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Survey of Labeling Techniques in Medical Visualizations

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Abstract

Annotations of relevant structures and regions are crucial in diagnostics, treatment planning, medical team meetings as well as in medical education. They serve to focus discussions, present results of collaborative decision making, record and forward diagnostic findings, support orientation in complex or unfamiliar views on the data, and study anatomy. Different techniques have been presented for labeling the original data in 2D slice views, surface representations of structures extracted from the data, e.g., organs and vasculature, and 3D volume rendered representations of the data. All aim at a clear visual association of labels and structures, visible and legible labels, and a fast and aesthetic labeling while considering individual properties of the data and its representation and tackling various issues, e.g., occlusion of structures by labels, overlapping labels, and crossings of lines connecting labels with structures. We survey the medical labeling work and propose a classification with respect to the employed labeling technique. We give guidelines for choosing a technique dependent on the data representation, e.g., surface rendering or slice view, the type of structures to be labeled, and the individual requirements on an effective label layout.

Categories and Subject Descriptors (according to ACM CCS): I.3.m [Computer Graphics]: Miscellaneous—J.3 [Computer Applications]: Life and Medical Sciences—

1. Introduction

The term *labeling* is used ambiguously in medical computing. On the one hand, it refers to automatically identifying anatomical structures in medical data such as specific segments of a vascular tree [BPC*13] or individual vertebrae of the spine [ACC11]. On the other hand, it is used for the process of annotating structures in medical visualizations by textual labels. This survey is dedicated to the latter.

Labeling medical visualizations has a centuries-long tradition in medical textbooks and anatomy atlases. Here, its main function is to communicate anatomical structures for education. In the age of modern medical imaging devices and computerized medicine, the range of possible applications has increased. Labeling plays an important role in diagnostics, treatment planning, medical team meetings, and in the education of medical students and patients. It is an everyday task for radiologists in diagnosing image data. Annotations serve to:

- record and forward diagnostic findings, e.g., to the transferring doctor or a medical specialist,
- focus discussions in team meetings, e.g., a tumor board discussing the therapeutic strategy,
- present results of collaborative decision making,
- support orientation in complex or unfamiliar views on the data, e.g., 3D views of highly branched vascular trees or (virtual) endoscopic views in sinus surgery,
- study anatomy in computer learning systems, e.g., the *VOXEL-MAN-series* [SFP*00],
- explain an intervention in patient education, and
- practice an intervention in a surgery training system, such as the *LiverSurgeryTrainer* [MMH*13].

Various labeling techniques which mimic hand-crafted visualizations of medical illustrators and techniques tailored to the particularities of computer support, e.g., a third dimension and interactivity, have been developed. Numerous approaches were proposed to labeling the original image data in 2D slice views, 3D surface representations of structures extracted from the data, e.g., organs and vasculature, and 3D volume rendered representations of the data.

In Section 2, we provide the foundation of labeling medical visualizations by discussing general and medicine specific requirements on an effective labeling and by introducing the employed labeling techniques. The latter serve as a classification scheme for our overview of medical labeling work in Section 3. We conclude in Section 4 with guidelines for choosing a labeling technique.

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2. Foundation of Labeling Medical Visualizations

Labeling may be accomplished automatically or interactively. Interactive labeling is performed, e.g., by radiologists when annotating their findings in a slice view. For instance, a label depicting measurement values and a comment shall be added to a pathologic structure that has been segmented before. Modern radiological workstations support this process by providing lines, arrowheads, and textual labels. While these features are useful, automatic labeling where the system (re)arranges the labels, relieves the user from taking care of, e.g., crossing lines, labels overlapping each other or other important findings, and proximity of a label to the related structure. This is gaining importance with an increasing number of labels.

In labeling scenarios where the structures and label texts are predefined, e.g., in a 3D view of an anatomy learning system showing the human body, interactive labeling is inappropriate. Instead, automatic labeling is accomplished and adapted to user-interactions, such as pan and zoom.

2.1. Requirements on an Effective Labeling

Ali, Hartmann, and colleagues pose some general requirements on an effective label layout for interactive 3D illustrations [AHS05, HGAS05]. While they do not specifically aim at medical visualizations, their working examples are mostly borrowed from that domain. The requirements are:

- **Readability** Labels must not overlap,
- **Unambiguity** Labels clearly refer to their objects,
- **Pleasing** Prevent visual clutter,
- **Real-Time** Compute layouts at interactive rates,
- **Frame-Coherency** Prevent visual discontinuities,
- **Compaction** Reduce the layout area.

