LAPPEENRANTA UNIVERSITY OF TECHNOLOGY
DEPARTMENT OF INFORMATION TECHNOLOGY

Image Annotation Tool for Collecting Expert Knowledge

Examiner: Prof. Dr. Lutz Priese
Supervisors: D. Sc. (Tech.) Lasse Lensu, M. Sc. (Tech.) Tomi Kauppi

Lappeenranta, September 27, 2007

Yoo-Jin Jeong
Görresstr. 2
56068 Koblenz
yoojin@uni-koblenz.de

Contents

1 Introduction

1.1 Background

Diabetes, a metabolic disease that is characterized by a high blood glucose level, is nowadays one of the most rapidly expanding threats in health care, not only in Finland but worldwide. At the present time, the number of people, who are afflicted with diabetes, exceeds 150 million people. According to the „World Health Organisation [1]“ it has been appraised that the number of with diabetes sickened persons will increase to 350 million by the year 2025 [2].

Merely in Finland there are approximately 200,000 Diabetes patients, according to the statistics accomplished by „KELA“ and the „Health 2000“ study performed by the „National Public Health Institute“ [3], 40,000 of them have type 1 diabetes, which occurs when the insulin producing cells are damaged, 160,000 type 2 diabetes, which is the insensibility against insulin or a low secretion of it [4]. This is nearly 4% of the whole population. Worldwide there is no country with an incidence number of type 1 diabetes exceeding the one in Finland [2]. Even though the occurence of type 2 diabetes is not that high, the amount of afflicted persons follows the western trend [3]. Alarmingly, about 50,000 people are predicted to be diabetes afflicted without knowing it [2].

Notwithstanding the amount of type 1 diabetes sickened persons is extensively smaller than that of people with type 2 diabetes, its rising occurence in young children, the possibility of complications caused by insufficient treatment and its long duration make diabetes an important issue for health care. [2]

Even though diabetes patients only represent 4% of the finnish population, the costs for the health care is over 11% of its total annual outgo. In the year 1997 the annual expenditure of the care of diabetics was about 875 million euros, therefrom about 58%, thus 505 million euros, were invested to treat especially the complications caused by diabetes. [4]

Diabetes can lead to a variety of complications, such as macro and micro vascular alterations that can cause heart disease and retinopathy. Kidney failure, one of the most serious seculae, as well can be evoked by this disease, whereas problems with feet and eyesight are the most common ones. [5]

Diabetic retinopathy is the leading cause of blindness in the working population of western countries. As it is a silent disease, a lot of people may not recognise it until the retinal alterations has reached a level, where adjuvant treatment is virtually impossible. The affection of diabetic retinopathy depends on the patient's age, the point in time when the disease appears and its duration. [1]

If the diagnosis of diabetic retinopathy is early enough, adequate treatment cannot prevent the disease itself, but the retinal complications can be alleviated. By dint of proper screening and laser surgery the probability of losing the eyesight can be decreased significantly. From the time when diabetes is diagnosed annual screening of patients for retinopathy is essential. This implicates a huge amount of retinal scans, which have to be examined by medical experts. This process obviously is time consuming and involves high costs. This fact and the lack of ophthalmologists impede diabetes patients from getting regular examinations. [1]

In the course of the development in diabetes-related research a collaborative project of Lappeenranta University of Technology, University of Kuopio, University of Joensuu, University of Bristol, London Imperial College, Mikkeli Polytechnics and a few eye clinics was created. [5] [6] [7]

This thesis is connected to this project called „ImageRet“ and contributes to the medical research of diabetic retinopathy. Primarily it deals with the extension and improvement of an „image annotation tool“, which was developed within the project.

1.2 Aims and Objectives

This thesis deals with the current version of the image annotation tool and its handling with the pen-based input. The main objective is the examination of the current version of the annotation tool, namely the understanding of its most relevant features, the testing of implementation possibilities for improved tools, such as the development of a new semi-automatic and pen-based functionality for the tool that should offer the expert a different kind of feature for marking regions and objects.

To fully understand the purpose of the image annotation tool and to be able to develop proper tools to support medical experts, it is essential to acquire a well-founded background knowledge of diabetes and its complications, especially diabetic retinopathy.

In addition, the initial step to modify the image annotation tool is the colour calibration of the used device, namely an Acer TravelMate C213TMi tablet PC with a pen-based input. This first task should be done, due to the fact that the hitherto existing works with the image annotation tool were based upon uncalibrated environments, which could have caused differences in image annotation results. But for the purpose of gathering reliable medical knowledge from digital images, the application of calibration is indispensable.

All tools are implemented in Matlab, as the current version of the image annotation tool is also written in that language. The high-level interpreted language Matlab has a lot of advantages, which can be exploited, especially for image processing works. It has three main advantages, namely a huge library of high level functions for mathematic and plotting uses, its use of arrays and images as named variables, and its interactivity.

2 Diabetes

Diabetes is a chronic metabolic disorder, which emerges on grounds of an insulin deficiency or an insulin resistance or both. This dysfunction provokes hyperglycemia, a high level of blood glucose. Depending on the cause of the disease there are different types of diabetes, which have similarities in their consequences though. Apart from type 1 and type 2 diabetes, there are also gestational diabetes, which originates due to a disorder of glucose metabolism and appears during pregnancy, and a few other special forms of diabetes [3].

2.1 Type 1 Diabetes

Type 1 diabetes, which used to be called „juvenile diabetes [3]“, occurs mostly in the adolescence and results from the destruction of the pancreas, the cells that produce the insulin [2]. This leads to the cessation of the insulin production in the body.

For the sickened person it is vital that this deficiency of the pivotal hormone insulin is being replaced, which primarily happens by multiple injections. In addition, insulin treatment, a special diet, physical workout and further treatments are necessary, so that the monitoring of the blood glucose level is guaranteed.

If one is afflicted by type 1 diabetes, it is a life-long disease. Anyhow, if the care of the disease develops successfully, the patient is able to handle his or her life as well as anybody else [2].

Type 1 diabetes is the most common chronic disease of children and adolescents [8].

2.2 Type 2 Diabetes

Type 2 diabetes for the most part affects middle-aged or elderly people and was therefore used to be termed as „adult-onset diabetes [3]". It has a slow development, while not having an insulin-dependent origin. It originates, however, from an increasing insensibility of the cells against the produced insulin and/or an abnormal low secretion of the hormone relative to blood glucose.

According to the „Swedish National Board of Health and Welfare 1999" the vast majority of diabetic patients, namely 85-90%, have this type of diabetes [2].

The main causes of diabetes type 2 are considered to be excessively rich nutrition as well as low physical activity, which both can lead to obesity and metabolic syndrome, which precedes this kind of diabetes.

Even though the concerned people in Europe are usually over 50 years old, the onset in younger age groups has been announced from several countries [2].

2.3 Complications

There are several complications, which can occur evoked by diabetes: sequelae specific to diabetes and other. Blood vessels affected complications are called, depending on the size of the vessel concerned, either micro- or macroangiopathic.

Microangiopathic sequelae, involved by the impairment of small capillaries, include retinal disease, the so-called „diabetic retinopathy", and kidney disease or „diabetic nephropathy", which may involve kidney dialysis and transplantation [2].

Neuropathy are the alterations, which affect the nervous system; as well as retinopathy and nephropathy one of the complications specific to diabetes, which late consequences can include foot injuries and lower limb amputations.

Complications, which pertain to macroangiopathy, can lead to coronary heart disease, blood circulation difficulties in legs and in the brain. Accelerated and rised arteriosclerosis can redound to these kinds of sequelae, which just as well can originate from other risk factors besides diabetes [3].

The severe complications, which can be aroused by diabetes, affect the patient's way of life considerably and bring in some cases premature death. [2]

The treatment of complications is the most expensive form of diabetes care, and their prevention should be invested at every stage of care and on every level of the care organization. Poor glycemic control is a major factor contributing to the development of the complications of diabetes, in addition to other risk factors. Therefore, more attention should be paid on the quality, follow-up and assessment of care. [4]

In comparison to many other countries, Finland is highly advanced with regard to diabetes care. Yet studies show that finnish people with diabetes have poor glycemic control and high prevalence of complications. [2]

3 Diabetic Retinopathy

3.1 The Anatomy of the Eye

The anatomy of the human eye is illustrated in Fig.1. It shows only the main components of the eye, which are described as follows:

