily available map API information, and a series of linear transformations and interpolations allow for commercial scalability.

There are a number of further advances possible. In this approach, locations were shifted radially from the center, however allowing for angular movement of points may have led to fewer artifacts in the warped representation. Additionally, this approach identified a center point, however, it is conceivable to create a representation without an arbitrary center. By observing travels times between all pairs of grid points, and creating a networked representation of grid points with connections weighted by travel time in a force-directed graph layout. This would create a representation stretching the image in slow-moving areas and compressing along fast corridors, but without identifying a single central point. This would enable a representation for an entire region that could be shared or marketed for everyone in the region.

The Temporal Distance Map presented here provides a new way to visualize travel time. Isochrone maps provide similar information, but this tool takes the concept a step further by morphing the underlying representation to make the information present in isochrone contours more directly accessible. This way the intuitive understanding of travel time for surrounding locations that a native resident feels is more accessible to people new to an area and more directly represents information of importance to them - time rather than distance.

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