Besides theses general requirements, medical visualizations pose specific ones. **(1)** The labels must neither occlude diagnostically relevant information, such as potential pathologies, nor patient information, e.g., from the DICOM header, which is superimposed on the visualization. **(2)** The slice-based investigation of image data is a specialty of the medical domain. Here, the interactive labeling of findings is crucial. Once all findings have been annotated, an automatic post-processing, rearranging the labels for an effective layout, is desirable. **(2a)** An important aspect of the layout is the slice-coherency of annotations. If a structure covers multiple slices, it should be labeled in each of them and annotations should not abruptly change their position while browsing the slices. **(2b)** Branching structures and elongated structures, e.g., vessels, appear disconnected in slice views. As long as they are located close together, they should be summarized by a single label. **(3)** It may be necessary to label also hidden structures to remind the viewer of their existence, e.g., in the course of evaluating all lymph nodes in 3D views of the neck anatomy [MP09]. **(4)** Transparent surfaces often serve as context information in medical visualizations, e.g., the transparent liver or brain surface with the respective inner vascular system rendered opaque. Visibility tests for checking whether a structure must be labeled need to take transparency into account. **(5)** In volume-rendered views, object visibility is also dependent on the transparency transfer function. If physicians adjust this function dependent on the anatomy of interest, e.g., bony structures or soft tissue, visibility computations and the labeling must be updated accordingly.

The fulfillment of all requirements is hard to achieve and may conflict, e.g., with the desire to label as many visible objects as possible [AHS05]. Sometimes, objective criteria are missing to evaluate whether a requirement has been met, e.g., for readability and unambiguity. In 3D visualizations, interactivity aggravates the compliance with each requirement since the labeling has to be updated once the object is rotated or zoomed in. Structures which were visible become hidden and vice versa, empty screen space used for a label may now be occupied by a structure, and graphics objects relating labels to structures may start to cross.

2.2. Labeling Techniques

In a review of medical labeling work, we identified five different labeling techniques. None of them has been specifically invented for or is restricted to medical visualizations. However, all have been extended and tailored to a specific type of medical data, e.g., containing tubular structures such as vessels, a particular use case, e.g., an anatomy learning system or a surgery trainer, or a certain type of medical visualization, e.g., surface-based, volume-rendered, or slice-based. Adhering to the identified techniques, we classify the labeling work into the categories (Fig. 1):

- internal labels
- external labels
- boundary labeling
- excentric labeling
- necklace maps

Internal labels are superimposed on the structure of interest and should fit its screen representation (Fig. 1a). A good legibility is achieved if enough screen space is available for a sufficient font size, a good contrast between label text and background structure is provided, and the label text is aligned horizontally. If horizontal text extends beyond the structure, it should rather be aligned along the centerline of the structure's screen representation [GAHS05]. For strongly bended centerlines, smoothing is advisable. Ropinski and colleagues argue that in 3D visualizations, internal labels should also convey an objects 3D shape and hence, be projected onto it [RPRH07].

External labels are positioned on empty screen space and connected to their structure by a line (Fig. 1b). This so-called *leader* connects an *anchor point* on the structure and

