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Metrics for Functional and Aesthetic Label Layouts

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Abstract. Co-referential relations between textual and visual elements in illustrations can be encoded efficiently through textual labels. The labels support students to learn unknown terms and focus their attention on important aspects of the illustration; while a functional and aesthetic label layout aims at guaranteeing the readability of text strokes as well as preventing the referential mismatches.

By analyzing a corpus of complex label layouts in hand-drawn illustrations, a classification of label layout styles and several metrics for functional requirements and aesthetic attributes were extracted. As the choice of a specific layout style seems largely determined by individual preferences, a real-time layout algorithm for internal and external labels balances conflicting user-specific requirements, functional and aesthetic attributes.

1 Introduction

Almost all illustrations in scientific or technical documents employ a large number of textual annotations in the form of labels. The labeling provides a direct way to visualize the *co-referential* relations between textual and visual elements.

Textual *labels* either overlay visual objects or are placed outside (*internal* vs. *external* labels). Moreover, the form and orientation of internal labels can target on readability (axis-aligned typing, see Fig. 1-1) or convey topological information (the text stroke provides indication for the shape and extent of area and line features, see Fig. 1-2) [14]. For external labels (see Fig. 1-3) additional meta-graphical objects like *connecting lines* and *anchor points* establish a co-referential relation between labels and visual objects. However, sometimes artists prefer to omit both anchor points and/or connecting lines if the layout remains unambiguous.

Learning materials typically employ annotated illustrations in order to convey many unknown terms in a domain-specific or foreign language in parallel, whereas complex spatial configurations are often described textually. However, an interactive exploration of complicated subjects (e.g., technical devices or organic structures) through 3D browsers can increase the learning efficiency [22,20].

The majority of learning and instructional material still employs static illustrations, as the depicted objects are carefully drawn by hand to convey the intended function and due to the complexity of the label layout problem. But in many technical and scientific domains the required resources are already available and can be exploited in on-line tutoring applications. Moreover, several research groups in computer graphics focus on those illustration techniques which are frequently used in technical and scientific illustrations (e.g., transparency [8], cutaways [8], explosion diagrams [1]). However, the automatic labeling of 3D models received almost no attention from the industrial or research community. Therefore, we implemented several layout styles for internal and external labels and integrated real-time label layout algorithms into an interactive 3D browser. Thus, the presentation style as well as the label content can be adapted in order to meet specific individual preferences and learning tasks.

An automated label layout system (a) *selects* those labels which the layout should contain, (b) *classifies* them into internal or external labels, and (c) determines all *style-specific parameters* for those labels.

This paper is organized as follows. Sec. 2 presents the State-of-the-Art of automatic labeling systems. From a manual analysis of hand-made illustrations, we extracted several label layout styles and classified them according to common properties. These individual layout styles aim at achieving specific functional requirements or are associated with a set of aesthetic criteria (Sec. 3). The metrics to measure these functional requirements and aesthetic attributes are presented in Sec. 4. Users can adjust the impact of these metrics with weights. These uniform metrics for internal and external labels allowed us to integrate labeling algorithms in a common layout architecture (see Sec. 5).

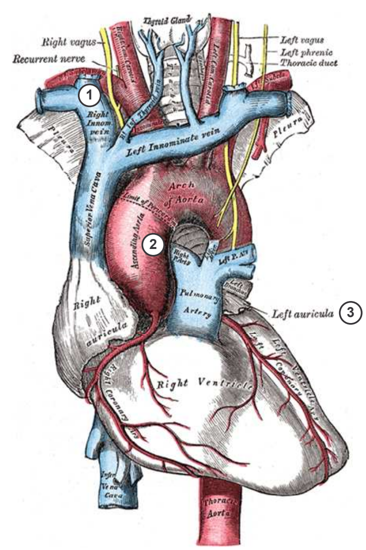

Fig. 1: Illustration with internal (1 and 2) and external labels (3). (Source: [13])

After presenting some examples in Sec. 6, we discuss directions of future research (Sec. 7). Finally, Sec. 8 summarizes the contributions of our work.

2 Related Work

The efficiency of multi-modal information presentation was studied within psychology, aiming at extracting principles that guarantee an effective design. MAYER [17] imposed the *spatial continuity principle*, assuming that the cognitive load to integrate co-referring multi-modal expression depends on the spatial distance between related elements. Hence, annotations should be placed as near as possible to their co-referring visual object. This distance is minimal, if textual annotations are drawn as overlay. Moreover, the *readability* of textual labels have to be considered.

