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Short Paper

Scale-Adaptive Placement of Hierarchical Map Labels

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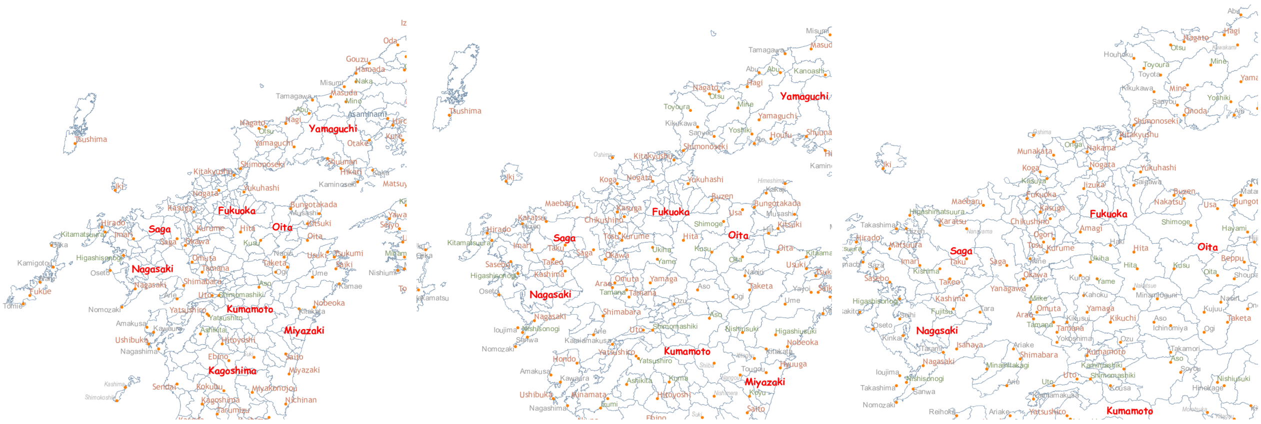

Figure 1: *Consistent scale-aware label placement in Hakata, Japan. From left to right, we monotonously increase the cartographic scale.*

Abstract

Nowadays, digital map services provide a large amount of spatial data and thus facilitate users to dynamically navigate map contents across multiple scales on small mobile devices. In this context, consistently placing map labels in interactive navigation is important but still technically challenging, especially when the labels are associated with multiple layers, which are inherent in map contents. In this paper, we introduce a genetic-based approach to optimize the placement of annotation labels with different ranges of map scales by maximizing label visibility of the existing scale while avoiding unwanted mutual overlaps and sudden popping effects. This is accomplished by grouping the label IDs into multiple chromosomes according to their importance and then forming composite chromosomes, each of which is reordered to optimize the overall visibility of the labels. Our formulation also allows the individual labels to move across the scale adaptively in order to further improve label placement on the respective scales. We show several experimental results to present the effectiveness of the proposed approach.

1. Introduction

With contemporary advancements and the integration of digital services, more users view digital maps not only with computers but also with mobile devices. Compared to classical paper maps, digital media allows users to intentionally enlarge and shrink the map domain according their own interests. This function is especially important for mobile users because it can achieve high visual readability of map contents regardless of limitations regarding the display size. Generally, if the map scale becomes large, we can enjoy more detailed map contents together with an increased number of labels within a limited screen space. Consistent label placement, in accordance with the map scale, thus becomes technically important due to the rapid increase in spatial data.

In practice, placing text labels to point out features is challenging [CMS95], especially for dynamic interactions [BSB*12, BGS*13]. Consistent map labeling problem across the scale has been formulated as *Active range optimization (ARO)* in [BDY06, BNPW10]. This approach assumes that each label is visible only