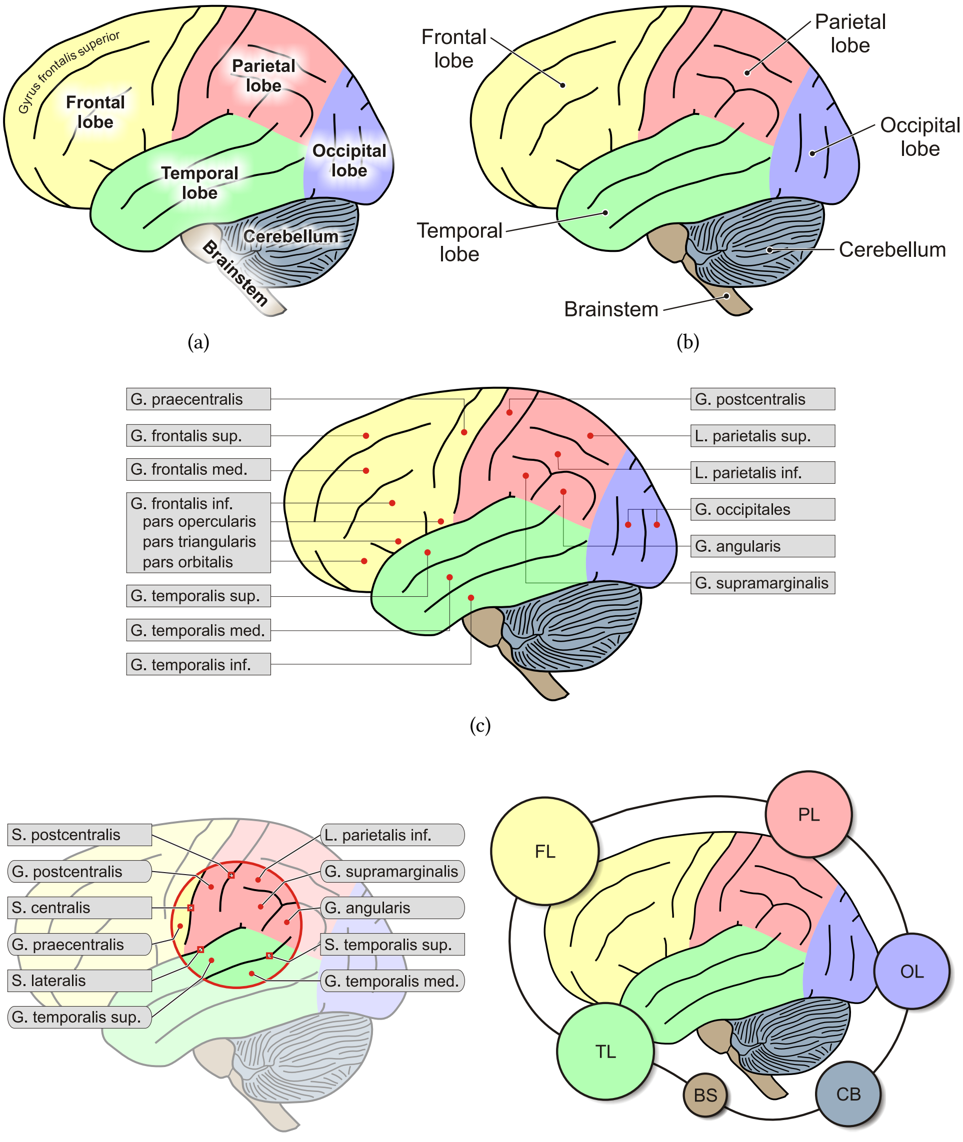


Figure 1: *Overview of labeling techniques in medical visualizations. (a) Internal labels are superimposed on the structures of interest. (b) External labels are positioned on empty screen space and connected to an anchor point on the structure of interest by a line. (c) Boundary labeling organizes the labels along a virtual rectangle enclosing all structures. (d) Excentric labeling annotates structures located inside a draggable, flexible focus region. Labels are stacked to the left and/or right of the region. (e) Necklace maps abandon connection lines and instead relate labels to structures by matching colors and spatial proximity.*

a point on the label box holding the label's textual representation. The definition of an anchor point is crucial. While the center of mass of an objects screen projection is suitable for convex objects, thinning algorithms shrinking the projection to a single pixel [HAS04] or algorithms computing the skeleton of a mesh in 3D [PR98] are generally applicable. Multiple anchor points may exist if an object is partially occluded and it must be decided which parts are to be labeled. External labels are often aligned along the silhouette of all objects in the scene [HAS04]. Close-up views form an exception since the entire screen space may be covered by objects. Mogalle and colleagues formulate requirements on external labels in 2D slice views, which can be generalized to 3D visualizations [MTSP12]. In summary, labels must not overlap with other labels and structures, they should identify a structure unambiguously, and visual clutter must be avoided. To meet the latter two requirements,

- the number of leader crossing must be minimum,
- labels must be placed in close proximity to the structure, i.e. the total leader length must be minimum, and
- leader shapes should be simple, e.g., horizontal or vertical lines instead of zigzagging polylines.

Internal and external labels may be combined in a dynamic labeling. If a structure covers more and more screen space while being zoomed in, its external label can be replaced by an internal one at some point [GAHS05]. Further aspects of dynamic labeling, e.g., level-of-detail dependent labeling and interactive labeling speed, were discussed in the context of street maps [BDY06].

Boundary labeling generates a very tidy layout by organizing all labels along a virtual rectangle enclosing the entire scene (Fig. 1c). While the term was coined by Bekos and colleagues [BKSW05], Preim and colleagues already used this technique for the exploration of anatomical models [PRS97] and Ali and colleagues referred to it as "flush layout" [AHS05]. Each label is connected by a leader to an anchor point on its associated structure. Optimization approaches for minimizing the number of leader crossings, the total leader length, and the number of leader bends have been proposed in the context of static 2D maps [BKSW05,BHKN09] and 3D interactive visualizations [AHS05]. A circular boundary shape has been employed in [BSF*11]. Note that the tidiness of a boundary layout comes at the expense of a restricted freedom in label positioning which must be accounted for in optimization.

For structures being partially occluded or structures of the same type spread over multiple locations in the scene, it might be desirable to connect a single label to multiple anchor points (*many-to-one labeling problem*, see the label "G. occipitales" in Fig. 1c). Solutions to this problem tailored to boundary labeling have been presented in [BCF*13,Lin10]).

Excentric labeling is dedicated to annotating subsets of dense data and was presented by Fekete and Plaisant [FP99] (Fig. 1d). Labeling a subset of the scene is in contrast to the previous techniques, which often aim at labeling large parts. It is accomplished by means of a moveable, flexible focus region which can be dragged by the user. The labels of the focused structures are displayed in stacks to one or both sides of the focus region and connected to the structures by leaders. Fink and colleagues extended excentric labeling by techniques for creating a visually pleasing annotation, e.g., the use Bézier curves instead of zigzagging polylines and the optimization of total leader length [FHS*12].

Necklace maps abandon leaders and instead relate labels to structures by matching colors and spatial proximity in order to generate an uncluttered visualization (Fig. 1e). They were proposed by Speckmann and Verbeek for visualizing statistical data on geographical maps [SV10]. In the necklace map approach, labels are referred to as *symbols*. They are organized on a one-dimensional curve (the necklace) that surrounds the map or a subregion. Circles and bars have been implemented as symbol shapes. A data attribute is mapped to the area of the circular symbols or to the length of the bar-shaped symbols, respectively. Optimizing symbol sizes and positions is NP-hard. Speckmann and Verbeek contribute an algorithm that is exact up to a certain symbol density.