These principles also dominate the label layout for point, line, and area features in cartography. There are numerous approaches to translate IMHOF's informal principles of label placements [14] into numeric scores or constraints which are solved using numerical optimization methods [7,10]. Several research groups also focus on interactive cartography (e.g., to develop algorithms for real-time label layout of dynamic maps ([18,9]) or to consider user-specific requirements within the map generation [2]. Recently, layout algorithms for external labels extend the classical cartographic methods [5].

These techniques influence label layout algorithms for internal and external labels in computer graphics and information visualization [11]. Recently, in AR/VR the term *view management* is used for a more general, but related problem: the smooth integration of additional 2D information (images, texts, annotations) into the view plane [6,4]. Other researches employ these techniques for the generation of instructional [15] or tutoring materials [21,23].

However, these research prototypes implement a small subset of those label layout styles found in scientific or technical documents [21] and they are based on rough shape approximations [6] or rely on user interaction to achieve an appealing label layout [15,23]. The approach of ALI et.al. [3] first implements a set of layout styles for external labels in an interactive 3D browser which also considers the correct shape of complex 3D objects.

3 Label Layout Styles

The material in this section is based on a manual analysis of label layouts in hand-drawn illustrations. For this purpose, we chose anatomic atlases, anatomic textbooks, and visual dictionaries as their illustrations employ very elaborated label layouts of extraordinary quality.

The manual analysis reveals that human illustrators use a number of different label layout styles with style-specific illustration techniques and properties. As their selection seems to be highly determined by aesthetic preferences, users should be able to specify style preferences and priorities for functional requirements.

There are two styles for **internal labels**: they could either be aligned to a horizontal line or their curvature can provide indication of the shape and extent of area and line features. Fig. 1 contains both types of internal labels. Moreover, slanted straight text strokes are used. As these strategies aim to achieve two conflicting cartographic principles (legibility vs. clear graphic association [14, pg.129]) users have to specify appropriate priorities.[1] The layout algorithm has to also consider additional constraints such as the amount of available space to display internal labels for linear and area features and the available background space for external labels.

[1] In Sec. 4 we introduce the terms *unambiguity* and *readability* as synonyms to IMHOF's cartographic terms.

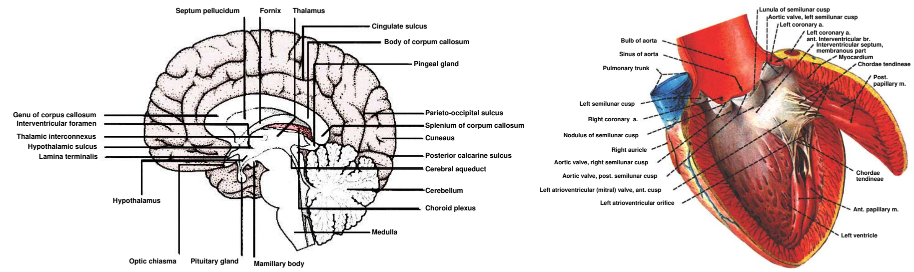

Fig. 2: External label layout styles: Orthogonal (left) and circular layouts (right). (Source: [24, pg.317] and [26, pg.81])

We extracted three main *features* of the layout styles for **external labels:**

1. the *style of connecting lines* (orthogonal with bends vs. straight lines),
2. the *labeling area* (rectangular arrangement vs. circular arrangement), and
3. the *label alignment* (labeling regions vs. object shape).

These features are used to define layout styles for external labels and their individual properties. The label layout of Fig. 2-left can be characterized as: orthogonal-lined, rectangular labeling area, and label-aligned, whereas the layout of Fig. 2-right is best described as: straight-lined, circular labeling area, and shape-aligned. For the sake of brevity, we refer to these labeling styles respectively as *flush left-right* and silhouette-based circular layouts according to the hierarchy presented in Fig. 3.

There are several functional requirements which are common to all layout styles:

1. Place labels near to their corresponding objects,
2. Labels must neither overlap one another, nor the objects, and
3. Prevent crossings of connecting lines.