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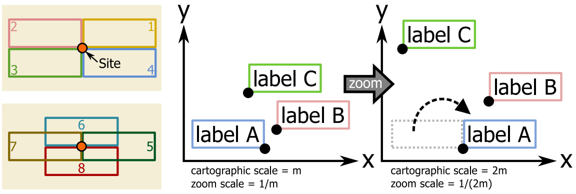
within its own active range, which represents the range of the label with respect to the scale in scale-adaptive map viewing. The problem can be solved as an optimization problem by maximizing the total active range of the labels, usually as a preprocess prior to user interactions. Nonetheless, the approach is still limited due its greedy range selection, which may miss the best choice. Moreover, to fine adjust the label placement, we can incorporate adaptive limits into their scale ranges according to their importance. This improvement is beneficial because we often assume a meaningful hierarchy among the labels, such as by geographic or administrative layers, which are likely to suppress the appearance of minor labels when we view the entire map domain. Adaptively moving individual labels across scales further improves the spatial efficiency of the map domain. Figure 1 shows a screenshot of the label placements over Hakata in Japan across multiple scales using our system, where each image represents a consistent label placement from a small to a large map scale. Our approach here successfully prevents the unexpected appearance or disappearance of labels and sudden leaps as the scale changes, which often disturb visual attention when reading the maps.

Our contribution lies in a novel genetic-based approach to solve scale-aware label placement problems. This is accomplished by introducing composite chromosome encoding that takes the hierarchical layers of labels into account, where we arrange the labels in the chromosome in such a way that the labels of upper hierarchical layers are placed earlier than those with low layers. Furthermore, we assume that each label has a specific range of scale according to its hierarchical level. In our formulation, we borrow the concept of ARO [BNPW10] and sum the ranges as a cost in the genetic algorithm. Our objective function aims to maximize the active ranges of all the labels so that each label persists as long as possible on the map while avoiding random changes in their positions at each scale. We also introduced a graph-based search to accommodate label movements across the scale in order to further improve their spatial placements.

The remainder of this paper is structured as follows. In Section 2, we briefly summarize relevant work on map labeling problems. In Section 3, we detail our labeling technique using the underlying improved ARO together with a genetic-based heuristic algorithm in a step-by-step manner. In Section 4, we present experimental results to demonstrate the feasibility of our approach. Finally, in Section 5, we conclude this paper and offers potential future extensions.

2. Related Work

Map labeling principles have been studied [Yoe72, Imh75, SMKH08], and the conventional results were summarized by Wolff [Wol09]. Classical techniques [Hir82, Zor86, CMS95] to solve static map labeling problems focus on the formulation of the problem, and an accelerated genetic-based approach [Rai98] is then proposed. More recently, sophisticated techniques have been developed to advance labeling results [BKSW07, BCF*15, LSC08, MZLL15, SV10]. In practice, with the development of mobile devices, the effective navigation of maps becomes crucial to this problem. Pioneering techniques are developed at a fixed scale and do not consider the visual consistency of label placement across multiple map scales [FP99, PGP03, Mot07, GNN13, FHS*12]. As a breakthrough, Poon and Shin [PS05] built a hierarchy tree to store precomputed greedy label placement for user navigation, while the label position and its orientation are fixed in their approach. The approach was then extended by Been et al. [BDY06, BNPW10], who relax the aforementioned restrictions. ARO has also been proposed for label placement by plotting rectangular pyramids in a 3D space to compute the conflicts of labels in a pre-processing step, and Zhang et al. [ZPLC15] extended this by maximizing the total weight of the associated ranges theoretically. Other extensions, such as slider-based [SHWZ14] and rotation-aware [GNR16] label placements, have also been investigated. In our approach, we further relax the limitations of the approach proposed by Been et al. in a more general fashion. More specifically, we introduce the well-known eight-position placement model [CMS95] when annotating each point site to allow labels to be moved in order to further improve their spatial placements.



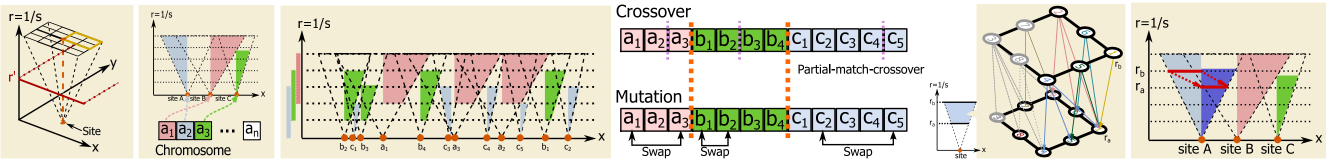
(a) (b)

