Extracting Important Routes from Illustration Maps Using Kernel Density Estimation

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Abstract. Illustration maps often direct our visual attention to the specific route with geographic symbols and annotation labels associated with important landmarks. This inspires us to evaluate the quality of such maps by analyzing the spatial distribution of visual attention over the map domain. In this paper, we introduce kernel density estimation in order to identify important routes that are implicitly designated by the map designers. Our algorithm begins by composing the density field as a combination of Gaussian kernels centered on the landmarks. The algorithm then allows us to extract an important route on the map as the trajectory of a ball running along the valley of the density field. We conducted a user study where we compared the routes reconstructed from the sequence of landmarks specified by the participants and their originally intended routes, and report some insight into possible aesthetic criteria in illustrating such maps.

Keywords: Map analysis, route estimation, kernel density field

1 Introduction

Nowadays, commercially available web map services, such as Google Maps, provide us with an effective means of exploring geographic features in our daily life. Most of these services produce geographic maps that are precise enough to make detailed travel plans and simulate virtual travels. On the other hand, hand-drawn illustrated maps successfully schematize geographic maps to emphasize important routes, and thus users can easily recognize such routes on the map and further memorize their geographic positions for their future travels.

However, little has been done for quantitatively evaluate the quality of such hand-drawn maps primarily because it strongly depends on the design intention of professional cartographers. For example, Fig. 1 shows a representative map drawn by Hatsusaburo Yoshida, who is a famous pioneer of bird's eye views maps in Japan. In practice, this map successfully directs visual attention from map users on the railway line running from top-right to bottom-left, by highlighting the route in red and placing geographic symbols and annotation labels around the

Fig. 1. Nanbu Tetsudo Zue illustrated by Hatsusaburo Yoshida in 1926.

it. This artwork has commonly been recognized as high quality while formulating such aesthetic quality of hand-drawn maps still remains to be tackled from a technical viewpoint.

In this paper, we introduce *kernel density estimation* as a tool for evaluating the saliency of such important routes implicitly designated by map designers. In our approach, the density field over the map domain is composed as a combination of Gaussian kernels centered at the landmarks, and corresponds to the distribution of visual attention on the geographic features such as landmarks, roads, and railways. We can also compute important routes over the map domain by tracking the trajectory of a ball running along the valley of the density field.

The remainder of this paper is structured as follows: Sect. 2 conducts a survey on relevant conventional techniques. Sect. 3 describes our approach to computing the density field from hand-drawn illustrated maps. After having presented several experimental results in Sect. 4, we conclude this paper and refer to future work in Sect. 5.

2 Related Work

Although it is important to provide precise geographic information on the maps as done in contemporary geographic information systems (GISs), schematic design of map contents has recently attracted much attention from map users due to its simple and clear representation of geographic information. Hatsusaburo Yoshida is one of the pioneering cartographer in the schematic map design, and many of his hand-drawn maps were intensively studied by researchers in cartography. A typical study was presented by Hotta [3], where he classified Yoshida's

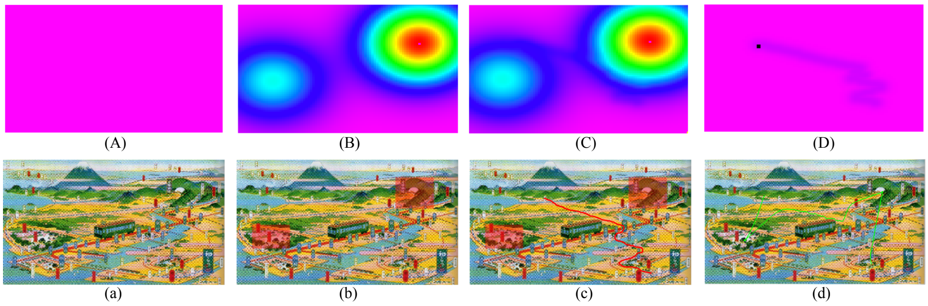

Fig. 2. A system overview of the present algorithm.

maps into different scene composition styles. Also, Yoshida himself left his own design process in a document of map design [12]. Another important direction is to directly distort map images in an aesthetic fashion. Dougenik et al. [1] proposed an algorithm for transforming country shapes while retaining topology of the entire maps, and further sophistication was done by House and Kocmoud [4]. Quite recently, the schematization of map contents has been further pursuited in more elegant fashion, including navigation tool based on hand-drawn maps [8], annotated railway maps [11, 10], and 3D route maps [2].