However, these functional requirements can interfere with style-specific aesthetic criteria. The average length of connecting lines for layout styles which utilize a separate labeling area and a label-alignment (i.e., *flush*) is greater than for styles which use a circular label arrangement and object alignment. Moreover, layout styles can incorporate

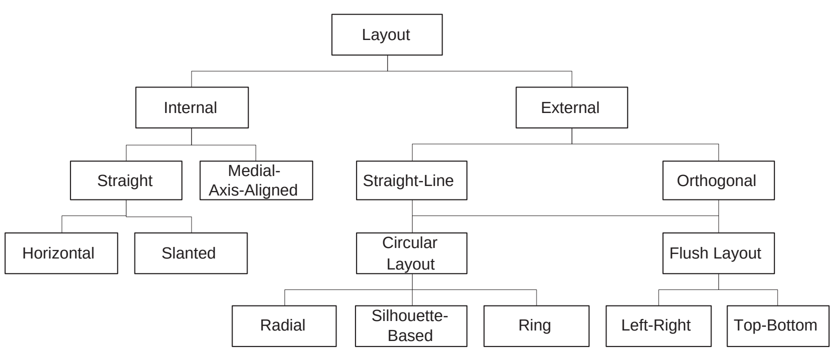

Fig. 3: Layout classification.

additional aesthetic criteria. An important aesthetic criterion for *orthogonal* layouts, for example, is to minimize the number of bends in orthogonal, axis-aligned connecting lines. Finally, functional requirements as well as aesthetic criteria might be not completely satisfied. For example, note that two connecting lines are crossing on the left side of Fig. 2-left. Moreover, the distribution of labels is not balanced on the right label area of Fig. 2-right. These examples demonstrate the complexity of the label layout problem.

Our system implements layout styles as classes and enables the illustrators to specify their own requirements on labeling styles.

4 Metrics of Functional Requirements and Aesthetic Attributes

The main challenge for human illustrators while placing labels is to consider a number of conflicting functional requirements and aesthetic attributes such as readability, unambiguity, aesthetic considerations, media capabilities, publishing costs, and subjective preferences. The label layout in interactive 3D browsers introduces additional requirements for an aesthetic *dynamic* label layout: frame-coherency and efficiency. Finally, the label layout should be *adaptive*, i.e., it should reflect contextual requirements. This could be achieved by considering the interaction context and user-specific requirements within the label selection and by displaying dynamic contents within the labels.

An aesthetic label layout (*form*) balances these contradicting requirements and supports the intended *function*[2] (i.e., explain the visual subject through annotations). There are different aspects within these criteria which have to be considered for internal and external labels:

The layout **readability** is affected by the label placement as well as from font attributes:

Internal Labels	Area and linear features have to provide enough space to contain internal labels, otherwise they are considered as point features and labeled externally. The text strokes could be either horizontally aligned or they should be drawn as smooth as possible, as a high *curvature* reduces text readability. *Steep* text strokes should be avoided as well. If the *path length* exceeds the required length to display text strokes, then search an appropriate path segment. Moreover, a minimal contrast between letterings and its local environment has to be guaranteed.
External Labels	External labels should neither overlap one another, nor the connecting lines and visual objects. As the majority of tutoring applications use a uniformly colored background, a maximal contrast for the label text can easily be achieved. A minimal contrast between meta-graphical objects (connecting lines and anchor points) and its local environment has to be guaranteed.

[2] The famous dictum of the architect Louis H. SULLIVAN "form ever follows function" became one of the most influencing guidelines in industrial design due to MIES VAN DER ROHE and other artists from the Bauhaus school.

Unambiguity. The layout should guarantee that the co-referential relation between labels and their associated visual objects can be easily recognized and prevent referential mismatches:

Internal Labels	Text strokes should be placed over salient regions of line or area features and must not leave the object's interior. Moreover, text strokes should not be placed at very narrow areas.
External Labels	Labels should be placed as close as possible to their co-referential visual objects. Anchor points must overlay their corresponding visual objects and be line-connected to related labels. The number of bends in connecting lines should be minimized and anchor points should not form clusters.

Aesthetic Considerations. Aim at achieving a symmetric layout and prevent visual clutter:

Internal Labels	If an internal label cannot be projected in an aesthetic way (e.g., high curvature) it should not be displayed internally but externally. However, this decision should consider a user-defined threshold value.
External Labels	The distribution of labels and anchor points in the layout should be neither too scattered nor too uniform. Moreover, external labels should either be aligned with respect to one another (horizontal or vertical alignment) or along the silhouette of visual objects.