Figure 2: *Possible label positions to given point sites. (a) The eight-position model in cartography [CMS95], in which the number shows each corresponding priority. (b) Changes in the label placement when zooming in the map, in which **label A** is moved to improve spatial readability.*

3. Interactive Map Labeling Framework

The technical challenge of our research is that we need to achieve scale-adaptive label placement to permit a specific scale range for each label according to its hierarchical level. To solve this, we introduced three primary design rules in the proposed approach. First, we prepare eight possible positions of a label around each point feature, as formulated by [CMS95]. Figure 2(a) illustrates the eight positions associated with a point feature, where a smaller index indicates the better priority of the corresponding label position. Second, we guarantee that all the labels are consistently placed to exclude mutual overlaps at any scale. In cartography, the scale s refers to the degree of magnification of the specific map region, which means that a large cartographic scale provides more detailed contents of a map. In this paper, however, we employ the inverse of the cartographic scale $r = 1/s$, i.e., the *zooming scale* [BDY06], as the map scale for convenience. Third, we allow the respective labels to move towards their better positions as the zooming scale reduces. Figure 2(b) shows such an example, where Label A (colored in blue) gradually moves towards the preferred position as more space becomes available with decreases in the map scale.

To achieve this objective, we develop our approach by breaking it into the following three steps: (1) the genetic-based optimization of active ranges, (2) the advanced genetic encoding of label hierarchies, and (3) a graph-based search for scale-aware label transitions.



(a) (b) (c) (d) (e) (f)

Figure 3: *Examples of labels with corresponding active ranges, where (a) indicates the pyramid-like 3D space of a label associated with its point site and r' shows the upper bound of the corresponding active range, (b) depicts an example of active range computation, which is defined by the map domain and the inverse of the map scales, (c) is a label placement with respect to the bounded administrative hierarchy, (d) presents a chromosome defined as a composite value-encoding sequence of label IDs, (e) shows an individual directed graph construction on each label to guide possible label movements, and (f) depicts linear interpolation, showing how to move labels without overlapping them.*

3.1. Genetic-based optimization of active ranges

In our approach, we assume that each label has a constant size within the screen space regardless of the map scale, and search for the most preferable layout by referring to the eight possible positions around the corresponding point feature. This requires us to consider the 3D space spanned by the 2D map domain together with the zooming scale r, which serves as an additional dimension for the dynamic label placement (Figure 3(a)). This setup actually allows us to explore the optimized arrangement of pyramid-like volumes swept by the respective labels in the 3D space [BDY06]. In practice, we employed genetic-based optimization to find better orderings of the label placements, primarily because we can effectively prevent unwanted local traps during the search process [WTLY11]. Suppose that we have a chromosome sequence as shown in Figure 3(b), in which label a_1 is placed first followed by labels a_2 and a_3. Following the classical GA, the quality of the chromosome pool is iteratively improved by reproducing better children from the superior parents through the evolution process. Our objective function is defined as follows by maximizing the total sum of the active ranges and position preference scores:

$$\{\text{Weight}\} \times (M - \{\text{Priority}\}) \times \{\text{Active range}\}, \qquad (1)$$

where $\{\text{Weight}\}$ represents the importance specifically assigned to the label, M ($= 10$ by default) signifies a constant value, $\{\text{Priority}\}$ indicates the priority index for the label position among the eight slots, and $\{\text{Active range}\}$ is the active range of the label.

3.2. Advanced genetic encoding of label hierarchies

Cartographers usually categorize map labels into prefectures, cities, counties, wards, towns, etc. according to the geographical/administrative hierarchy and expect to see the labels of these categories in this order during the zoom-in process. This means that the labels of each category have their own predefined range of the scale (Figure 3(c)) and should stay on the map as long as possible within that specific range. Therefore, we incorporated this property into our genetic algorithm, where we classify label IDs according to their administrative levels and optimize the order in each subsequence independently, as shown in Figure 3(d). This is accomplished by grouping the labels of each category to form a sub-chromosome of the label IDs, and then merging the sub-chromosomes in order of importance as a composite chromosome. Different from the previous case of single-layered labels, each sub-chromosome is reordered independently in this hierarchical version. For example, as shown in Figure 3(d), we assume that three sub-sequences, which are colored in red, green, and blue, correspond to the labels of prefectures, cities, and counties, respectively, while we only allow for crossover and mutation operations of the same category, in order to retain the initial categorizations of label IDs in the composite chromosome.