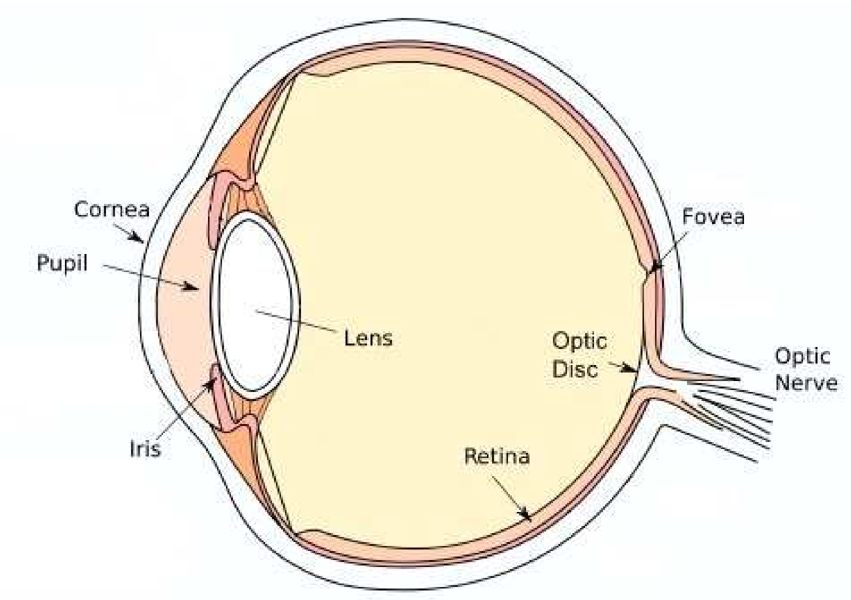


Figure 1: Section of the human eye with its basic components. [12]

The **cornea** is a transparent layer just in front of the eye, which is the first structure, the light passes, when it enters the eye. The usually half a millimetre thick cornea is responsible for about 70% of the total focusing functionality of the eye. [9] [10]

Right behind the cornea lies the **iris**, a thin diaphragm, that controls the amount of light, which arrives the retina. It contains an opening, the **pupil**, with whose constriction and dilation the regulation of the light can be made [10].

The next layer, the **lense**, a complex multi-layered structure, refracts the incoming light. It is able to change its shape, during the process of accommodation, that is the act of focusing objects at various distances. [9] [10]

The human **retina**, which, to a large extent, is less than half a millimetre thick, possesses about 200 million nerve cells that are indispensable for the human visual ability. It is a thin multi-layered sensory tissue that forms the back of the eyeball [10]. The retina, which is largely transparent, cannot be visualized by an ophthalmologist, but what medical experts can see through the ophthalmoscope is actually the so-called **fundus** [5] [10]. Vessels, which provide the retina with blood, are silhouetted clearly against the red-orange background and therefore can easily be examined.

The surface of the retina is covered by millions of two kinds of photoreceptors, **rods** and **cones**. The light-sensitive rods are responsible for the scotopic, night vision, whereas the cones are used for the photopic, daytime vision; the latter enable the perception of colour and the ability to see fine details. [10]

Furthermore, the retina contains a number of other types of cells, which connect all the nerve fibres to the **optic nerve**, which leaves the eye at the **optic disc**, the blind spot of the human eye. The optic nerve conveys the received visual information to the brain; the retina and the optic nerve emerge as an outgrowth of the brain, therefore the retina is part of the **central nervous system** [1].

The **macula**, a round spot near the central region of the retina, is about 4 to 5 millimetre in diameter [1]. In its centre it has a smallish depression about 1.5 millimetre in diameter, the **fovea**. This depression forms the region of visual fixation and embodies the location of the most acute vision. [10]

3.2 Diabetic Retinopathy

One of a microvascular complication caused by diabetes, is „diabetic retinopathy“. Usually retinopathy is symptomatic which means that the early stages of retinopathy have no striking symptoms. Hence, the diagnosis of this complication happens in many cases too late. There are three main known forms, namely background retinopathy, maculopathy and proliferative retinopathy. [1]

If the identification of diabetic retinopathy occurs early enough, visual losses, like shown in Fig.2, can be avoided in large parts [6]. However, untreated, the complication can even lead to blindness. In Europe diabetic retinopathy is among the most common causes for blindness in the working age population, thus among people between 20 and 65 years [11].

(a) Normal human eyesight. [12]

(b) Eyesight with diabetic retinopathy. [12]

Figure 2: Comparison between normal vision and visual losses caused by retinopathy.

As the prevalence of diabetic retinopathy rises with the duration of the affection, 80% of the people afflicted with type 1 diabetes evolve retinal changes within 20 years. Diabetic 2 patients have a lower probability of this type of complication, even though about 50% show symptoms of retinopathy after 10 years of diabetes. It is vital that all diabetic patients are aware of the complication risks and therefore undergo regular retinal examinations. [2]

3.3 Abnormalities in the Retina

In perpetuity diabetes can cause retinal complications, which can be detected by examining the diabetic patient's retina. The medical expert, such as an ophthalmologist, scans fundus images for abnormal lesions, like small bleedings, exudation of lipids or regions of swelling, which can be induced by the leakage of oedema. Particularly alarming, if those swellings appear near the macula, since the patient's visual ability can become affected. The following abnormal lesions can be retinal consequences of diabetes [1]:

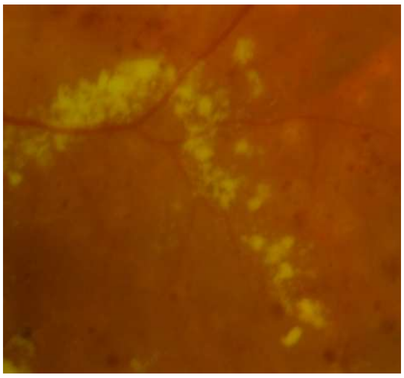
Microaneurysms: The first detectable indication of diabetic retinopathy are usually small changes in the retinal capillaries, focal dilations of the small blood vessels, the so-called microaneurysms. Visually, they appear like small round dark red dots (see Fig.3(b)), whose number rises as the retinal disease proceeds. Due to the fact that microaneurysms are the primal observable abnormalities, their identification is of prime importance, so that the disease can be treated early enough. Unfortunately they are quite difficult to detect in fundus images. [5] [6] [8]

Haemorrhages: Intraretinal haemorrhages contain blood leaked from ruptured vessels, which is caused by the afore-mentioned local distensions of the retinal capillaries, the microaneurysms. They are visible either as red, round-shaped spots or blots, barely distinguishable from microaneurysms when they are covered with blood, or flame-shaped areas [5] [8]. Their colour is almost the same as the one vessels have [6] (see Fig.3(a), Fig.3(d)).

Hard Exudates: Hard exudates contain both blood plasma and lipids, which leaks from damaged blood vessels in their surroundings. They are the most common abnormal lesions in diabetic retinopathy. In the fundus image they are visible as yellow-white spots with varying sizes and shapes [1], but with quite sharp margins (see Fig.3(a), Fig.3(b)). [6] In many cases they appear as accumulations and in circles. If those lipid abnormalities reach the area of the macula, this can lead to serious problems concerning the patient's visual ability.

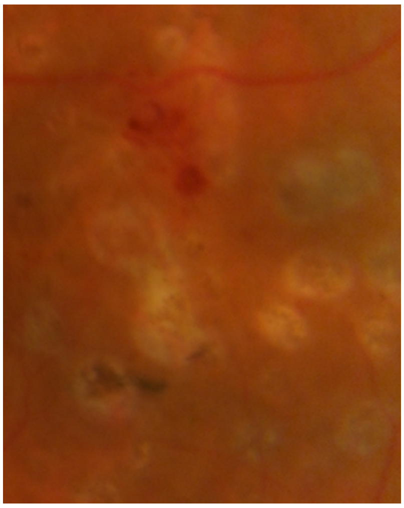
Cotton Wool Spots or **Soft Exudates**: The micro-infarcts emerging in the diabetical

(a) Hard exudates and haemorrhage.



(b) Hard exudates and red dots.

(c) Neovascularization.



(d) Soft exudates and haemorrhage.

Figure 3: Retinal abnormalities caused by diabetic retinopathy.

eye are called cotton wool spots or soft exudates. They are usually visible as whitish round- or oval-shaped spots with fuzzy edges. [6] Often they are located contiguous to haemorrhages (see Fig.3(d)). They occur as a result of a swelling of the retinal nerve fibre layer, which is evoked by the obstruction of the blood supply and therefore lack of oxygen.

Neovascularization: Neovascularization is noticeable as unusual growing of abnormal retinal vessels, also called proliferation. This nonnatural vessel increasing has its seeds in the lack of oxygen in the retinopathic eye caused by the impairment of the blood supply. This lesion can lead to profound difficulties and can be seen as the most severe type of retinopathic abnormality, since the new emerged vessels feature fragile walls, which can easily tear (see Fig.3(c)) [5] [6]. The resultant exceeding bleeding may entail drastic impairment of the acuteness of vision, in some cases actually blindness [1] .

The initial stage with microaneurysms, hard exudates and retinal oedema is the moderate non-proliferative diabetic retinopathy; in the event of microvascular leakage of oedema, blood or lipids appearing in the central vision area, it is called diabetic maculopathy and results in blurred vision. [1] If the amount of intraretinal haemorrhages, soft exudates or intraretinal microvascular abnormalities increases significantly, it is defined as severe non-proliferative diabetic retinopathy. This state can rapidly turn into proliferative retinopathy, namely when neovasularization appears.

3.4 Treatment

If retinopathic complications are not detected before a severe impairment of the eyesight, the possibilities of effective treatment is often poor. Thus, dilated examinations by an ophthalmologist in regular intervals are vital. It is unlike that the complication appears before puberty, but then it should be performed at least every second year; in case that diabetic retinopathy is diagnosed, the person concerned should repeat the eye examinations in shorter intervals.

