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Technical Section

Layout-aware optimization for interactive labeling of 3D models

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ABSTRACT

We propose a novel method for computing labeling of 3D illustrations in real-time. We solve a multiple criteria optimization problem in which we consider the desired layout already in the stage of searching for salient points of the labeled areas. In the solution we employ fuzzy logic combined with greedy optimization. The method runs on the GPU and achieves interactive rates on medium sized models. The results indicate that the method compares favorably to the state-of-the-art interactive labeling techniques.

1. Introduction

Illustrations are an important visual component of communication. They are used to visually expound various objects and support their textual description. In the latter case the reader needs to link the terms contained in the text with the illustration. The relation between textual and visual representations of information is mediated through *labeling*, i.e. assigning textual labels to various parts of the illustration. Digital media offer new possibilities for illustrations, such as 3D models, which the reader can manipulate interactively.

In this paper we present a novel labeling method which is targeted at interactive illustration of 3D models. The three main contributions of the paper are: (1) We formulate the labeling as multiple criteria optimization problem which considers the desired layout already in the stage of searching for salient points of labeled areas. This improves the resulting labeling compared to previous methods especially in the areas with many labels (see Fig. 1). (2) We use fuzzy logic and greedy optimization to solve the multiple criteria optimization problem. (3) We describe a GPU implementation of the method, which achieves interactive rates on medium sized models. Since the labeling is recomputed every frame, our method supports arbitrary manipulations of the model as well as interactive modifications of the model and of the labels.

The paper is organized as follows: Section 2 introduces terms used in the area of labeling. Section 3 summarizes state-of-the-art in the area of labeling. Section 4 formally describes the problem of external labeling. Section 5 presents our solution to the problem, which is summarized once more in Section 6. Section 7 presents results and comparisons and finally Section 8 concludes the paper.

2. The labeling problem

In this section we describe the labeling problem and define terminology used later in the paper.

2.1. Basic terminology

We assume that the model consists of n objects $O_i, 1 \le i \le n$ and each object O_i is assigned a unique label. After projection of the model to the screen, object O_i becomes visible in the screen area A_i. Note that if O_i is invisible then $A_i = \emptyset$.

The interior area A_I is a superset of the union of A_i over all objects. In our case we deal with a convex A_I, which is constructed to include a small boundary area around the model. The exterior area A_E is the complement of A_I with respect to the total screen area A_S ($A_E = A_S - A_I$). If the labels are placed in the interior area we call the labeling *internal*. If the labels are placed in the exterior area we call the labeling *external*. Our method deals with external labeling and thus we describe it in more detail in the next section.

2.2. External labeling

In external labeling a label is associated with the *anchor*, the *leader line*, and the *label box*. The anchor $\mathbf{a}_i$ is a point inside the area A_i. The label box L_i is a rectangle containing the label typically in the form of a short text string. Leader line $\mathbf{l}_i$ is a line segment connecting the anchor $\mathbf{a}_i$ and the label box. The endpoint of the leader line is denoted $\mathbf{e}_i$ (see Fig. 3).

The label boxes in external labeling can be either floating or fixed. A floating label box can be placed at any position in the external area while a fixed label box can be placed only at several fixed positions (the number of these positions is typically the same as the number of label boxes).

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Similarly, the anchors and endpoints of leader lines can be floating or fixed. A floating anchor can be placed at any position inside the corresponding area while the fixed anchor has a one or several fixed positions. A floating endpoint can be placed at any position on the boundary of the label box while a fixed endpoint has only one or a few fixed positions. We call a labeling method *automatic* if it deals with both floating anchors and floating endpoints.

With floating label boxes, a set of *principal* directions D can be used to specify the desired layout of the leader lines. Then each leader line l_i should be parallel to some principal direction $d \in D$. However, this is not always possible for all leader lines without introducing overlaps of the leader lines or the label boxes. If this happens there are two commonly used solutions:

- The leader lines remain straight lines, but some of them are no longer parallel to any principal direction.
- Some of the leader lines are split into two orthogonal lines with one bend, where the segment from the anchor to the bend is orthogonal to $d \in D$ and the segment from the bend to the endpoint is parallel with d.

Examples of layouts with different sets of principal directions and type of leader lines are shown in Fig. 2.

3. Related work

The labeling problem has first received attention in the cartographic domain for assigning labels to static features. A comprehensive bibliography of these labeling techniques can was presented by Wolff and Strijk [19].