Boundary labeling, excentric labeling, and necklace maps may be seen as variants of external labeling since all position labels outside the structures of interest. We think however that they exhibit sufficient unique characteristics to be treated as unique labeling techniques.

3. Overview of Medical Labeling Work

Preim and Botha dedicate a section of their book to labeling medical visualizations [PB13]. We extend their set of reviewed techniques, update and extend their classification, and we provide guidelines for choosing an appropriate labeling technique. We collected labeling work from the IEEE and ACM electronic libraries and a Google search and categorize it according to the employed labeling techniques. We dedicate an extra category to labeling slice-based visualizations since they are most prevalent in clinical routine.

3.1. Internal Labels

Mori and colleagues describe a method for the automatic extraction of the bronchial tree from Computed Tomography (CT) images and for the automatic identification and naming of the bronchial branches [MHST00]. The surface of the extracted tree serves as the input for a virtual bronchoscopy system facilitating flights through the bronchus. Interpreting the images rendered from a viewpoint inside the tree is hampered by a lack of spatial orientation. To improve this situation, the name of the current branch is superimposed and outgoing child branches are annotated.

Petrovic and colleagues present a GPU-based approach for efficiently rendering very large sets of fiber tracts derived from whole-brain Diffusion Tensor Imaging (DTI) data [PFK07]. They propose a Level-of-Detail management system and a streamtube imposter construct for fast rendering and the reduction of overdraw. Curvature-correct text labels are employed for annotating the simulated tubes. The labeling is integrated in the fragment processing leading to the impression of text being attached to the imposter's surface. Special care is taken to orient the text right-side-up and to draw labels only if their corresponding geometry is close enough for the text to be legible. Fading labels in and out by alpha blending prevents label popping.

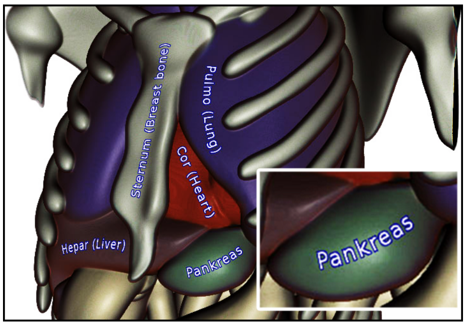


Figure 2: *Internal labels are projected onto the surface in order to convey its 3D shape. Image adapted from [RPRH07].*

Ropinski and colleagues argue that in surface-based 3D medical illustrations, internal labels should not only match the screen representation of an object but also convey its 3D shape, i.e. its varying depth structure [RPRH07]. Hence, they project a label onto the surface (Fig. 2). Special care must be taken to maintain legibility in case of noisy, strongly bended surfaces, and highly occluded regions, e.g., the sulci of the brain's surface. As a solution, the label is projected onto a smooth intermediate surface, a bezier patch in [RPRH07] and a *text scaffold* in [CG08], whose adherence to the original surface can be adjusted. Furthermore, the intermediate surface is oriented along the medial axis of its object as it is defined in image space and such that perspective distortion of labels is minimized [RPRH07].

Jiang and colleagues propose a method for annotating vascular structures in volume rendered views integrated in computer-assisted surgery systems [JNH*13]. While investigating highly-branching structures, surgeons strongly benefit from guidance by labeling. First, a surface model of the vasculature is constructed based on centerline and radius information. Then, in a two-pass rendering process, labels are projected from the current viewpoint onto the surface model which is after that rendered into a depth buffer image (first pass) followed by a ray-casting of the original data volume considering the depth buffer (second pass). Since vessels are often partially occluded by other vessels or organs, they are assigned multiple identical labels at intervals along their run. The legibility of labels may be hampered along surface parts generated from jagged centerlines. The problem is mitigated by centerline smoothing. The impact of transfer function adjustment on the visibility of vessels and the legibility of labels is not discussed.

Major an colleagues present the automated landmarking and labeling of spinal columns in CT images [MHSB13]. Disks are first superimposed on the automatically detected intervertebral spaces. The mean of the disks' positions is then employed for placing the corresponding vertebral text labels. The labeling approach is integrated in 2D slice views as well as in 3D volume rendered views.

3.2. External Labels

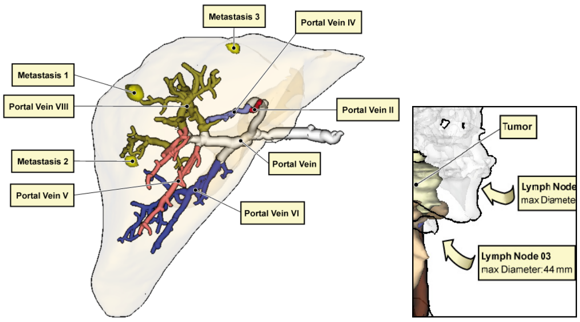
Hartmann, Ali, and Strothotte employ dynamic potential fields to generate effective and appealing label layouts for complex-shaped anatomical 3D models [HAS04]. Requirements on a layout, such as proximity of object and label and prevention of overlapping labels, are formalized in terms of attractive and repulsive forces steering the label placement. Anchor points are computed via thinning an object's screen projection to a single pixel. Limiting to the labeling approach is its inability to prevent leader crossings and visual discontinuities during interaction (frame-coherency).

