Visual Analysis of Abnormal Thickness of Intraretinal Layers

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ABSTRACT

Optical coherence tomography (OCT) enables high-resolution 3D imaging of intraretinal layers to understand a variety of retinal and systemic disorders. Yet, discovering and relating localized changes of layers in complex OCT datasets is challenging. We propose a combination of systematic data reduction and interactive visualization to support the analysis of abnormal layer thickness. First, we classify and extract regions of abnormal thickness per retinal layer. Second, we compile the regions in a composite map and show their spatial distribution in a novel overview visualization. Third, we integrate coordinated interaction to quickly browse through the data and investigate selected regions in detail. Altogether, our solution enables a fast and targeted analysis of abnormal changes of intraretinal layers for assisting medical diagnoses.

Index Terms: Human-centered computing—Visualization—Visualization application domains—Visual analytics

1 INTRODUCTION

Optical coherence tomography (OCT) is a widely-used noninvasive technique to capture high-resolution 3D images of retinal substructures. Ophthalmologists analyze the resulting data to understand a variety of retinal and systemic disorders, e.g., diabetic retinopathy, age-related macular degeneration, and glaucoma. Particularly, the thickness of segmented intraretinal layers is used to assess the condition of the retina. However, identifying and relating regions of abnormal thickness in complex OCT datasets is challenging.

Previously, layer thickness has been visually analyzed per selected part of volumetric OCT datasets (Fig. 1a). Mainly two approaches exist: (i) cross-sectional visualizations of individual 2D image slices together with overlaid thickness profiles (Fig. 1b) and (ii) visualizations of individual thickness maps per retinal layer (Fig. 1c). Yet, common OCT datasets consist of hundreds of slice images and thickness maps of up to 14 segmented retinal layers. Hence, discovering and keeping track of abnormal regions while switching between those parts is time-consuming. Moreover, correlations between spatially separated regions may go unnoticed by viewing each slice image or thickness map individually. Capturing localized regions and evaluating their spatial distribution is however mandatory for identifying early signs of diseases and investigating progressions.

We aim at supporting ophthalmologists in analyzing all regions of abnormal thickness in all parts of a OCT datasets. To this end, we address three fundamental questions: (Q1) how to extract regions of abnormal thickness from the data, (Q2) how to visualize their spatial distribution, and (Q3) how to investigate selected regions in detail.

2 EXTRACTION OF ABNORMAL REGIONS

We apply systematic data reduction to extract all regions of abnormal thickness from a given OCT dataset (Q1). To this end, we use a three-step procedure: (i) classifying thickness data as normal

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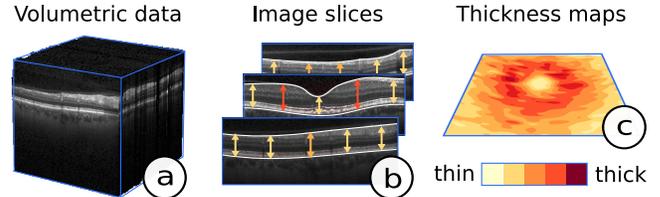
Figure 1: Common approaches for visualizing retinal thickness data. The OCT data (a) are either shown image slice by image slice with overlaid thickness profiles (b) or layer by layer via thickness maps (c).
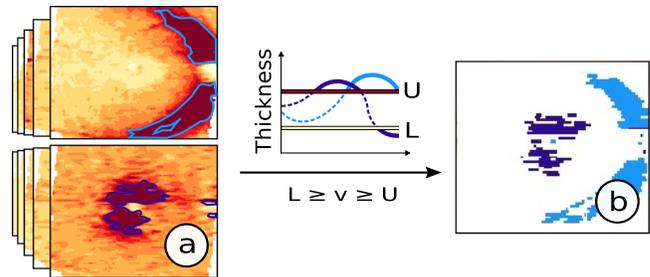

Figure 2: Extracting and compiling regions of abnormal thickness. All thickness values v exceeding the lower L or the upper U threshold are classified as abnormal (a). Abnormal regions (outline) are extracted per retinal layer and compiled in a composite map (b).

or abnormal using suitable thresholds, (ii) extracting regions of abnormal thickness from each retinal layer, and (iii) compiling all resulting regions in one composite map.

Thickness classification We first compute precise thickness values for every point on the retina for each segmented layer of a dataset. We then apply thresholding to classify the values as normal or abnormal (Fig. 2a). Two types of thresholds per layer are applied: (i) general clinically established thickness ranges or (ii) confidence intervals of a specific control group. In the first case, two boundary values are given for each layer. In the second case, boundary values vary point by point on the layers. This allows to judge the thickness data both globally and locally in relation to normative data [4].

Region extraction After thickness classification, regions of abnormal thickness are extracted. With both thresholding types, all thickness values that exceed the applied boundary values are marked as relevant (Fig. 2a). All other values are considered to be not of immediate importance and are treated as supplementary information. Regions of abnormal thickness are formed by adjacent points with marked values on each retinal layer. Extracting these regions effectively reduces the amount of data to be analyzed.