Although we deal with external labeling we identified several methods for internal labeling that are related to our work: The method of Götzelmann et al. [8] determines the positions of internal labels using a multiple criteria optimization. In the method of Ropinski et al. [15] the labels indicate the shape of the overlaid part of the 3D object. The method of Maass and Döllner [13] integrates the labels into a virtual reality environment.

In the case of external labeling we split the discussion of the related work into four parts according to the flexibility of anchors and label boxes (fixed vs. floating).

Fixed anchors and fixed label boxes: Bekos et al. [3] defined the boundary labeling problem where the label boxes are arranged on the rectangle enclosing a set of anchors. They study various types of leader lines, arrangements of label boxes and sizes of label boxes. Their primary focus is on efficient labeling algorithms that calculate leader lines whose combined length is minimal. Later, Benkert et al. [5] formulated the boundary labeling problem as a multiple criteria optimization problem where the length of leader lines, the number of bends, and the distance of anchors to leader lines are used to find an optimal solution of one-sided labeling (all label boxes are on one side of the enclosing rectangle).

Floating anchors and fixed label boxes: Bekos et al. [2] extended the boundary labeling problem. Each anchor can float within a polygonal area. They propose efficient labeling algorithms for various types of leader lines under some restrictions on the polygonal area with the aim of minimizing the combined length of leader lines.

Fixed anchors and floating label boxes: Stein and Décoret [17] presented a greedy algorithm for the labeling of fixed anchors attached to 3D objects. The occlusion of the 3D objects is minimized by placing label boxes in empty areas. Shadow regions and a summed area table [11] are used to prevent the crossing of leader lines and overlaps of label boxes.

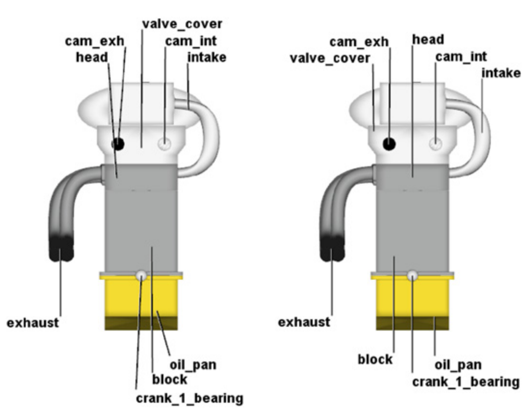

Fig. 1. A comparison of our method with the method of Ali et al. [1] on an engine model using top–bottom layout. (left) Ali et al. [1], (right) the proposed technique. Note that in our method the leader lines are distributed more evenly over the model, which according to our opinion increases their saliency and leads to more aesthetic labeling.

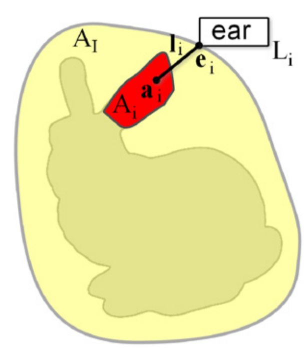

Fig. 3. Illustration of the basic terms used in external labeling.

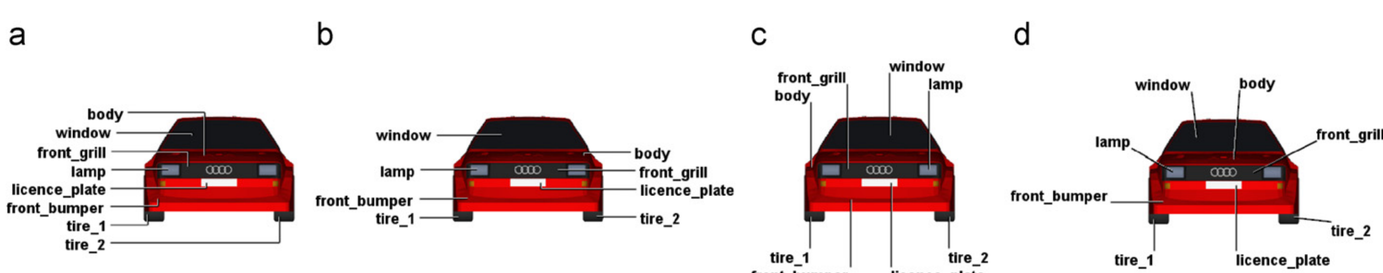

Fig. 2. Examples of different label layouts: (a) left layout with orthogonal lines, (b) left–right layout with orthogonal lines, (c) top–bottom layout with straight lines, (d) silhouette based layout with straight lines.