The detection of retinopathy can happen with dint of an ophthalmoscope by an medical expert, nonetheless, it is more reliable to examine the retina by fundus photography through a widened pupil.

Ophthalmoscopy, which can be performed directly or indirectly, is a cost-saving, transportable and widely available method. Though **retinal photography** is more expensive, it has the advantages of being more sensitive and provide the possibility of ongoing documentation. Besides, ophthalmoscopy should be always accomplished by an expert, retinal photography, however, can also be done by technical personnel and later appraised by a specialist. [5] [8]

There are several possibilities to perform retinal photography; one is to use a colour fundus camera, another one would be the additional use of filters on grey-level cameras. Conventionally a combination of a green filter and a grey-level camera for screening the wavelength of green colour is used. Another method is the use of fluorescein angiograms, where the diabetes patient gets a fluorescent liquid injection before the angiogram is taken. It is used to detect blood vessels and microaneurysms, as they can be easily noticed, due to the fact that the parts of blood flow are far brighter than other parts. Haemorrhages, which include not flowing blood, appear as dark areas in the angiogram. [5]

Laser treatment in an appropriate manner can be deployed to prevent total loss of vision, even though keeping the reading eyesight cannot be assured. If successful, it can reduce the risk of visual loss by 50-90% [8]. Intraocular haemorrhages and in some cases retinal oedema can be medicated with vitreous surgery [2].

3.5 Perspectives

As the treatment of diabetic retinopathy requires regular and frequent examinations, annually a huge amount of retinal images is recorded, which should be checked and evaluated by experts. For this purpose it would be highly adjuvant to develop automatic methods to support the specialist. This could be either an automatic initial screening system of the retinal images to alleviate the medical expert's work or the creation of a proper support-system, which assists the specialist during his annotation work. [1]

4 The Image Annotation Tool

4.1 The „ImageRet“ Project

In the course of the current research in diabetic retinopathy a project called „ImageRet“ has been established. Its goal is the development of state-of-the-art hardware and image processing methods, so that efficient, accurate and reliable decision-support of medical experts in diabetic retinopathy, as well as optimal detection of the disease can be assured [7].

The project, which is based on the preliminary results of the previous project called „Retina“, was founded with the collaboration of Lappeenranta University of Technology, University of Kuopio, University of Joensuu, University of Bristol, London Imperial College, Mikkeli Polytechnics and further companies; Kuomed Oy, Perimetria Oy, Pfizer Oy, Santen Oy, Mawell Oy. [5] [6] [7]

It is contained in the FinnWell technology programme under the „finnish funding agency for technology and innovation [13]“ Tekes, „the main public funding organisation for research and development in Finland [13]“. The project is going to take three years, from 2006 to 2008.

4.2 The Image Annotation Tool

In order to comprehend the physiological parts and abnormal indications of the retina and to support the current treatment of diabetic retinopathy, it is essential to gather expert knowledge of fundus images by reliable clinical experts.

Hence, during the ongoing „ImageRet“ project a graphical tool for gathering expert knowledge from fundus images was developed. It offers both a convenient basis for comparing, developing and testing medical image processing methods and an applicable supporting programme to collect a reliable knowledge foundation, provided by physicians. [6] It includes a selected set of high-quality retinal fundus images, which have been confirmed by experts. A medically educated and in ophthalmology specialised person is regarded as an expert.

It should be noted that in the earlier works the workstation displays were not calibrated. Therefore, the diabetic retinopathy findings were not equally visible on all displays. However, the situation corresponds to the current best practices.

The „image annotation tool“ was not merely developed in the field of diabetic retinopathy, but to be universal. Therefore its field of application can be manifold. [6]

4.2.1 Functionalities

The graphical image annotation tool was devised to gather expert knowledge from retinal fundus images. It provides the possibility to make multistage annotations of abnormalities and functional elements in the eye. It is used to procure a reliable background for multilevel ground truth. By dint of it, it is possible to collect a „public fundus image database“ and an evaluation basis for diabetic retinopathy. [6]

The image annotation tool enables the user, which are considered to be medical experts, to evaluate fundus images and examine them for abnormal lesions, which could be evoked by diabetic retinopathy, for instance microaneurysms, haemorrhages, hard and soft exudates and neovascularization. Furthermore, it offers the possibility to mark regular retinal features, such as the optic disc.

By using the tool, the expert is able to load an image, to activate a zoom-function for a

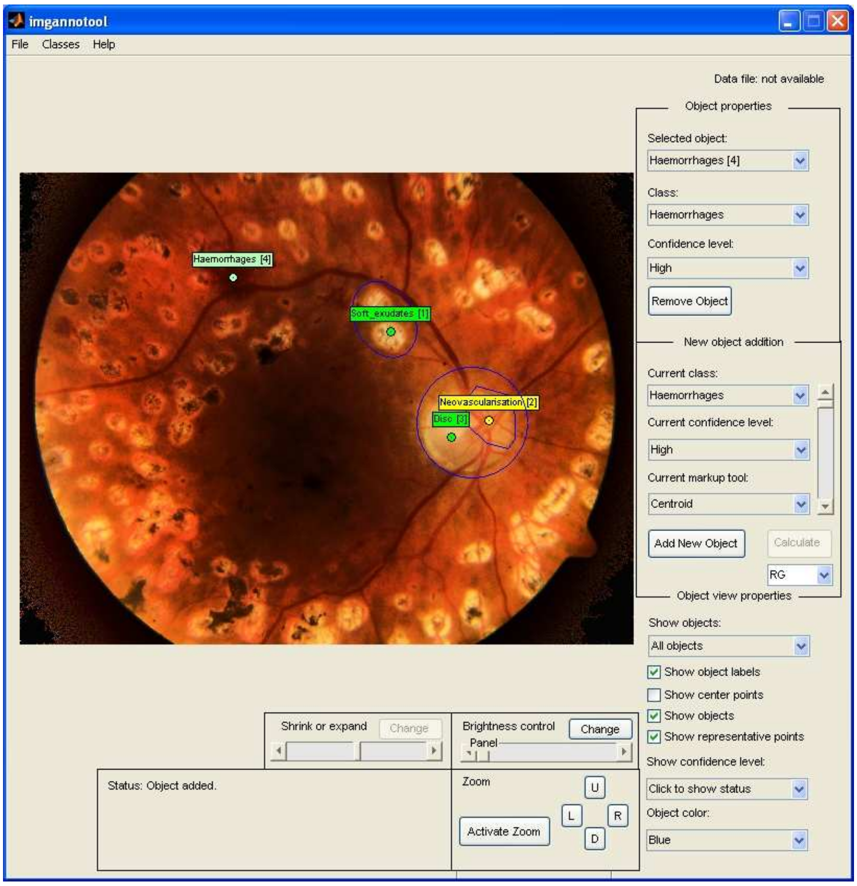
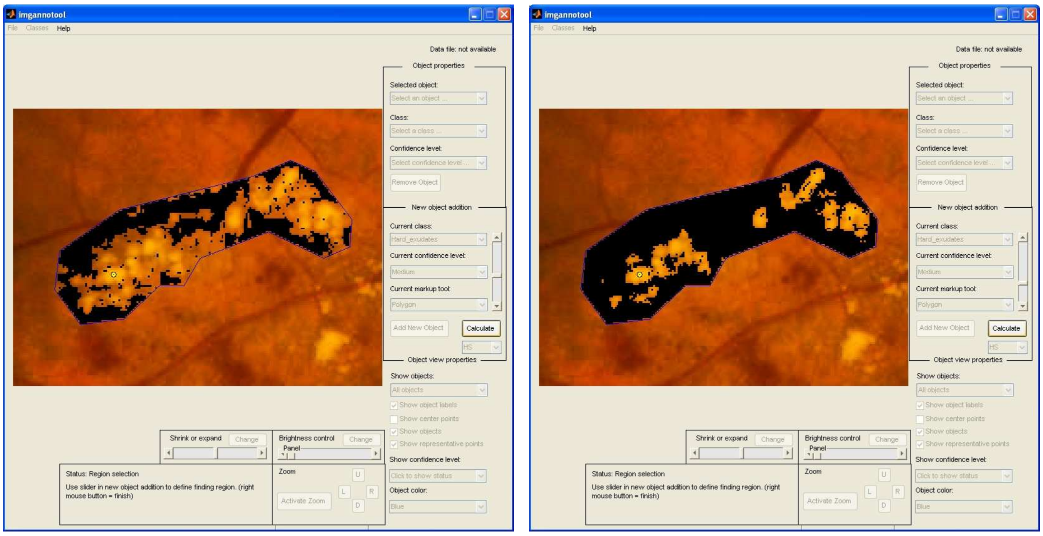


Figure 4: Annotated abnormalities in a fundus image by using the cetroid, ellipse, circle and polygon markup tool.

closer observation or to apply a gamma correction of the image by using a slider, though the original image won't be changed.

Regions, which are classified as remarkable or abnormal, can be marked with different markup tools, whereas it is important that the marked areas are assigned in such a way that the borders must not contain pixels, which belong to the finding. Possible markup tools are polygons, centroids, circles and ellipses, as shown in Fig.4.