3.3. Graph-based search for label transitions

Finally, we further maximize the objective function by allowing the respective labels to slightly move around the corresponding point features during changes in the map scale. This implies that we search for the optimal trajectory of each label across the scale so that the label can stay at the preferred position around the corresponding point feature within the permitted range of the map scale. This has been accomplished by first checking the availability of the eight label positions at the scale samples and then connecting the positions at the adjacent scale samples to draw a proper label trajectory across the scale in the 3D space. We constructed the directed graph to represent the possible routes of labels between the scales r_a and r_b ($r_a < r_b$) in the 3D space (Figure 3(e)) and then found the optimal route using Dijkstra's algorithm. Here, the nodes of the graph correspond to the eight possible positions of the label around the corresponding point feature at the scale samples, and the edges represent the possible transitions between the label slots in the scale range $[r_a, r_b]$. Furthermore, we considered network connectivity in such a way that the labels move towards the preferred position, that is, the top left slot of the point feature, as the zooming scale becomes small. Thus, we connected the label positions indexed as 2, 6, 4, and 5 with that indexed as 1 from top to bottom (as the zooming scale decreases) in Figure 3(e).

Once we have extracted an optimal scale-adaptive route for each label, we can smoothly move the label between the label positions between the two neighboring scales simply by linear interpolation. Figure 3(f) illustrates this, where the possible movement of label A (in blue) is outlined in red. As exhibited in the figure, we block two label slots in the range bounded by the two adjacent scale samples so that the corresponding label has no conflicts with other labels during its spatial transition. Finally, since we incorporated changes in the spatial position of the label, the value $\{\text{Priority}\}$ in Eq. (1) is no longer constant for each label with respect to the scale. Thus, we replaced $\{\text{Priority}\}$ with the average of the position indices at the scale samples in our computation in order to allow the label to move around the point features.


(a)

(b)

Figure 4: *Consistent scale-aware text label placement of Tokyo, Japan. (a) Optimization using a composite value-encoding sequence of label IDs. (b) Optimization using a composite value-encoding sequence of label IDs, while allowing label movement along scales. From left to right, we monotonously increased the map scale.*

4. Results

We implemented our system on a desktop PC with Intel Xeon E5 CPU with 6 cores (3.5 GHz, 256 KB L2 cache per core and 12 MB L3 cache), 32GB RAM. The source code is written in C++ using Qt and OpenGL for drawing maps, and GAlib for optimization process. The present dataset includes 3,887 point sites, including 47 prefectures, 160 cities, 653 counties, 546 wards, 1,923 towns, 534 villages, 18 branches, and 6 remarkable names, respectively [MIL].

Figure 1 shows a screenshot out of label placements over Hakata, Japan. Note that, from left to right, we zoomed in on the map by decreasing the zooming scale. As shown in these images, our approach can consistently place annotation labels while preventing unexpected pop-up effects. Figure 4 shows optimal label placement around Tokyo, Japan. Here, the top row employs hierarchical value-encoding sequences, and the bottom allows the labels to move around the reference sites across the scale. The results also demonstrate that the annotation labels adaptively move towards preferable positions without occluding their corresponding reference sites. We could further minimize the objective function by 1.06% and 1.37% in Figure 4(a) and (b), respectively, against [BDY06]. Our results are also demonstrated in the accompanying video.

One limitation of our approach is that we need a relatively large amount of computation time to reach an acceptable solution for the genetic-based optimization, even when we employ composite chromosomes that reflect the hierarchy of annotation labels. This can be alleviated by carefully decomposing the entire chromosome into smaller clusters and sophisticating the evolution operations.

5. Conclusion and Future Work

This paper has presented a genetic-based approach for optimizing active ranges of labels in order to achieve consistent label placement across the scales. Future research should focus on the acceleration of our genetic-based computation by decomposing the entire map domain into several meaningful local regions in order to group labels into several clusters. Furthermore, the scale-aware simplification of such geographical features together with the proper selection of labels would be also an interesting topic for future research.

Acknowledgements

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