Ali, Hartmann, and Strothotte extend their work by a variety of real-time label layout algorithms eliminating these limitations [AHS05]. Each algorithm is designed for a combination of a particular layout and leader style and demonstrated by an anatomical model. The proposed *flush* layout corresponds to boundary labeling (Fig. 1c) while the circular layout aligns the labels along the silhouette of the 3D model. Straight and orthogonal leaders are supported. The latter represent axis-aligned lines with their bends made at orthogonal angles. Anchor points are computed by applying a distance transform to an object's screen space projection. The pixel with the largest distance is chosen.

Sonnet and colleagues augment interactive explosion diagrams of complex 3D models by dynamic, scrollable annotations [SCS04]. They demonstrate their approach amongst others by anatomical models. The user may move the pointer over an object causing its textual description to be displayed. The closer the pointer gets to the object's centroid, the larger the label box becomes revealing more and more of the text. At entering the object, only a small box is displayed to account for the possibly unintentional or temporary hovering on the way to another object. The box is connected to the object's centroid (anchor point) by a transparent triangle emphasizing togetherness.

Bruckner and Gröller integrate external labels in the *VolumeShop* system to simplify orientation in an interactive environment, e.g., when exploring anatomical models [BG05]. They propose a simple algorithm aligning labels along the convex hull of the projected bounding volumes of all visible objects. This resembles the silhouette-based circular layout by Ali and colleagues [AHS05]. Special care is taken to resolve leader crossings and overlapping labels, which however causes visual discontinuities in animated views due to the extra computational effort. Details on the computation of anchor points are not given.

Mühler and Preim present techniques for annotating 3D structures reconstructed from medical image data in surgery planning [MP09]. They extend the work of Ali and colleagues [AHS05] by tackling the labeling of structures located inside or behind semi-transparent objects, e.g., the portal vein and metastases inside the liver parenchyma (Fig. 3a). Standard visibility tests by means of depth buffering return no objects to be labeled in such situations.



(a) (b)

Figure 3: *(a) Labeling of the portal vein and metastases located inside the semi-transparent liver parenchyma. Standard visibility tests by means of depth buffering would return no objects to be labeled here. Image from [MP09]. (b) Hidden lymph nodes labeled by bended arrows indicating presence and location. Image adapted from [MP09].*

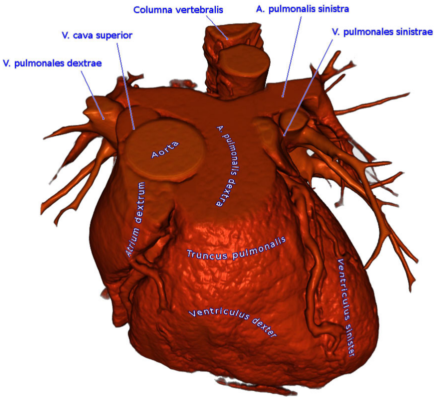


Figure 4: *Hybrid layout comprising internal and external labels. If the screen coverage of a projected object is sufficiently large, an internal label is drawn. Image from [RPRH07].*

Hence, a multi-buffering approach is proposed treating all objects as visible and computing a set of anchor point candidates for each of them. The candidates are derived by distance transforms applied on the buffers. Next, rays are cast from each anchor point to the viewer and the opacity of intersected objects is accumulated. If it is above a threshold for each anchor point, the object is not labeled. Otherwise, the point with the "smallest" occlusion is chosen.

A further contribution is the labeling of currently hidden objects to recall their existence. For instance, no lymph node must be overlooked in planning neck dissections (Fig. 3b). Bended, arrow-shaped leaders indicate the presence and location of currently invisible lymph nodes.

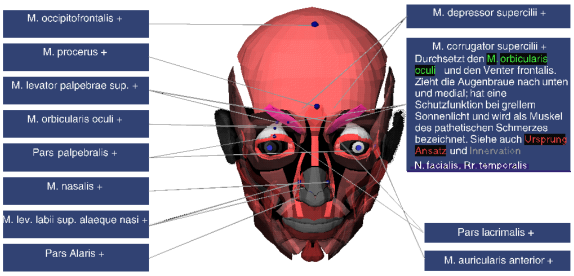
3.3. Internal and External Labels

Götzelmann and colleagues propose a hybrid label layout comprising internal and external labels [GAHS05]. The label type is chosen depending on the zoom level. For instance, if an object gets closer to the camera and occupies more screen space, an external label is replaced by an internal one to exploit the gained space. During interaction, the entire scene is continuously projected to screen space and the skeleton of each object's projection is determined. It is then tested, whether an internal label would be given sufficient space to be placed along the skeleton while guaranteeing minimal readability. If this is not the case, an external label is drawn whose anchor point is computed according to [AHS05]. The labeling approach has been integrated in a framework for anatomical education [VGHN08].