Additionally the expert is asked to select one pixel within the region, which incorporates the visually most representative point of the whole region. After determining the most representative point within the annotated region a semi-automatic tool can be used, which provides a proper definition of the regions. This semi-automatic tool uses the colour information, which was given by the selection of the most representative point, to select certain regions in the marked area, as seen in Fig.5.



(a) Smaller threshold. (b) Greater threshold.

Figure 5: Applied colour semi-automatic tool with different thresholds.

Furthermore, three ranges of confidence level, high, medium and low, are integrated into the tool, which specify the expert's certainty that the located abnormality really matches the chosen preset class. Potential preset classes are so far red small dots, haemorrhages, hard exudates, soft exudates, IRMA, neovascularisation, disc and fundus area, though the user has the opportunity to add new classes into the existing list of preset classes or delete one of the listed ones.

Subsequently there is also the possibility to delete marked points or to change their chosen class or confidence level.

The markings of the different confidence level are visually represented in different colours. The user can also decide to display a part of the annotated markings, e.g., only objects of a certain confidence level, a single object or objects of a certain chosen class. Moreover it is easy to fade the object labels, the centre points, the objects or the representative points in and out.

The markings can be saved, however it is important to remember that the input image is not going to be changed. The information about the markings are backed up in a separate dot-file, which bears the same name as the corresponding image, into the same directory as the image is located. If the user wants to reload the image afterwards, all the markings are going to be shown as well and the user has the opportunity to make modifications, if desired. The file contains all information for the objects: their centre points, classes, edge lines, confidence levels and representative points.

4.2.2 Enhanced version

In addition to the afore introduced image annotation tool, an extension was implemented. This enhancement enables the expert to use another markup tool for marking the findings, namely the annotation of blood vessels.

Technically speaking, a vessel forms a region, thus, it can be graphically represented by a polygon. Therefore vessels can be handled and integrated in the same way as the other objects in the image annotation tool.

The two types of vessels, namely arterys and veins, are classified into two different kinds of object types, whereas also branches represent a separate class.

The marking of a vessel proceeds in such a way that the initial point is either been chosen at the beginning of a branch or at the optic disc. After seating the initial point, the course of the vessel is defined by marking additional points, which have direction and width.

The extended version is not integrated into the current version of the image annotation tool, but works together with an older version called „Datatool“, which includes far less functionalities. However, the basic structure and the elementary functionalities exist in the anterior version as well (see Fig.6).

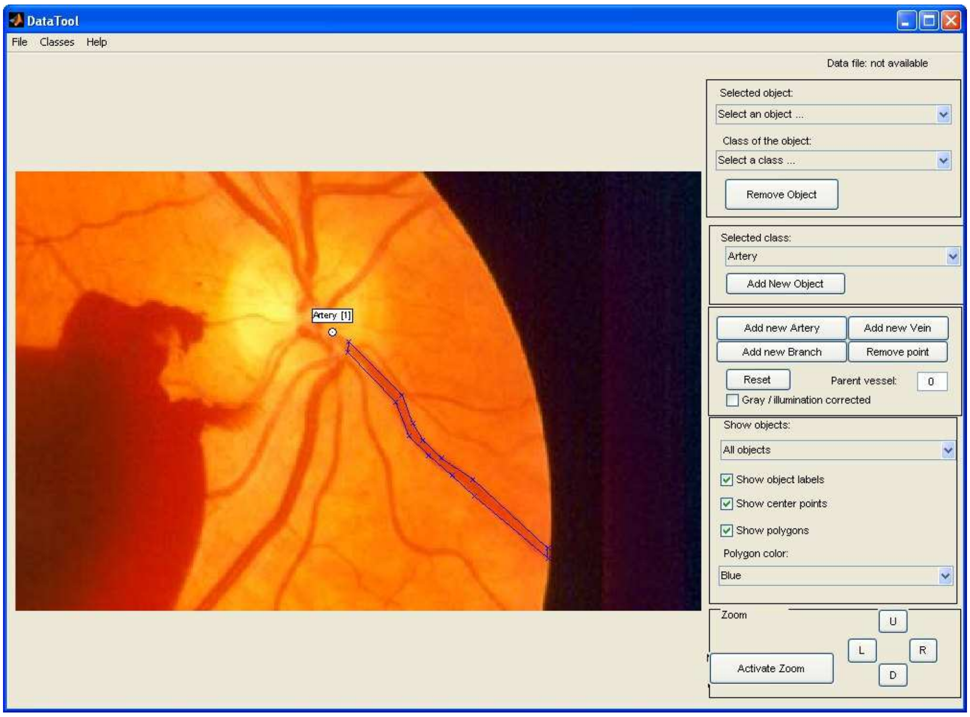


Figure 6: Older version of the image annotation tool called „Datatool“, including one vessel marking.

4.2.3 Possible Extensions

Even though the current version of the image annotation tool features plenty of useful functionalities, there are certainly various possibilities to extend it. The tool establishes a proper basis for further improvements.

During usability and functionality tests of the image annotation tool with the pen input some smaller matters to correct, as well as some bugs occured.

In addition, several ideas for an improvement of the current version of the annotation tool were developed, which concern the flexibility, intuitivity and interactivity of the tool.

A more detailed list of possible extensions is visible in Appendix A.

5 Colour Calibration

5.1 Colour

5.1.1 Definition

Since colour is an impression that is created in the human's brain as a response to the light, it is principally a subjective phenomenon [14] [15]. Hence, the perception and appraisement of colour can differ between individuals, even the same individual can make dissimilar assessments of colour, according to the date and his or her condition at that time. Though the colour of an object stays the same, even if the intensity of a light source would be changed, colour has to be an invariant property in relation to the light intensity. [10]

Anyhow, there is in fact a physically measurable property to describe colour, namely its spectral power distribution, that is the magnitude of the visible electro-magnetic radiance at several wavelengths. Spectral light is more or less reflected from an object's surface; a quantity which is measurable. However, the description of colour cannot only depend on the change of intensity invariance. [10]

Perceived colour can basically be described with the dint of three attributes; **hue**, **saturation** and **lightness**.

The attribute hue describes the dominant wavelength of a colour in accordance with the human sensation, namely if a perceived colour appears to be similar to one or to proportions of two of the sensed colours, red, yellow, green and blue.

Saturation of a colour represents the colourfulness of an object in relation to its brightness.

With the lightness the perception of an object's brightness is meant, in respect of an equally illuminated reference white. [10] [14] [16]

5.1.2 Human Colour Vision

The process of colour perception begins at any light source wherefrom light has been released to get reflected from an object to arrive at the human's eye. It is only possible to perceive something if there is a source, which illuminates the observed object. An illuminating source indeed can have a colour of its own, which obviously affects the colour of the object, we are looking at. Hence, the wavelengths which are finally reaching our eyes are a combination of the light source's and the sample's colour, which makes the light source an indispensable aspect in the human colour vision. [14]

When the reflected light, thus, enters the eye through the cornea and the lens, it reaches the retina, and as well the photoreceptors in it. These specialized cells absorb the incoming patterns of light and convert them into neuronal signals, which are carried through a number of retinal layers, until they leave the eye through the optic nerve. The optic nerve reaches the brain, where the incoming signals are processed by various parts of the human brain, which finally leads to an image, which is the perception we have of a certain scene.

The colour, the human senses, depends on the wavelength of light that reaches the human eye and is absorbed by the photoreceptors. There are three different kinds of cones, long L-, medium M- and short S-cones, depending on the wavelength. Each of these cones imbibes incoming light over a wide band of wavelengths, though has its peak absorption at a differing wavelength. The L-cones are responsible for the red sensation, the M-cones for the green and the S-cones for the blue one. Since the absorption of the cones lies minimal outside the margin 400-700 nm, it is defined as the visible spectrum of humans. [14] [15]

5.1.3 Colour Models and Colour Spaces

A colour model is a way to describe colours, which can be represented as a set of primaries, such as tuples of numbers, typically as three, e.g., RGB, or four, e.g., CMYK, values. There are some colour modes, such as L*a*b*, which were developed on the basis of the human perception of colour. They contain the whole range of colours that are visible to humans and have a determined scale. A certain colour will therefore always be represented with the same set of values.

Hence, there is a broad range of colour models without any standard defined reference or scale; therefore it is not possible to specify a particular colour. Just if such a model is being connected with concrete instructions, how the model components has to be construed, the resulting amount of all possible colours is called a colour space. Thus, a colour space, such as sRGB, is defined as a colour model, which has a determined reference or specific colometric scale.

Finally, there are colour spaces, which are connected to a specific device, the so-called device-dependent colour spaces, and those, which are independent from any instrument. [5] [17]

5.1.4 Gamut

The gamut is the whole range of colours, which can be described by a specific device or a given colour space. Formally speaking, the gamut is the subspace within a colour space, which can be generated by interior coloured mixture. [17]

5.2 Colour Calibration

5.2.1 Definition

Each colour imaging device like printers, scanners and monitors behaves in a different way, therfore, each device has „its own personality [14]“. In colour imaging these differences between devices can redound to unpredictable and inaccurate results, that is why it is necessary to accommodate these advices to each other. [15]

Colour calibration refers to the process of setting the colours of an output device to correspond to another. At this, the calibration source describes the device that is to be calibrated, whereas the device, which is used as the measuring standard, is called the calibration target. In this connection both calibration source and target can be a colour space as well as a colour chart, a monitor, a scanner and so on.