As mentioned before, the objective of this study is to identify important routes implicitly specified by the map designers. Only little has been done on this study while route selection estimation was conducted for car navigation systems [6] and the mobile devices were tracked in a traffic system for inferring typical route choices [9]. In this paper, we employ kernel density estimation where the density field represents aggregated area in the distribution of visual attention over the map. Kernel density estimation has also been employed for visualizing dynamic distribution data [7] and bundling network edges [5].

3 Extracting Routes from Density Fields

This section describes how to create our density field as a combination of Gaussian kernels associated with landmarks and along the specified route. We begin with an overview of our system and then move on the details of the proposed algorithm.

Fig. 2 gives an overview of our prototype system. Firstly, we generate a constant density field (Fig. 2(A)) over the input map (Fig. 2(a)). Secondly, we ask map users to provide landmarks such as geographic symbols and annotation labels in which they are interested. In practice, We allow users to design their kernel density field by themselves by selecting interesting features on the map (Fig. 2(b)). This can be done manually, and the density field can be composed of Gaussian kernels centered at the specified landmarks as shown in Fig. 2(B). More details of the algorithm will be described in Sect. 3.1. In addition, all the roads on the map are also incorporated (Fig. 2(c)), in the same way, into the density field so that we can further accommodates Gaussian kernels along the roads (Fig. 2(C)). Finally, the users are also expected to specify the initial position of the route. As mentioned previously, the trajectory of a ball running on the density field indicates the important route by passing through landmarks one by one. In our formulation, every time when the ball passes through a landmark, we exclude the kernel associated with the landmark and then update corresponding kernel density field. This procedure continues until all the landmarks are visited (Fig. 2(D)), and the final trajectory is drawn on the map as shown in Fig. 2(d).

3.1 Kernel Density Estimation over the Map Domain

Suppose we have a density field $\mathcal{M} \subseteq \mathbb{R}^2$, and the domain $\mathcal{M}$ coincides with the entire map domain. Let us denote a sample point on the hand-drawn illustrated map by a 2D vector $\boldsymbol{x} \in \mathcal{M}$. In our formulation, a density value $\rho(\boldsymbol{x})$ at $\boldsymbol{x} \in \mathcal{M}$ is defined as a sum of the two density functions as:

$$\rho(\boldsymbol{x}) = \rho_{\mathcal{L}}(\boldsymbol{x}) + \rho_{\mathcal{R}}(\boldsymbol{x}). \tag{1}$$

Assume that user specify the position of the i-th landmark as $\boldsymbol{y}_i$, and its size by manually outlining the landmark area as s_i. Note that the weight value s_i indicates the *degree of attraction* of the landmark. The first density function $\rho_{\mathcal{L}}(\boldsymbol{x})$ in terms of landmarks is defined as follows:

$$\rho_{\mathcal{L}}(\boldsymbol{x}) = \frac{\sum_{i=1}^{N} s_i K(\frac{|\boldsymbol{x} - \boldsymbol{y}_i|}{h})}{\sum_{i=1}^{N} s_i}, \tag{2}$$

where K represents the kernel function and h is a bandwidth given by the users for smoothing the distribution. Here, we employ the Gaussian function for K.

As for the computation of the road density, we first define M roads on the hand-drawn illustrated map, where roads $\mathcal{R}_1, \mathcal{R}_2, \ldots, \mathcal{R}_M$ are represented as sequences of n points as:

$$\mathcal{R}_i = \langle \boldsymbol{z}_{i,1}, \boldsymbol{z}_{i,2}, \ldots, \boldsymbol{z}_{i,n_i} \rangle \quad \text{where} \quad \boldsymbol{z}_{i,j} \in \mathbb{R}^2. \tag{3}$$

Moreover, we define $\xi_i(\boldsymbol{x}) \in \mathbb{R}^+$ as the minimum distance between $\boldsymbol{x}$ and all the points on the segments of $\mathcal{R}_i$. Thus, the second density function $\rho_{\mathcal{R}}(\boldsymbol{x})$ in terms of roads is defined as follows:

$$\rho_{\mathcal{R}}(\boldsymbol{x}) = \alpha K(\frac{1}{h} \min_{i \in \{1,\ldots,M\}} (\xi_i(\boldsymbol{x}))), \tag{4}$$

where α indicates the relative weight of roads with respect to that of landmarks and is set to 0.05 empirically.