Frame-Coherency. To prevent visual discontinuities during user interactions the distance of identical layout elements between subsequent frames have to be minimized:

Internal Labels	Even minor changes in the shape of objects may result in drastic changes of the skeleton. Therefore, those segments of the skeleton which minimize the displacement of text strokes are extracted. However, this feature should be disabled to achieve more aesthetic text strokes for static images. Moreover, *salience* (i.e., larger area features or longer line features) offers a greater stability in the layout.
External Labels	The displacement between subsequent anchor points and label positions should be minimized. Moreover, the number of permutations in the label sequence and the assignment of labels to the different label area should be minimized.

Fig. 5 summarizes the metrics. They can be used to evaluate the quality of a label layout with respect to functional requirements and aesthetic criteria. However, the user should be able to adjust the impact of individual criteria. Moreover, we store these values in log-files while the user interacts with a 3D browser in order to analyze the overall aesthetic measure of different parameter configurations and layout styles.

5 Label Layout System

The computation of label layout can be considered as an optimization problem, as the placement of an individual label might effect the quality of the label layout in general.

Thus, even a simpler problem (finding an optimal layout for the point-feature labeling problem) has been proven to be NP-hard [16]. Therefore, our layout algorithm heavily relies on several layout heuristics.

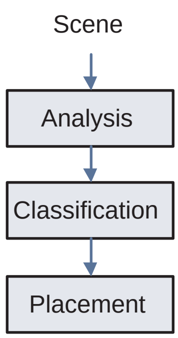

Fig. 4: Label layout architecture.

First, we estimate the quality of internal and external placements of labels locally (*analysis*). Since the layout algorithms for both label classes are based on medial axis transformations, a common data structure, the skeleton graph, is also constructed in this module.

Due to the spatial continuity principle (see Sec. 2) the classification algorithm prefers to label internally, provided there is enough space and the readability has some defined quality. However, an internal labeling is enforced if there is not enough space to display external labels.

The *placement* module determines the remaining parameters required for the specific layout style. Internal labeling selects an appropriate path segment on the object skeleton to display the original or abbreviated text. For external labeling, a point on the skeleton is chosen as anchor point which optimally satisfies the set of functional and aesthetic heuristics. In order to enhance the readability and consistency, the label text is rendered with identical font parameters for internal and external labels. Moreover, we consider the local contrast around internal letterings to enhance the contrast with halos. The architecture of the label layout system is presented in Fig. 4.

The metrics of functional and aesthetic attributes presented in Sec. 4 are subsequently used to improve an initial label layout through efficient real-time optimization processes. A detailed description of our implementation is provided in two technical papers [12,3].

Attribute	**Metric**	
	Internal	**External**
Readability	Curvature Steepness Contrast	No. of label - label overlaps No. of label - connecting line overlaps
Unambiguity	Salience Min. Extend	Avg. length of connecting lines No. of bends in connecting lines Salience of anchor points Anchor point clusters
Aesthetic Considerations	Curvature	No. of connecting line intersections Label distribution Anchor point distribution Label alignment
Frame-Coherency	Label displacement Salience	Anchor point displacement Label displacement Label permutation

Fig. 5: Functional and aesthetic metrics.

6 Results

Fig. 6 and 7 present screen-shots of our integrated label layout system [12] and the specialized layout system for external labels [3]. The main advantage of the integrated system is that it can adapt its presentation style (internal vs. external) according to the available space and the user preferences. Fig. 6 demonstrates this feature by zooming into the motor model.

The interactive exploration of 3D models also improves the annotation of geometric models with correct references by the domain expert. The domain expert can interactively specify the content to be displayed in labels. Moreover, abbreviations can be specified, which are displayed in internal labels. These results are stored in an internal database and reused in subsequent interactions with these 3D models. For unknown geometric objects the system displays the internal reference names.

The speed of calculation mostly depends on the CPU and bus transfer speed as our algorithms require color-coded projections of the scene. For the heart model (see Fig. 7), we achieved the following frame rates at a resolution of about 800x600 pixels:

CPU	*RAM*	*GPU*	*FPS*
P4 2GHz	512MB	GeForce4	10
Centrino 1.6GHz	512MB	ATI 9700m	>25
P4 HT 3.3GHz	1GB	ATI X800	>30

7 Future Work

We are currently working on enhancing the quality of label layouts and improving our algorithms to extract more accurate skeletons in order to increase the readability of text strokes. Furthermore, we plan to integrate additional aesthetic metrics for evaluating their impact in a user study.

Label Layout: A label re-classification (internal $\leftrightarrow$ external label) implies large incoherencies in the label layout. Moreover, connecting lines of external labels may cross internal labels. We also aim at implementing multi-line labels for both label placement modes.