One of the simplest calibration methods, which should better be referred to as coarse adjustment, comprise, for instance, the setting of the brightness and contrast of the used monitor. These methods may derive the best possible results, however, getting the true colours on the monitor is not warranted. For a much more accurate calibration, the use of special software, which enables the calibration of the monitor as well as printer, scanner and further devices, is unavoidable, for instance, the „eye-one color management system “ by Gretagmacbeth, which has been used in this work.

Especially when scanning and processing digital images, it is important to be sure to get the correct colours on the display, therefore, colour calibration is fundamental. Particularly for serious design works and accurate colour matching colour calibration is essential. As well, in medical image processing colour calibrated devices should be used, since the representation of colour images, which should be examined and assessed, should be correct, so that accurate and precise decisions can be assured.

5.2.2 Colour Temperature and Gamma

There are two magnitudes, which virtually indicate the calibration grade, namely the colour temperature and the gamma. The colour temperature determines, psychologically speaking, the caloric, that is the warmth related, impression of an image and is measured in Kelvin. By modifying the gamma value, the brightness of the middle hues can be adjusted. The standard measurements are usually 6500 K for the colour temperature and 1.8 (on a Mac) or 2.2 (on a Pc) for the gamma [18].

5.3 Colour Management

5.3.1 Colour Management and Profiles

Colour management denotes the controlled conversion between the colours of any colour devices, such as monitors, digital cameras or printers. At this, obtaining a precise correspondence across colour devices is the major goal.

A colour management process can be described by three steps: calibration, characterisation and conversion. After calibrating a device, the procedure of characterisation follows, which is the creation of a so-called profile. This process happens in such a way that the characteristics of a certain device is tested by measuring the device's colorimetric response to a test chart, a proper sample assortment of colour patches. In this connection the gamut results from the ability of a device to produce colour. By dint of building the profiles a mathematical relationship between the device values and respective colour space data is generated. The basic component of a profile are single and multidimensional lookup tables, which include these transformation information. The last step of colour management is the conversion, which means that images are transformed from one colour space into another. For instance converting an image from a scanner RGB colour space by dint of the scanner profile into LAB and then into corresponding CMYK via the printer profile. Being hierarchical, each of the three components of a colour management process depends on the preceding step. [15]

To accomplish such a colour management procedure, colour management systems, CMS, are used, whose assignment are the three afore-mentioned steps; the conversion of a device-dependent colour specification using a corresponding colour profile into a device-independent profile connection space and therefrom out again, with the goal to obtain approximate colour representation of every involved devices.

The colour spaces to be used in colour management are usually RGB for digital cameras and monitors, the device-independent CIE L*a*b*, which serves as the profile connection space, and CMYK for printers.

The standard format of such colour profiles was developed by the „International Color Consortium“, ICC. Each device that is involved in a conversion needs its own ICC-profile, which enables to convert colour data from one to another colour space. A generated profile though describes invariably a particular state of the concerning device. Instancing a monitor as the concerning device, the modifying of the brightness control can lead to a deviant display of the colours.

6 Border Pixel Tool

6.1 Possible Modifications

Based on discussions and feasibility tests, several ideas for the implementation of a new markup tool were developed. In the following the modifications under discussion will be listed.

6.1.1 Freehand Curve

The main idea of the „freehand curve“ is that the user sketches the course of a freehand line without any restrictions to mark an object of interest. Thereupon, the image annotation tool would create a curve through all drawn pixels to represent the line.

The main problem, which occurred during the feasibility test, was to find a proper way to get all marked points in the development environment Matlab, while the user is holding the left button of the mouse or is drawing the curve on the tablet PC. Furthermore the idea was discarded, since the freehand curve wouldn't be an accurate way to get the exact borderline of an object.

6.1.2 Curve Modelling via Control Points

The basic concept of this approach is, as the name already reveals, the modelling of a curve by using several defined pixels as control points, with the precondition that every marked point should be an exact border pixel. In addition to the control points marked by the user, several auxiliary pixels would be found, which should be as well border pixels and lie between the two marked points. Using all points, both the manually marked and the automatically computed ones, a curve should be modelled, which includes the notable region. The preceded idea of modelling a curve to represent a marking was transferred to the new idea.

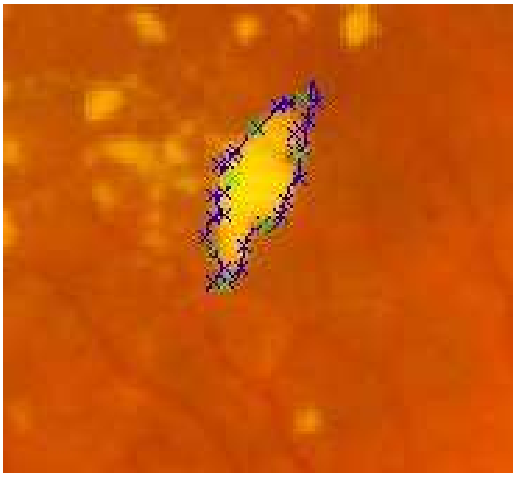
This approach was fully implemented, even though it was not integrated into the current version of the image annotation tool. For the implementation of that approach, a small but sufficient framework, which worked independently from the image annotation tool, was developed.

The occurring problem, however, was that the modelling of the curve couldn't be done reasonably. Due to the fact that the marking was not a „real" curve, but a border around an object, no curve representation could model the marking appropriately. A solution for that was the concept of separate the marking into partial curves and straight lines, but the results were not accurate and satisfying enough, as shown in Fig.7, thus, a new approach was developed.

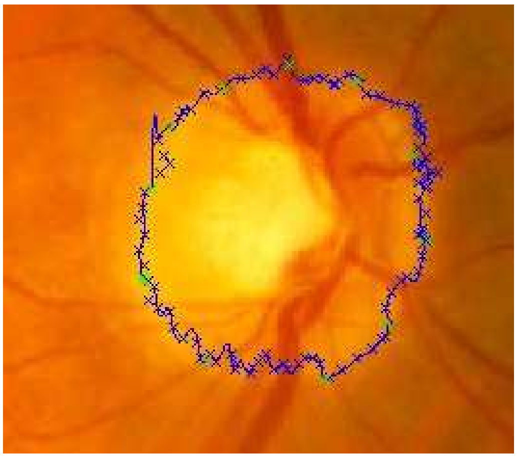
6.1.3 Tracking of the Borderline

The main purpose of the „borderline tracking tool" is to get all exact border pixels of an object, being a hard exudate or the optic disc, for instance. The process would be as followed that the user starts to mark exact points on the border of a certain object. Between the recent marked point and the new added one, the exact course of the object border would be tracked and all found pixels would be stored, so that all more or less exact border pixels of an object would be computed.

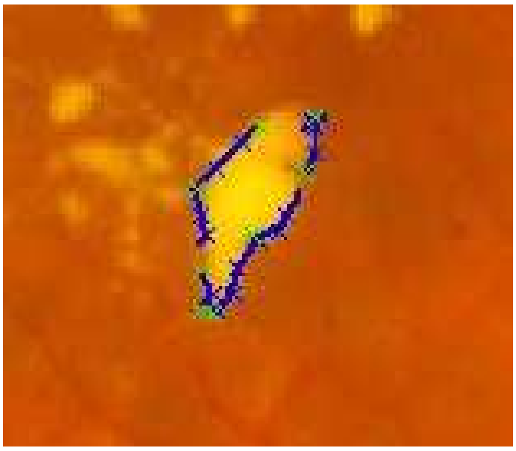
This idea seemed to be adequate as an additional markup tool to the image annotation tool, therefore at first it was implemented in a separate framework and later integrated into the current version of the annotation tool.



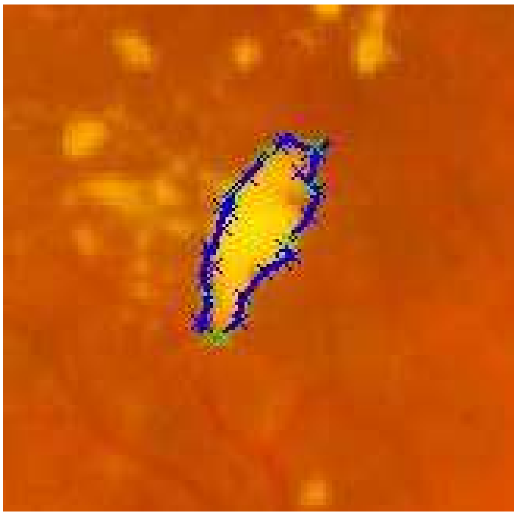
(a) Cubic spline data interpolation of an exudate.



(b) Cubic spline data interpolation of the optic disc.



(c) Smoothing spline of an exudate.



(d) Least-squares spline approximation of an exudate.

Figure 7: Curve modelling using different types of curves.