We place a ball at the specified starting point so that it will illuminate the important route as its trajectory when running along the valley of the density field $\rho(\boldsymbol{x})$. The trajectory of the ball can be obtained by calculating the following differential equation:

$$\frac{d\boldsymbol{x}}{dt} = h\frac{\nabla\rho}{||\nabla\rho||}. \tag{5}$$

Moreover, once the ball passes through some landmark, we remove the kernel function centered at the landmark and update the density function $\rho(\boldsymbol{x})$, until all the landmarks will be excluded from the definition of $\rho(\boldsymbol{x})$.

4 Results

Our prototype system has been implemented on a laptop PC with 1.7GHz Intel Core i7 CPU and 8GB RAM, and the source code was written in C++ using OpenGL for rendering. We also incorporate an interface for assigning user specified landmarks and roads on the map. As a result, the system shows the extracted route by simulating a running ball on the estimated kernel density field. To demonstate the usability of our prototype system, we compare the extraced route manually generated by the participants and the one generated by our prototype system. Four participaints are involved in this user study, including three males and one female between the age of 23 and 28, and none of them are experts in cartography.

In the study, we asked each aprticipant to explore the hand-drawn illustrated map, and specify his intended route as a first step. Based on this manually specied route, the first map for our user study is created by drawing them on the map. The second one is generating by our prototype system through inputing a sequence of landmarks and their corresponding degree of arrtaction proposed by the participant. Our study aims at comparing these two map and try to understanding the underlying strucuture of the hand-drawn illustrated maps. Actually, the input of the degree of attration s_i in Sect. 3 is estimated by the size of landmarks in the photogtaph taken by the participant, and the center point $\mathbf{y}_i$ is also manually defined from center of the landmarks in the photograph.

Two hand-drawn maps are involved in out user study. The first one is prepared for hiking in a gorge named Sunmata-kyo as shown in Fig. 3. The second one is an antique hand-drawn map for the sightseeing in the whole of Kanto region (see Fig. 4). The knowledge we retrieved from our experiments is that our order of landmarks on the extracted route maybe completely different from that of the users' originally intended one.

5 Conclusion and Future Work

This paper has presented an approach to extracting important routes specified by the map designers using kernel density estimation, which inspires us to evaluate the quality of hand-drawn illustrated maps by analyzing the spatial distribution of visual attention over the map domain. Moreover, a user study is also conducted to report some insight of the possible aesthetic criteria by comparing the routes reconstructed from the sequence of landmarks specified by the participants and their originally intended routes. Our future extensions include the mathematical formulation of the extracted aesthetic criteria from the kernel density field so as to automatically generate the hand-drawn maps based on the formulation.

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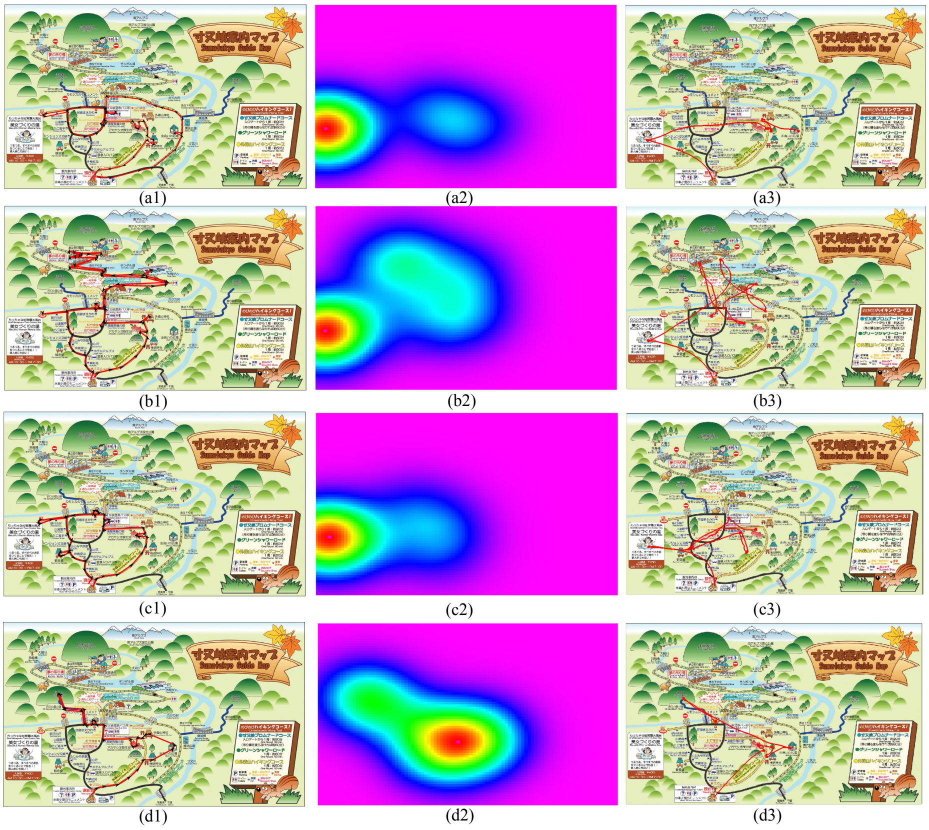

