Characterizing the Swarm Movement on Map for Spatial Visualization

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Abstract

Visualization of maps to explore relevant geographic areas is one of the common practices in spatial decision scenarios. However visualizing geographic distribution with multidimensional criteria becomes a nontrivial setup in the conventional point based map space. In this work we present a novel method to generalize from point data to spatial distributions, captivating on the swarm intelligence. We exploit the particle swarm optimization (PSO) framework, where particles represent geographic regions that are moving in the map space to find better position with respect to user's criteria. We track the swarm movement on map surface to generate a relevance heatmap, which could effectively support the spatial analysis task of end users.

Index Terms: I.2.11 [Distributed Artificial Intelligence]: Intelligent agents— [H.5.2]: User Interfaces—[User-centered design]

1 Introduction

In several planning and spatial decision scenarios people look to analyze spatial distribution of geographic areas. Geovisualization approaches have often been used in such scenarios to provide the visual overview over map surface [1]. Heatmap based representation is one of the principal phenomenon in geovisualization approaches. Most of the traditional heatmap geovisualizations are statically generated for few selected dimensions, e.g., representation of population, demographic details. However in specific scenarios of decision making [5, 4] multiple criteria of interest become simultaneously significant, e.g., suitable geographic regions for living might contain different criteria of geo-entities such as the availability of shopping facilities, medical facilities, a good connection to public transport and road network, a green environment and lake nearby, good social atmosphere, etc. The conventional spatial visualization method in such scenario would consider all possible points or divisions of map space, e.g., grid raster [6]. However, due to the complexity of spatial databases and huge amount of multidimensional geoentities in geographic areas it would be a computationally expensive task. In this work we inherit a heuristic based PSO approach [3] where the search process starts with few points (intelligent particles) which cordially move in the map space to identify most relevant regions. By tracking the particle movement we generate heatmap visualizations in proficient manner that could represent the relevance as good as the conventional approaches. We provide an end user Web interface to visualize and explore the spatial search process of PSO. Users could select a reference query region or specify list of criteria, and request PSO algorithm to generate a relevance heatmap to suggest which areas are more suitable.

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2 Particle Swarm Optimization for Geographic Relevance

Inspired by the success of PSO as a common heuristic technique for multi-criteria optimization and decision making problems [7], we derive a PSO-based method to search for geographic regions with multiple criteria of interests and assist the geovisualization process. To apply PSO algorithm for regional search, we mapped some concepts of PSO to the spatial decision problem. Particle stands for a circular region on the map as a candidate solution. For a particle p_i, the position X_i stands for the current location of p_i on the map, i.e., geocoordinate of the centre of circular region. Velocity V_i implies for the movement direction of particle on the map surface. In the initial step, a set of particles as candidate solutions are generated with random position and velocity. Then the particle updates its velocity and position based on the equations 1, 2. The particle is evaluated by a fitness function and the local best position of the particle (P_{best}) and the global best position of the swarm (G_{best}) are updated based on the fitness value of particle. The individual particles are drawn stochastically toward the position of their own best performance and the best performance of the swarm. If a particle does not find a better solution in a considerable number of iterations, its history is cleared by resetting the speed and position to a random value.

The fitness of a particular particle is computed with respect to its similarity to the user specified criteria of interest. The relevance of a particle region is based on its possibility to generate/replicate the queried region [5]. The criteria dimensions considered in this paper is classified by geo-located facilities or landscape structure from OpenStreetMap data sources, e.g., transportation, education, sport, shopping, residential or industrial area, landscape etc. al.

$$V_{i+1} = w * V_i + c1 * rand() * (P_{best} - X_i) + c2 * Rand() * (G_{best} - X_i) \quad (1)$$

$$X_{i+1} = X_i + V_{i+1} \quad (2)$$

- Here i stands for current generation of the iteration process. $w, c1, c2$ are the momentum coefficient, recognise coefficient, social coefficient respectively. $rand()$, $Rand()$ are the functions that generate random numbers between 0 and 1.

3 Spatial Visualization via Swarm Movement

During the PSO search process the particles are always moving towards the better position, hence the particles staying in an area for longer duration is apparently an indication of higher relevance in nearby regions. We employ this heuristic to exemplify the path of the swarm to characterize the map space. We apply RGB color scheme adjacent to the particle movement to generate a heatmap, where the regions get intensified based on the presence of particles. The map on right side of Figure 8 shows the example heatmap of swarm movement in the city map space. The red spots in the center are the high density areas where the particles stayed for longer duration; the yellow, green, blue and purple colors specify the density in decreasing order respectively.