Map composition In this step, all extracted regions are transformed into a common spatial frame of reference. As a result, we obtain one composite map per dataset (Fig. 2b). Each point of this map stores information about abnormal thickness of all source layers. The map can then be queried regarding the existence and numeric value of abnormal thickness at a specific point or subarea of the
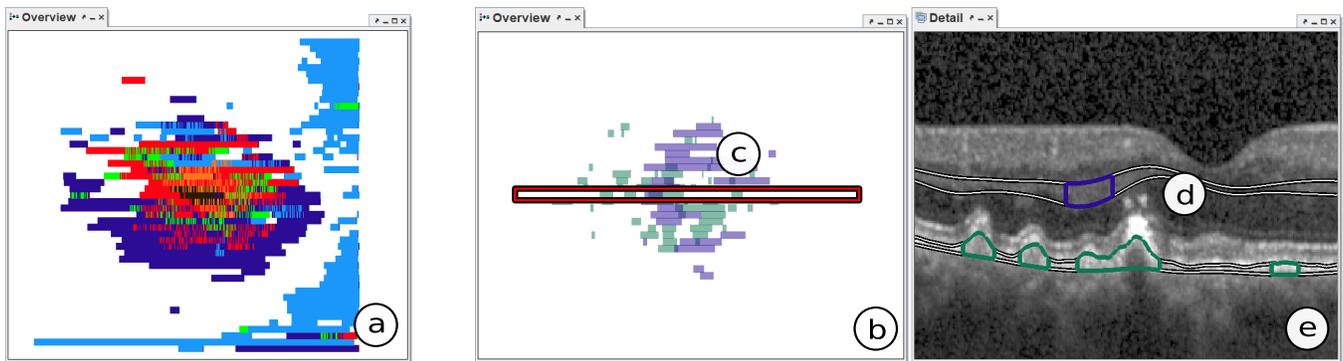
Figure 3: Visualizing regions of abnormal thickness. The overviews show two datasets: a severe case with many overlapping regions of several layers (a) and a mild case with localized regions of two layers (b). The regions are colored by source layer and drawn via random weaving (a) and transparency (b). A region is selected in an overview (c) and matched parts of a slice image are highlighted (d) in a linked detail view (e).

retina or with respect to what layers are affected. This provides the basis for subsequent visual analysis of the reduced data.

3 VISUALIZATION OF ABNORMAL REGIONS

We visualize abnormal regions in the context of entire datasets to support ophthalmologists in understanding their spatial distribution (Q2). For this purpose, we design a visualization tool based on multiple coordinated views (Fig. 3). Two types of interlinked views are supported: (i) an overview of all regions based on the composite map and (ii) detail views of regions per image slice or layer.

Overview visualization   The overview shows the spatial distribution of all extracted regions of all retinal layers in a combined 2D map. To differentiate between regions of different layers, each layer is assigned a unique color and all associated regions are colored accordingly. In addition, dedicated rendering techniques help to deal with overlapping regions. Three options are available: (i) a user-specified drawing sequence, (ii) transparency, and (iii) weaving [1, 2]. The first and second option are suitable for few affected layers with regions being either disjoined or colocated, respectively (Fig. 3b). The third option reveals the degree of overlap and which layers are affected most, even in case of many overlapping regions from several layers (Fig. 3a). This design extends existing displays, in that it allows to view all regions of an entire dataset at a glance without having to flip through individual image slices or thickness maps of layers manually. Hence, abnormal characteristics and spatial correlations between layers can be easily discovered.

Detail visualization   The detail views show extracted regions either in individual image slices or in thickness maps per retinal layer. For each image slice, regions are encoded as highlighted image parts and affected layers are depicted as superimposed lines (Fig. 3e). This helps to relate the spatial extent of regions to the raw OCT data and to the exact profiles of the segmented layers. For each layer, regions are displayed as highlighted parts of associated color-coded thickness maps. This allows to inspect the value range of regions in the context of the entire thickness data of the layers.

4 INVESTIGATION OF ABNORMAL REGIONS

We integrate coordinated interaction techniques to facilitate interactive investigation of selected abnormal regions (Q3). Particularly, we support (i) filtering of regions and (ii) browsing through regions.

Region filtering   The extraction and visual encoding of regions are steered via controls of the user interface. Especially, the thresholds for classifying thickness values as normal or abnormal can be interactively adjusted. This way, values far beyond or close to the original boundaries are displayed. For example, by slightly narrowing the normal thickness range per layer, mild changes in an

early stage of a disease that not yet exceed the predefined thresholds may become visible. In addition, regions of certain layers and regions with thickness values that only go beyond lower or upper boundary values may be filtered out. This allows ophthalmologists to concentrate on patient-specific aspects, e.g., spatial correlation of neighboring layers with respect to abnormal thinning or thickening.

Region browsing   Starting in the overview visualization, extracted regions or user-specified subareas of the retina can be interactively selected (Fig. 3c). The detail visualizations are then updated accordingly and continuously display matched image slices or thickness maps with abnormal parts of affected layers highlighted (Fig. 3d). This allows to quickly browse through the data and to directly view all abnormal regions in detail, even in case of scattered and localized changes. Moreover, by going from overview to detail, ophthalmologists can easily investigate only those areas of the retina in the complex datasets that are relevant for their diagnoses.

5 APPLICATION

We integrated our solution in a visual analysis tool for retinal OCT data [4]. Our approach is currently tested by domain experts. They were already able to quickly identify regions of abnormal thickness in their datasets and to investigate correlations of these regions between layers. They also confirmed that discovering such regions and analyzing their spatial distribution are essential steps in their analysis workflow [3]. Accordingly, our tool will be used as a basis for further extension, fine-tuning, and evaluation together with them.

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