6.2 Edge Linking and Boundary Detection

6.2.1 Gradient Direction and Magnitude

The gradient vector of an image $f(x, y)$ at a specific location (x, y) points in the direction of the greatest change of f at (x, y). It is formally defined as:

$$\nabla \mathrm{f} = \begin{bmatrix} G_x \\ G_y \end{bmatrix} = \begin{bmatrix} \frac{\partial f}{\partial x} \\ \frac{\partial f}{\partial y} \end{bmatrix}$$

By using the formula

$$\nabla f = \mathrm{mag}(\nabla \mathrm{f}) = \left[G_x^2 + G_y^2\right]^{1/2}$$

the magnitude of the gradient vector can be computed, an important quantity in digital image processing, especially in edge detection. It represents the maximal amounts of increase of $f(x, y)$ per unit distance in the direction of $\nabla \mathrm{f}$.

By applying the fundamentals of vector analysis, the direction angle $\alpha(x, y)$ of the direction vector $\nabla \mathrm{f}$ at the coordinate (x, y) can be computed, namely:

$$\alpha(x, y) = tan^{-1}\left(\frac{G_y}{G_x}\right),$$

in which the angle is denoted regarding the x-axis. Assuming that the gradient is computed that way and points to the direction of the greatest change, the direction of an edge at a position (x, y) is perpendicular to the direction of the certain vector. [19]

6.2.2 Algorithm

In order to find connected sets of edge pixels, the easiest way is to examine the characteristics of pixels within a small neighbourhood, say 3x3 or 5x5, around every pixel (x, y), which was selected to be an edge pixel. All points within this neighbourhood, which satisfy certain determined criteria are defined as similar and, thus, linked to represent a set of connected edge points of an object in an image.

Adjacent edge pixels can be linked, if they accomplish two principal properties, which determine the similarity of edge pixels, as follows:

1. the gradient magnitude, ∇f
2. the gradient vector's direction.

A pixel with the coordinates (x_0, y_0) in a neighbourhood of (x, y) is similar to the centre pixel (x, y) of the neighbourhood in terms of the gradient magnitude, if the following condition is fulfilled:

$$|\nabla f(x, y) - \nabla f(x_0, y_0)| \leq E$$

At this, E should be chosen as any reasonable, non-negative threshold.

If

$$|\alpha(x, y) - \alpha(x_0, y_0)| < A,$$

a pixel at (x_0, y_0) in a neighbourhood of (x, y) resembles the pixel at (x, y). Here A is also a variable non-negative angular threshold.

Only if both conditions are met, the considered pixel is linked to the pixel at (x, y) as an edge pixel. It should be mentioned that if the algorithm is not applied in a reasonable way, for instance, scanning only along horizontal or vertical lines, it is more likely that it generates clusters of connected pixels than single-pixel thick lines.

The algorithm normally adds every pixel in the predefined neighbourhood to the set of edge pixels, if both criteria are fulfilled. For the implementation of the border pixel markup tool however, only one pixel is going to be added. This is, because the purpose of the markup tool is to detect the exact borderline, which should be ideally only one-pixel thick. [19] [20]

6.2.3 Detailed Workflow

The diagram in Fig.8 illustrates the workflow of the user interaction with the borderpixel markup tool of the image annotation tool. It begins with the black dot, when the GUI of the image annotation tool starts to open, and terminates either if the user pushes the right mouse button or selects, what step to do next. In the following the tracking part of the markup tool, namely the finding of new border pixel will be explained in detail.

If the second point is marked by the user, the tracking of the trail between the two at last marked points begins. The neighbourhood, selected as 5x5, of the first marked point is determined and all gradient quantities are computed. The neighbourhood is exclusively taken from the green channel of the image, due to the assumption that retinal abnormalities, such as hard exudates have a high value in the green channel and therefore a higher contrast than, e.g., in the grey image version of the fundus image (see Fig.9) [1] [5].

As the purpose is to find one trail between two marked points, in other words to follow the border line of a certain object, the tracking should lead to only one direction, namely in the direction to the second marked point. Therefore, not the whole neighbourhood, but a part of it should be examined, as Fig.10 illustrates.

The case might occur that the algorithm finds more than one possible adjacent edge pixel. For this, there should be an additional condition that decides about which one is the „better“ candidate. In this case the one with the greater gradient magnitude is chosen.

The tracking terminates, if at one point no possible edge pixel is found, which could be due to the fact that the track led into a wrong direction on grounds of profound colour changes, such as a vessel passing the way. The other termination option is that the last found pixel „passes“ the last marked point by the user, that is that both x and y coordinates of the detected pixel area higher than the last marked pixel's coordinates. In the first case the possibility is offered to move the point to another place or to skip an impassable region with a straight line, e.g., as shown in Fig.11.

The output of this markup tool is a set of pixels, which should include all border pixels of a certain object. The markup tool leads directly into a continuative tool, the semi-automatic tool, to improve the result.

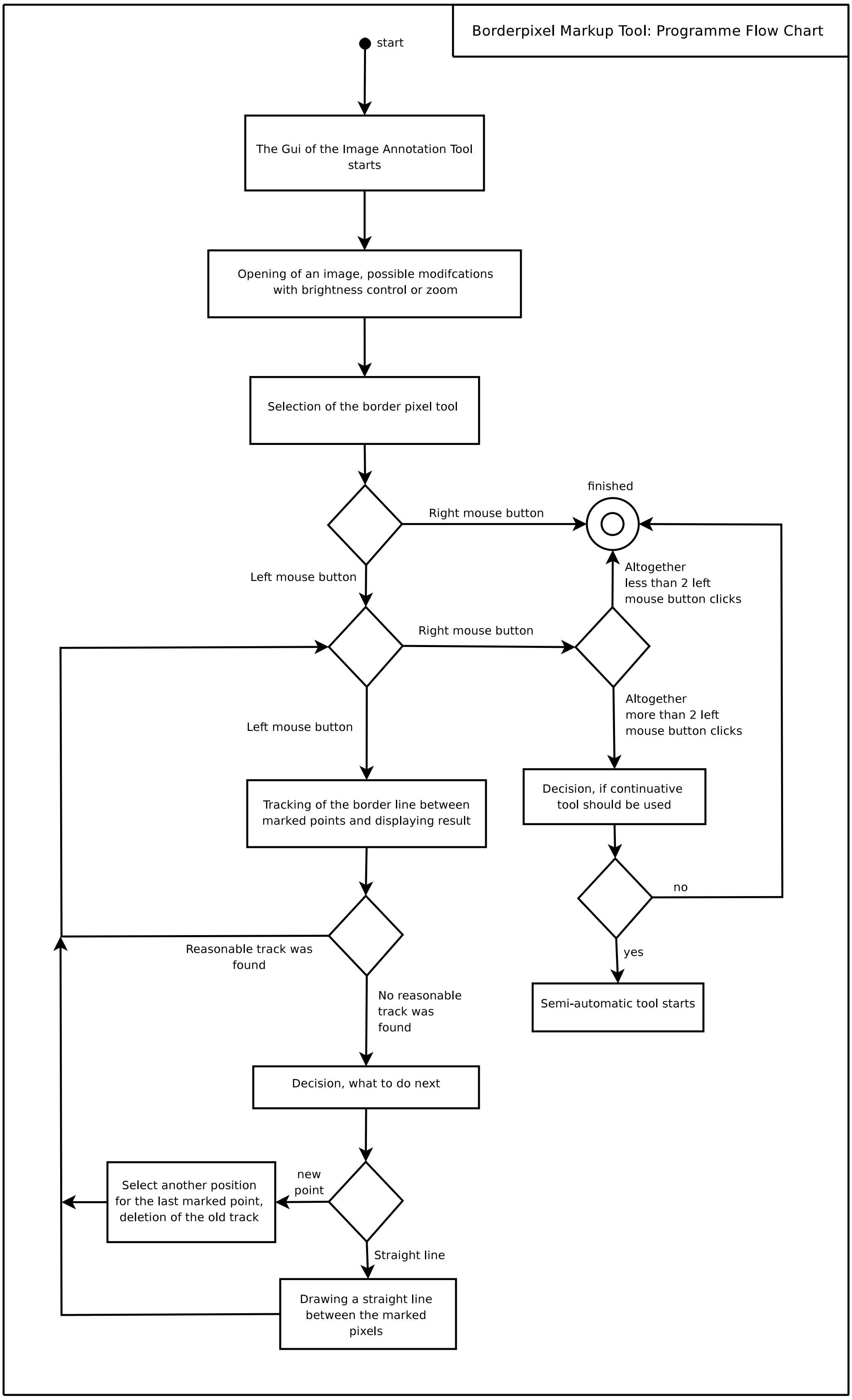


Figure 8: Program flow chart of the borderpixel markup tool.