Ropinski and colleagues also propose a hybrid layout [RPRH07]. If the screen coverage of a projected object is sufficient to place a label along the pojection's medial axis while guaranteeing a minimum label size, an internal label is drawn. Otherwise, external labels are employed (Fig. 4).

3.4. Boundary Labeling

Preim and colleagues present a system for the exploration of anatomical models which combines zooming techniques, fisheye views, and interactive external labels [PRS97]. The labels are aligned on the left and right boundary of a rectangle enclosing the model (Fig. 5). They are connected via straight lines to anchor points on the model parts. The computation of the anchor points is not described. The focus is on the interaction with the model and the labels. For instance, selecting a label causes (1) an enlargement of the corresponding model part and a simultaneous shrinking of the other parts (fisheye technique) as well as (2) an enlargement of the label box gaining space for a more detailed description. In (2), neighboring labels are automatically relocated and minimized if necessary. Assigning a single label to multiple model parts (many-to-one labeling) is supported, e.g., to facial muscles in both sides of the face. However, optimization with respect to leader crossings and total leader length seems to be missing (Fig. 5).



Durchsetzt den M. orbicularis oculi und den Venter frontalis. Zieht die Augenbraue nach unten und medial; hat eine Schutzfunktion bei grellem Sonnenlicht und wird als Muskel des pathetischen Schmerzes bezeichnet. Siehe auch Ursprung Ansatz und Innervation

N. facialis, Rr. temporalis

Figure 5: *Boundary labeling of facial muscles. A label of muscles above the eye has been selected causing a description to be displayed (right), the muscles to be enlarged, and two labels to be pushed downward. Image from [PRS97].*

Eichelbaum and colleagues visualize human brain connectivity derived from Diffusion-weighted magnetic resonance imaging (DW-MRI) data [EWH*10]. They employ fiber tracking and clustering to generate fiber bundles which illustrate the connection of brain regions. The bundles are displayed together with the regions inside a semi-transparent surface of the brain. The regions are labeled according to [BKSW05] for improving spatial orientation.

Battersby and colleagues [BSF*11] employ *ring maps* for visualizing multivariate epidemiological data [BSF*11]. A ring map shows a 2D geographical map enclosed by a virtual circular boundary shape along which glyphs are aligned. The glyphs are composed of n parts for encoding n variates. The parts are located at an uniformly increasing distance to the boundary. Each set of parts with equal distance to the boundary represents a ring. The glyphs and county names are connected to their respective map region via straight leaders. Label and anchor point positions are chosen such that glyphs are uniformly distributed, located close to their region, and leaders do not cross.

3.5. Excentric Labeling

Fekete and Plaisant introduce excentric labeling for the annotation of dense, point-based data representations, e.g., scatter plots [FP99]. A circular focus region is dragged across the representation and labels of the objects in focus are displayed in stacks to the left and/or right of the region. Multiple labeling variants are proposed. In the basic variant, straight lines connect points – coincident with the anchor points here – and labels. In the radial variant, leader crossings are prevented by first connecting the labeled point with a point on the boundary of the focus region and then, bending towards the sorted stack of labels. In further variants, the label order and justification reflect the y- and x-position of the labeled points, respectively. However, this is at the expense of crossing-free leaders. Plaisant and colleagues integrate excentric labeling in *LifeLines* – a system for visualizing personal histories [PMR*96]. They demonstrate how the investigation of patient records benefits from labeling health-related events (Fig. 6).

Luboschik and colleagues present a point-feature labeling approach, which is fast and avoids overlapping labels as well as the occlusion of other visual representatives such as leaders and icons [LSC08]. In contrast to the work of Fekete and Plaisant [FP99], each point is initially labeled. In the first step of an iterative, particle-based approach, all points with sufficient empty space in their direct neighborhood are annotated by an adjacent label (no leader). Then, the remaining points are annotated by positioning the label as close as possible and connecting it to the point by a straight line. The labeling approach is coupled with a movable label lens. Labels of focused points are relocated along the outside of the lens such that they do not overlap other labels. Straight leaders are drawn to convey correspondence. The approach has been demonstrated amongst others for the labeling of symbol maps encoding health data.

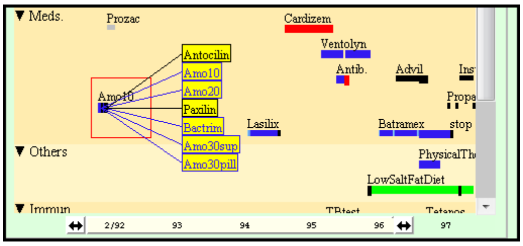


Figure 6: *Excentric labeling in LifeLines [PMR* 96]. A rectangular focus region is dragged across events in a patient record. Drugs administered in a narrow time frame become readable.*

3.6. Necklace Maps

Glaßer and colleagues apply necklace maps to labeling clusters of breast tumor tissue with cluster-specific perfusion information [GLP14]. The necklace surrounds an abstract representation of the tumor (Fig. 7). Each set of equally-colored, spindle-shaped extensions represents a cluster of voxels exhibiting similar perfusion characteristics. The extensions originate at the cluster's center and are directed towards the subregions of the tumor. For each cluster, a label is strung on the necklace and colored according to the cluster's color. Proximity of labels and clusters is not optimized. Each label shows an iconic representation of the wash-in and wash-out of a contrast agent.