Skeletonization: A huge variety of these algorithms were developed within the field of image processing (2D skeletons) and computer graphics (3D skeletons). As a definition of an optimal skeleton still lacks, one has to define application-specific quality measures. We focused on a low computational effort in order to achieve interactive frame rates, a sufficient quality and a high robustness.[3]

The modular architecture of our system enables us to experiment with several skeletonization algorithms. Our current implementation employs a scan-line algorithm [19]

[3] Skeletonization algorithms are normally very sensitive to noise, i.e., the resulting skeleton differs heavily for even small changes in the object silhouette.

on the horizontal axis. This choice is motivated by the preferred left-to-right reading direction for on-line documents and the low computational effort and the robustness of this algorithm with respect to noise. The resulting discontinuities and jumps are easily removed with median filters. The more elegant distance transformation [25], as implemented in the original label layout algorithm for external labels [3], was replaced by the scan-line algorithm to increase the frame-rate.

Evaluation: We are preparing several user studies with our label layout prototype to evaluate different settings (like the weights and the coherent movement of the letters) and styles. Moreover, we want to study how interactive labeling can applications support different learning tasks. This would also incorporate dynamic content within labels as introduced by PREIM's ZOOM ILLUSTRATOR [21].

Since our algorithms internally work on color-coded 2D images, we can compare the layout of human experts and automatically generated layouts. Therefore, we plan an evaluation where users should score the different layout styles, specify criteria of their pros and cons in several applications and identify hand-made layouts from automatically generated layouts. Further evaluations aim at comparing the impact of layout features on the efficiency in different search tasks (reading time, error rate).

8 Conclusion

The impact of a beautiful illustration might be spoiled due to a poor label layout. An aesthetic illustration raises the interest of viewers, whereas an appealing label layout smoothly guides the viewer's attention. Based on the principle "form follows function", the design of an aesthetic label layout is an efficient way to increase the functionality (speeding up search tasks) of technical and scientific illustration. We propose several metrics of aesthetic attributes which are used to improve the visual balance of an initial label layout through an efficient real-time optimization process. While users can specify a preferred layout style for internal and external labels, the classification and the layout algorithm balance all constraints in order to achieve a readable, unambiguous, aesthetic, and coherent layout.

The main focus and the new contribution of our approach is to increase the coherency of the label layout during user interactions. The label layout styles presented in this paper support an interactive exploration of complex spatial configurations within a 3D browser by efficient real-time layout algorithms and a minimal layout flickering. As functional requirements and aesthetic attributes often interfere and are also subject to individual preferences, our implementation was also designed to evaluate their impact on the layout.