Fig. 3. The resultant images about the hand-drawn map for hiking, that is Sunmatakyo Irasuto Map by Kawanehoncho Town in 2005 (coutesy of Kawanehoncho Town Hall, Japan). (a1)(b1)(c1)(d1) The subjects designed the map routes. The routes are colored as red. (a2)(b2)(c2)(d2) According as the landmarks the users' selected, the kernel density fields were calculated. (a3)(b3)(c3)(d3) From each kernel density field, important routes were extracted, where black dotted lines mean original trajectory and red lines mean extracted routes by force the trajectory move along the nearest road.

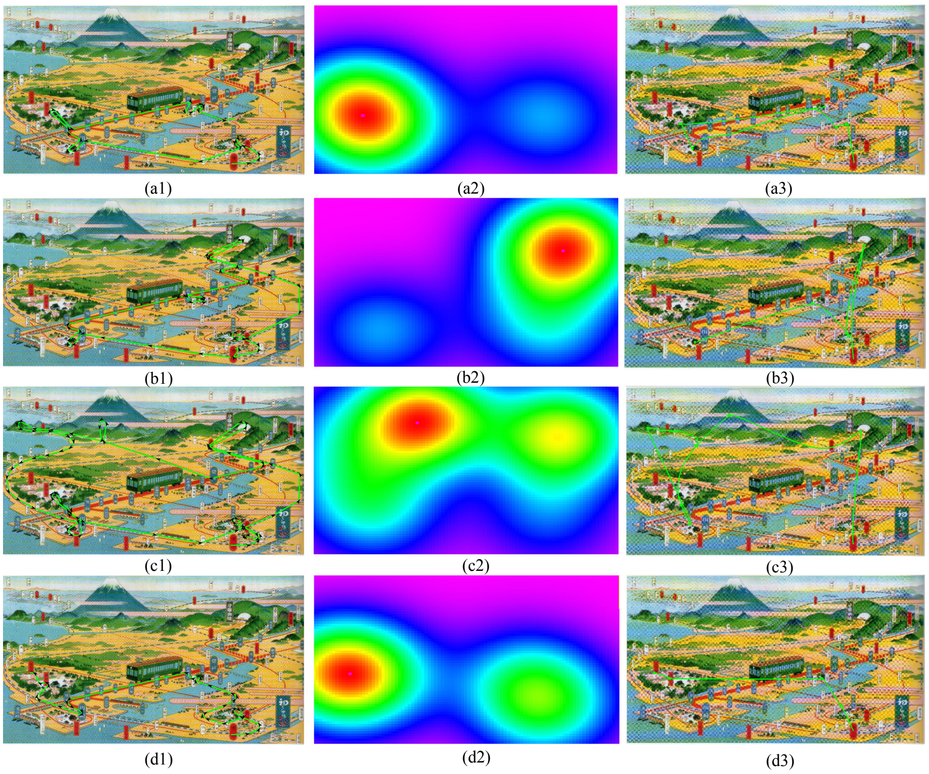

Fig. 4. The resultant images about the antique hand-drawn map, that is Nanbu Tetsudo Zue. (a1)(b1)(c1)(d1) The subjects designed the map routes. The routes are colored as green. (a2)(b2)(c2)(d2) The kernel density fields. (a3)(b3)(c3)(d3) Extracted important routes.