Oeltze-Jafra and colleagues combine dynamic excentric labeling and static necklace maps for the interactive visual exploration of multi-channel fluorescence microscopy data [OPH*14]. Nested necklaces show information aggregated over all channels as well as individual channels.

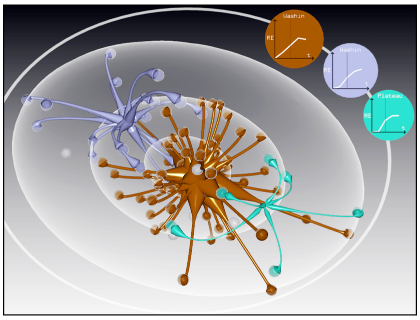


Figure 7: *Abstract visualization of three regions with distinct perfusion in a breast tumor. Labels showing plots of contrast agent accumulation are strung on a surrounding necklace. Correspondence is conveyed by color. Image based on [GLP14].*

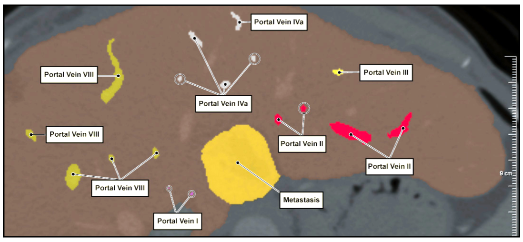


Figure 8: *In a slice view, branches of the portal vein and metastases inside the liver parenchyma (brown, large region) are annotated. Disconnected, but close parts of the same branch are summarized by one label. Image from [MP09].*

3.7. Labeling Slice-Based Visualizations

The manual annotation of digital images is crucial in clinical routine. Efforts were made to advance the generation, management, and dissemination of annotations. Cai and colleagues present a web-based system for the collaborative generation and editing of labels supporting collaborative decision making [CFF01]. Goede and colleagues propose a methodology and implementation for annotating digital images [GLC*04]. They define a set of rules to standardize the annotation process.

Mühler and Preim discuss important aspects of automatically labeling slice views [MP09]. If empty space exists in the image, e.g., around the head in images of the brain, external labels should be placed there. Otherwise, they should be positioned on less important structures, e.g., on the liver parenchyma in an examination of inner metastases and vessels (Fig. 8). Elongated structures with a small diameter, e.g., vessels, often appear as disconnected components. They should be summarized by one label if they are located close together (Fig. 8). Slice coherency of labels must be guaranteed to support their visual tracking and to avoid flickering artifacts. Mühler and Preim lock the position of a label across multiple slices until it overlaps with a crucial image region. They also employ many-to-one labeling and achieve crossing-free leaders.

Mogalle and colleagues present an optimal placement of external labels representing radiological findings in 2D slice data [MTSP12]. They focus on avoiding leader crossings, mutually overlapping labels and labels occluding findings, and on minimizing total leader length. A local optimization algorithm achieves a trade-off between speed and labeling quality. It samples directions for label placement starting at the anchor point of a structure and assesses a direction's compliance with each of the requirements (inset of Fig. 9). This results in a set of weighted candidate directions for each object. The final layout is derived from these sets either by a greedy optimization or a label shifting approach (Fig. 9). The labeling is limited to ≈ 10 annotations, which is however realistic for radiological data.

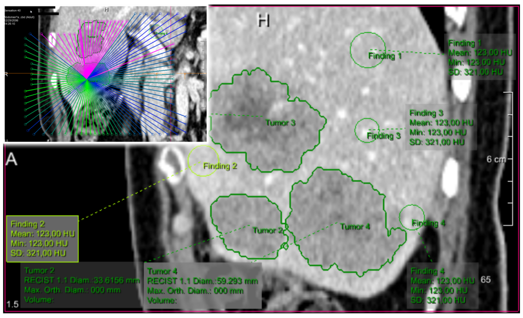


Figure 9: *Labeling radiological findings in 2D slice data. Label positions for each finding are searched in discrete directions starting at the finding's anchor point (inset). Green rays represent directions complying to a set of constraints, e.g., no occlusion of other findings. Image adapted from [MTSP12].*

4. Guidelines for Labeling Medical Visualizations

The search for a suitable labeling technique is first guided by the visual representation of the data, second, the type of structures to be labeled, and third, the individual requirements on an effective label layout (Sec. 2.1). This order is reflected by the decision diagram in Figure 10. The decision process leads to publications describing a suitable technique. For instance, if surfaces of arbitrary shape shall be labeled and readability of the labels, unambiguity of the association between label and structure, and the tidiness of the label layout are the may concerns, boundary labeling according to [PRS97, EWH*10] is suitable.