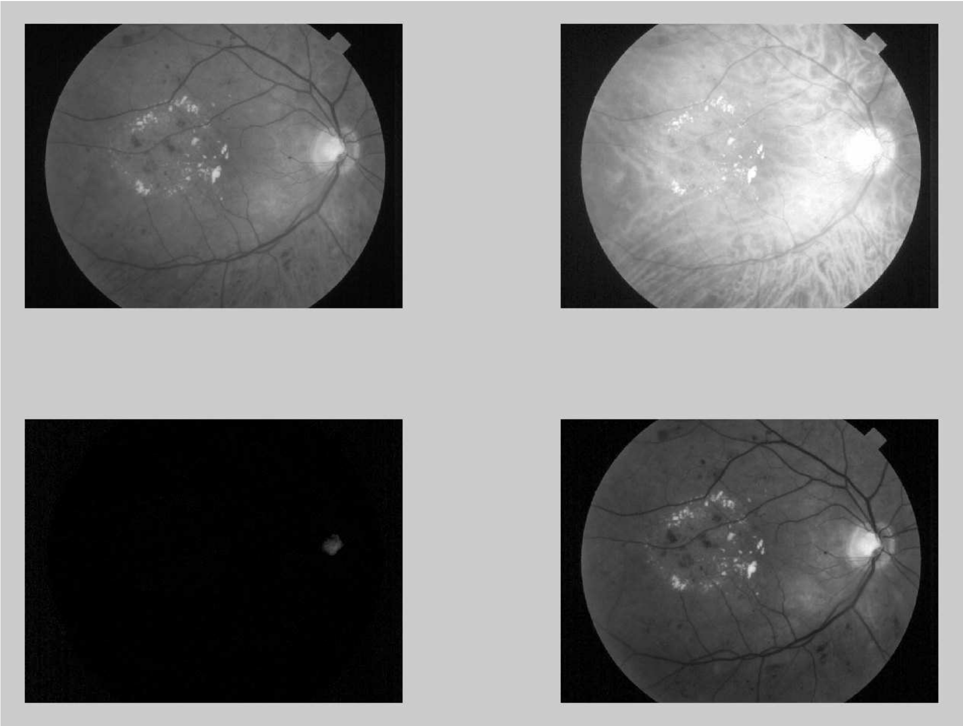


Figure 9: The grey image and the red, blue and green channel of a fundus image.

However, the basic problem with this approach is, like in almost all cases that colour changes or noise in the fundus image can lead to deceptive results. One possibility would be a proper preprocessing method of the image to reduce noise or to better the image contrast.

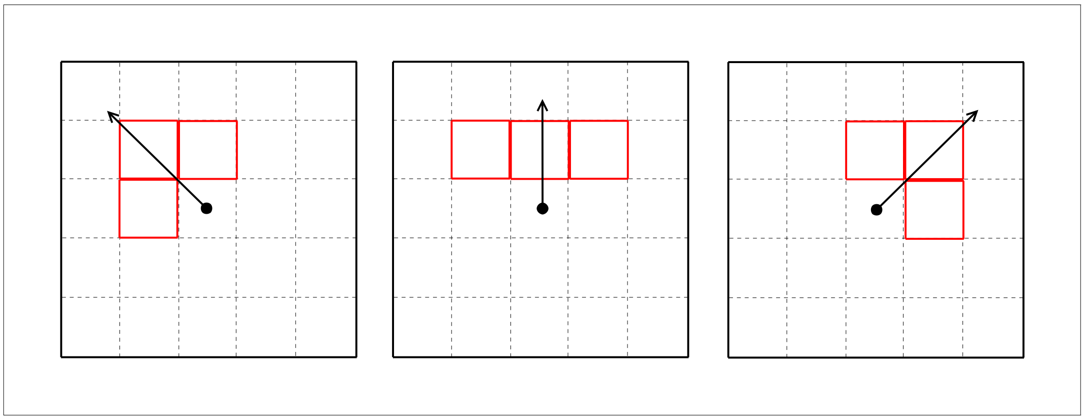


Figure 10: Depending on the direction vector of the two marked points, three suited pixels are examined, analogue for the five other directions.

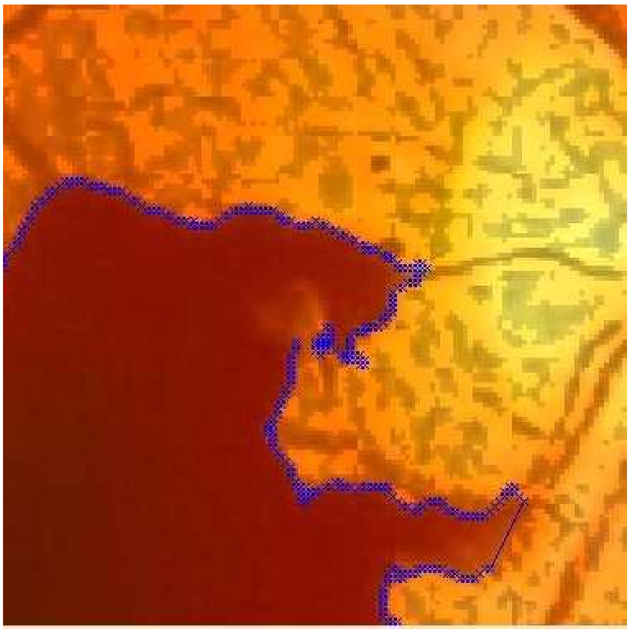


Figure 11: Marking of a border, including a line.

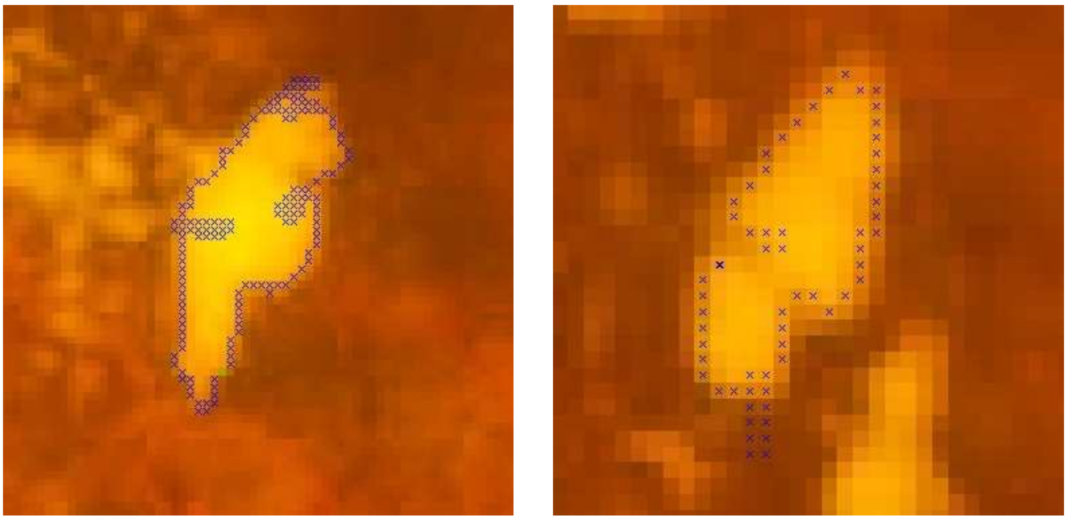
7 Semi-Automatic Tool

The semi-automatic tool works as a post-processing tool, which is offered to be applied after using the border pixel markup tool. Its purpose is the improvement of its input, namely the result of the preceding border pixel markup tool, a set of border pixels.

Due to the fact that it is nearly impossible to get a perfect result with images from the real world, there are several problems, which can occur, such as the following:

- Pixel crowds, which lead to no precise definition of the course of the edge of an object (see Fig.12(a)).
- Gaps between the pixels, where no reasonable track was found (see Fig.12(b)).

Solving such problems and the improvement with respect to the accuracy of the border pixels are the main goals of the semi-automatic tool.



(a) Inaccurate marking with pixel clusters. (b) Holes in the borderline.

Figure 12: Problems, which can occur using the borderpixel tool.

7.1 Morphological Operators

Dilation and **erosion** are the fundamental operations in morphological processing and, therefore, plenty of algorithms are based upon these basic operations. While dilation in general causes objects to expand, erosion provokes the opposite.

The dilation of two sets A and B, where A is usually seen as an image and B as the structuring element, which can be compared to a convolution mask, is denoted as $A \oplus B$:

$$A \oplus B = z|(\hat{B})_z \cap A \neq \oslash$$

The initial step is to reflect B about its origin, which is denoted as $\hat{B}$, and then translate it by z. Thus, the dilation is defined as the set of all shiftings, z, so that $\hat{B}$ and A have at least one common overlapping point.

The erosion of A by structuring element B, denoted as $A \ominus B$, is the set of all elements z , so that B, shifted by z, is completely contained in A:

$$A \ominus B = z|(B)_z \subseteq A$$

[19]

7.1.1 Opening and Closing

By combining the afore-mentioned fundamental morphological operations dilation and erosion, we can obtain two higher order operations, namely **opening** and **closing**.

In general opening smoothes the edges in an image, deletes thin juts and breaks narrownesses. Even though closing, as well, smoothes contours, it does in addition the opposite to opening; it fills small holes and merges thin gaps.

The opening of A by B , denoted $A \circ B$, is specified as

$$A \circ B = (A \ominus B) \oplus B,$$

whereas the closing, denoted $A \bullet B$, is defined as

$$A \bullet B = (A \oplus B) \ominus B.$$

At this, B is as well a structuring element.