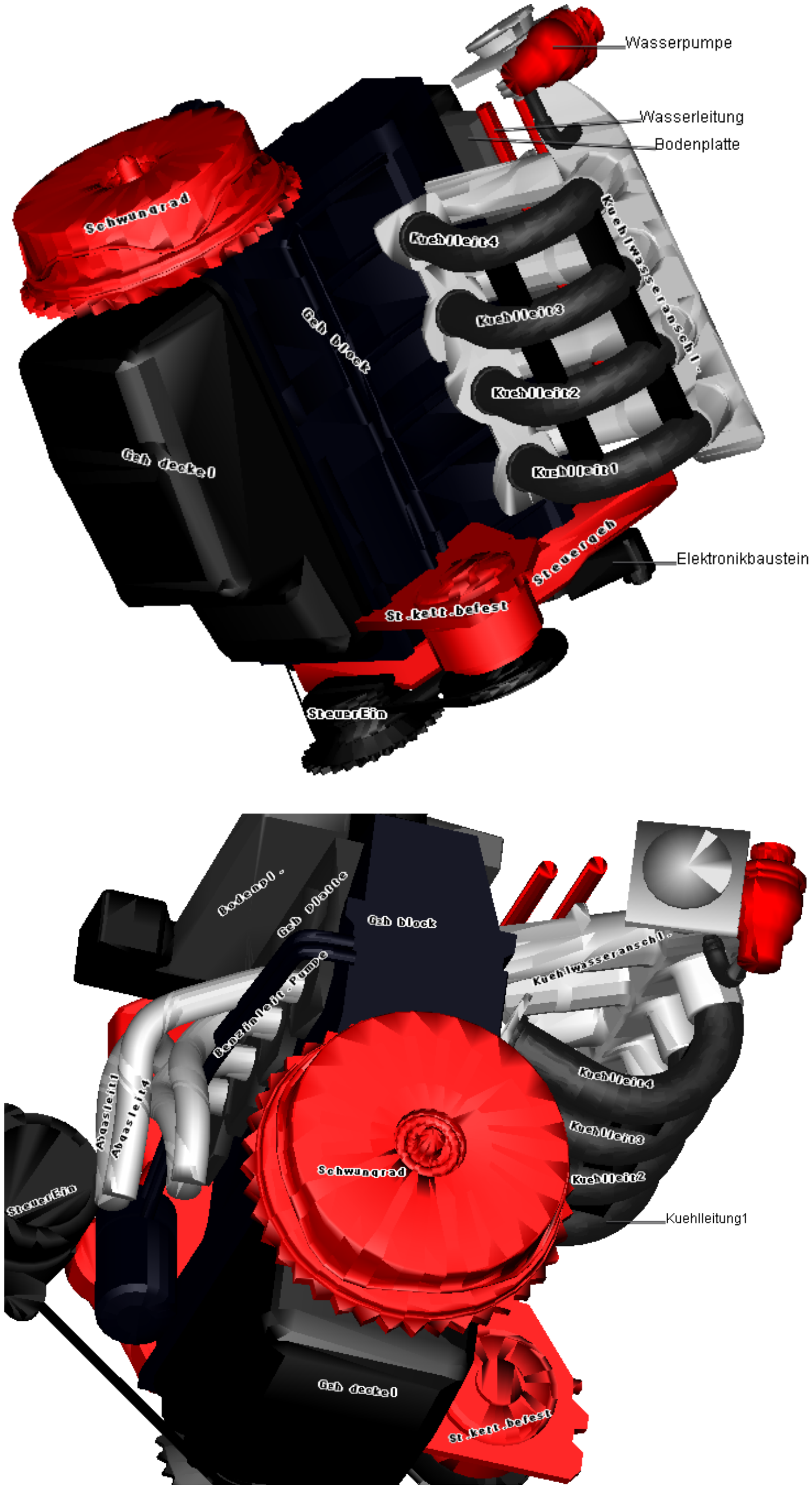

Fig. 6: Integrated label layout.

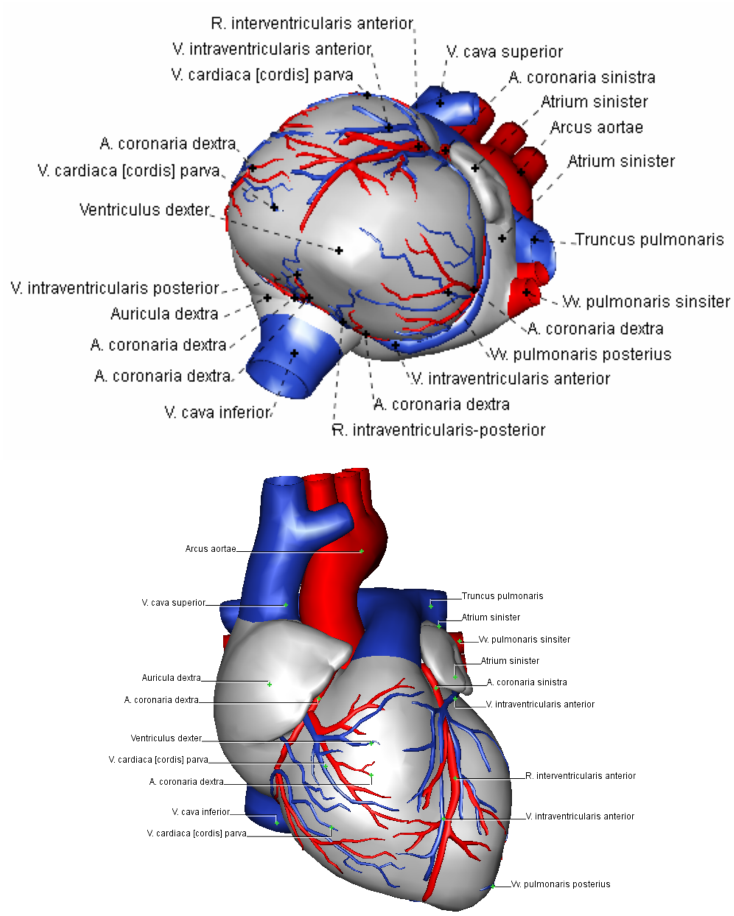

Fig. 7: External label layout styles.

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