In general, *internal labels* facilitate an easy visual association with a structure and lead to a compact label layout. *External labels*, do not occlude their associated structure, are easier to read, and better suited for small structures and dense data. However, they demand extra effort to establish the visual association with a structure. Leaders, proximity, and color are employed requiring optimization steps, e.g., to reduce leader crossings, achieve sufficient proximity for all labels, and avoid overlapping labels. A dynamic application of both *internal and external labels* dependent on a structure's screen coverage is appropriate in interactive 3D views where zooming is frequently used. The main strength of *boundary labeling* is the tidiness of the label layout providing a fast overview of all labeled structures. *Excentric labeling* is particularly suited for the piece-wise exploration of very dense data. So far, it has only been demonstrated for representations of abstract data, such as patient records [FP99]. Another potential application area could be the exploration of large, annotated microscopic images, e.g., in histology. *Necklace maps* avoid the visual clutter caused by leaders and show little occlusion of the data at the expense of additionally required screen space and weaker visual association of labels and structures. They could prove beneficial in *volume renderings* where separate

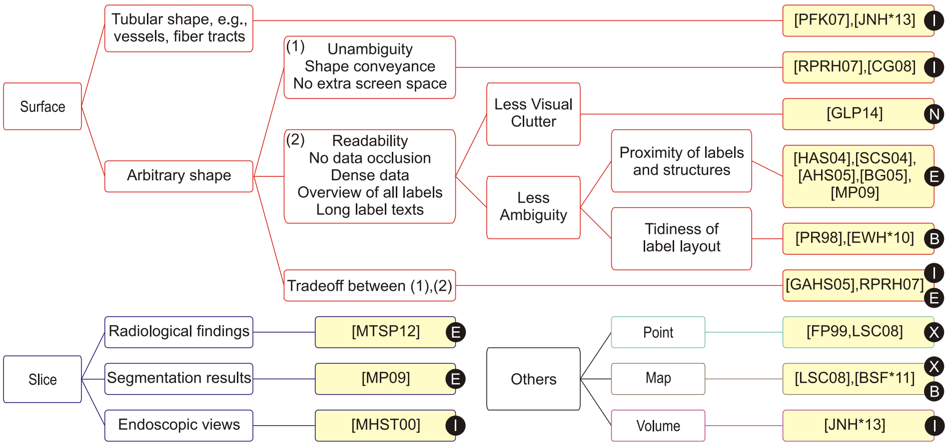


Figure 10: *Decision diagram for choosing a labeling technique dependent on the data representation (surface rendering, slice view, point set, map, or volume rendering), the type of structures to be labeled, and the individual requirements on an effective label layout. The yellowish boxes show the related work. The circled letters encode the labeling technique: I=internal labels (Sec. 3.1), E=external labels (Sec. 3.2), B=boundary labeling (Sec. 3.4), X=excentric labeling (Sec. 3.5), and N=necklace maps (Sec. 3.6).*

structures are discernible due to different colors and opacities but not processable, e.g., for anchor point computation.

In *medical education* systems, 3D surface models should be annotated by a combination of internal and external labels according to customs in hand-drawn medical illustrations. External labels and boundary labeling are better suited for displaying long label texts, e.g., descriptions or links to other structures, and for generating foldout groups of labels, e.g., all bones of the foot. In *intervention planning* and *medical training* systems, external labels should be used since they are more legible than internal ones, provide a clearer overview of all relevant structures, may indicate currently hidden objects in 3D scenes [MP09], and above all, they do not occlude structures. Occlusion is critical since, e.g., the irregular and complex shape of an object may influence the interventional strategy. In 3D views of *vasculature* and *fiber tracts*, internal labels should be employed. Thin, elongated structures are often only visible at intervals due to mutual occlusion and occlusion by other structures. Identical internal labels applied to these intervals avoid the visual clutter that would be induced by an external many-to-one labeling [JNH*13]. An exception are 2D and 3D views for *vascular diagnosis*. Here, external labels are more appropriate since internal ones may interfere with the perception of pathologic shape variances, e.g., stenoses, and the evaluation of vascular cross-sections and compositions of the vessel wall, e.g., in plaque detection. External labels are generally recommended for slice views in *radiology* since they do not occlude the associated findings. Boundary labeling treating the image border as boundary would be best here in terms of occlusion but would also require shrinking the image to make space for the labels. Optimization with respect to placing labels on less important image parts is more promising [MTSP12]. A similar situation exists in *virtual endocsopy* where the endoscopic view should occupy maximum screen space. However, internal labels are more appropriate here, e.g, for annotating branches, since their in-site position causes less distraction while navigating the endoscope. Pathologies, e.g., polyps should again be annotated by external labels.

5. Concluding Remarks

We provided an overview of the existing medical labeling work and proposed a classification with respect to the employed labeling techniques. Furthermore, we gave guidelines for choosing a suitable technique. The labeling of 3D surfaces is the most extensively researched subfield. Labeling medical volume renderings and slice views are underrepresented measured against their wide-spread use and may pose interesting directions for future work. Labeling slice views may benefit from transferring more knowledge in cartography, where labeling is widely studied.

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