We used Google Maps as a map framework, the visualizations were built using Data Driven Documents[1] (D3). The heatmap color

[1]http://www.d3js.org/

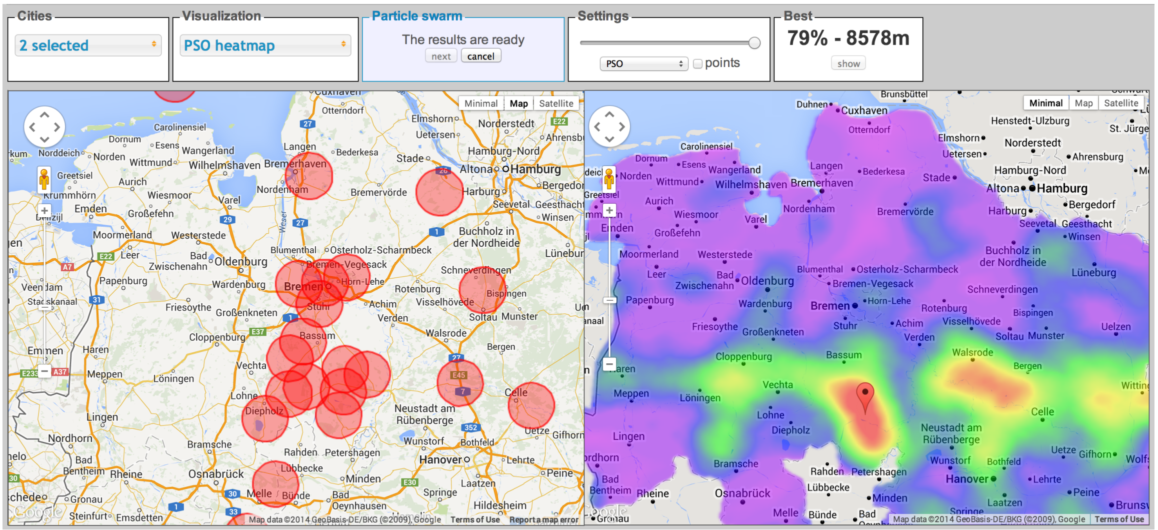

Figure 1: PSO visualization on map surface

scheme was chosen with the support of ColorBrewer[2]. Figure 1 shows the Web interface of the proposed system. Here users could select a particular city or multiple cities for geovisualization. In the shown example, the user intends to explore the Lower Saxony area (State in Germany) with respect to a specified region in Bavaria State (In the scenario such as moving from one place to other). The system triggers several particles in the map of Lower Saxony. These particles start moving across the map to find the best region with respect to user's criteria. Users could view the particles and swarm movement on the map interface (left), and they could also control the speed of the swarm via the top panel of interface. Here they could also spot the current status (maximum similarity) of the search process. At any state when user intends to visualize the characteristics of whole state he could generate the heatmap of swarm movement (right side map). We could perceive that the area near Bassum is most relevant for user; moreover there are other considerable regions near Walsrode.

4 Evaluation

To evaluate the efficiency of our PSO approach, we performed experiments on huge geospatial data of Germany and Austria. Results indicate that our PSO framework is able to locate relevant areas in a computationally efficient manner. We compare the PSO method with more conventional approach of regional search, where each possible region in the map boundary becomes the candidate solution. This inherently means that the entire map space would be devised in a grid raster [6]. For the 1400 test runs, PSO could achieve significant performance in 1.05 seconds compared to 13.99 seconds taken by complete search. We observed that the performance gap between complete search and PSO methods significantly depends on the complexity and size of search space. This indicates that PSO methods are even more beneficial for geovisualization when the magnitude of spatial database is larger, and could be a practical application in the scenarios when the search space is really huge.

5 Discussion and Future Work

We believe that swarm intelligence is an incredibly powerful method to perform the multi-criteria spatial decision task of geovisualization, and its applicability becomes more significant as the search space or database becomes larger. One of the distinctive aspects of our work is the visualization and interaction with PSO to end users. There have been some use cases of PSO in popular application scenarios such as Web search, retrieval and spatial optimization [2, 7]. But the inference has been more on the algorithmic level, as compared to our approach where user could view and control the PSO search process, as well as generate movement pattern as heatmap. The heatmap representation, and the visuals of the particle movements on map interface provide the relevant indication of important areas dynamically to end users.

In future we would like to examine other optimization and evolutionary algorithms to generalize from point data to spatial distributions, and extend the evaluation framework for comprehensive comparison with other geovisualization approaches.

[2]http://www.colorbrewer.org

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