In words, the opening of A by B is the erosion of A by B, followed by the dilation of the result by B. The closing of A by B is simply the opposite process, namely the dilation of A by B, followed by the erosion of that result by B. [19]

7.1.2 Boundary Extraction

Boundary extraction, a basic morphological algorithm, is used to get the contour of an object in a binary image.

For this purpose a boundary β of a set A can be computed as follows:

$$\beta(A) = A - (A \ominus B).$$

In other words, first A is getting eroded by B, a proper structuring element, and then the set difference between A and its erosion with B is computed. There are plenty of possibilities to select a structuring element, but for the use of getting an one-pixel thick boundary, a 3x3 structuring element of ones should be used. [19]

7.2 Average and Standard Deviation

The statistical features **average colour** and **standard deviation** are going to be shortly defined.

The average colour can be computed by the formula

$$\bar{x} = \frac{1}{n}\sum_{i=1}^{n} x_i$$

At this, n is the total amount of values. The mean locates the „centre“ of the values in a given set.

The standard deviation defines the square root of the variance, which is the average of the squared differences between the values and the mean. Thus, standard deviation can be defined as

$$\sigma = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(x_i - \bar{x})^2}$$

It is a measure for how spread the values of a distribution are about the mean. [21]

7.3 Chebyshev's Theorem

Chebyshev's Theorem, also known as „Chebyshev's Inequality“, applies to any data set, not exclusively to the normal distribution. It describes how the standard deviation can be applied to distributions. It says that the fraction of any pack of data within k standard deviations of the mean is at least $1 - \frac{1}{k^2}$, whereas k is to be selected as a value greater than 1.

For $k = 2$ for instance, $1 - \frac{1}{k^2} = 1 - \frac{1}{2^2} = \frac{3}{4}$, which is 75%. That means that within two standard deviations of the mean 75% of the data lies. [21]

7.4 Detailed Workflow

As Fig.13 illustrates, the semi-automatic tool works together with the interaction of the user. Therefor, the user is able to move a slider and expand or shrink the area enclosed by the border pixels. In the diagram there are two positions marked, which are going to be explained in detail:

1. Initial automatic computation (marked as * in the diagram) and
2. User Interaction (marked as ** in the diagram).

It is important to note that the shrinking and expanding of the area bordered by boundary pixels are not going to proceed evenly: For a small interval from three steps down (to shrink) and three steps up (to expand), only a subset of the pixels is going to move. If the user wants to expand enclosed region, only those points, which belong to the marked object are going to move, those, which are categorised as background pixels won't move, if the option of shrinking is chosen, the operation works analogue.

In the case that the selected shrinking value exceeds the small interval, normal erosion and dilation respectively is used.

The purpose of the operating manner in the small interval is that the semi-automatic tool tries to support the user in his or her goal to find the exact border of an object. There may be cases, as shown in Fig.14(a), where the pixel set includes both object and background pixels, however, what we desire is to get a result as illustrated in Fig.14(b) or Fig.14(c), namely merely object or background pixel.

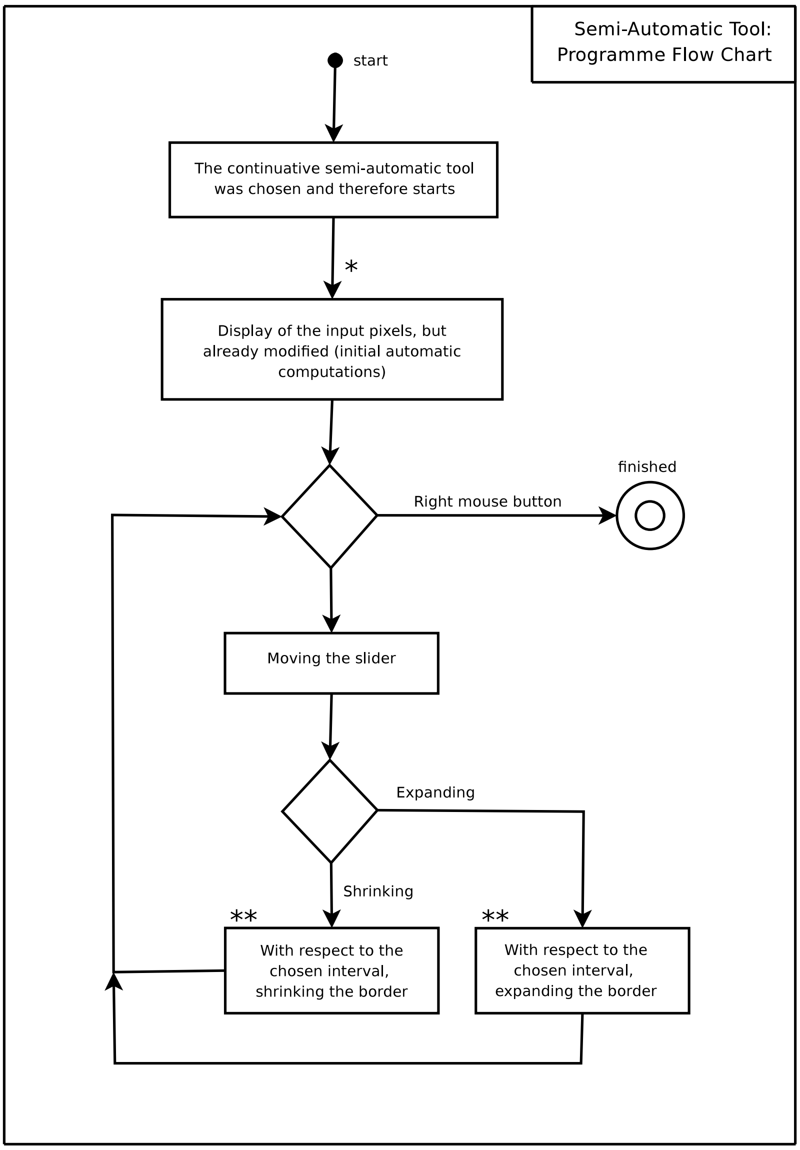
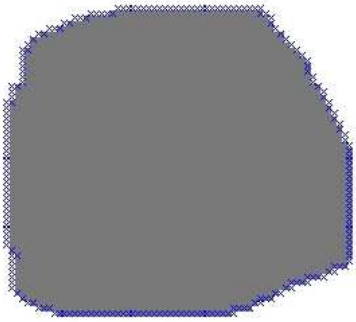


Figure 13: Program flow chart of the semi-automatic tool.

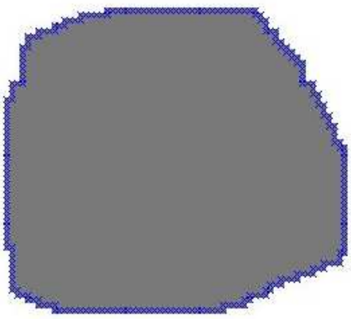
7.4.1 Initial Automatic Computation

The first step of the automatic computation is the minor modification of the input pixel set, namely a closing of it to ensure that all gaps between pixels are closed. By using the morphological operators to extract the boundary of the closed object, pixel crowds can be avoided and the object's border is just one-pixel thick, as desired.

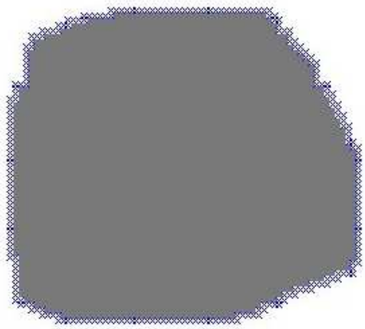
The idea of moving only a subset of the pixel set within the predefined interval requires the classification of the input pixels into background and object pixels. For this purpose



(a) Result of the border pixel tool, including both object and background pixels.



(b) Result of the semi-automatic tool, including only object pixels.



(c) Result of the semi-automatic tool, including only backgroundpixels.

Figure 14: The border pixel tool achieves with artificial images a mixed set, however, desired is a set that contains only pixels of one of the distributions.

statistical features, namely the average colour in the L*a*b* colour space and the standard deviation, were computed to serve as classification features. As the average and the standard deviation of each colour channels is computed separately, altogether there are six features.

The categorisation into background and object pixels uses the idea of Chebyshev's theorem. It happens in such a way that the current colour gets classified into that distribution, object or background, whose properties are fulfilled with the smaller k-value. In other words, it is checked, if the current colour lies within the interval, which is defined as the average colour of object and background respectively subtracted by the variable k, which was chosen to start at the value 1.1, as it should be greater than 1, multiplied by the standard deviation of object and background respectively. The colour is classified into that class, in whose interval the colour laid with the smaller k-value.

After computing these initial steps, the user interaction can start.

7.4.2 User Interaction

The user has the possibility to move the slider and thereby change the size of the area enclosed by the border pixels. If the user chooses a small step, for instance, just one step to the right, which is synonymous with expanding the border about one pixel, all the object pixels are being moved one step in the direction of the background, certainly the new border contains still contiguous pixels. The new border pixels are again classified into one of the two categories. The shrinking happens analogously.

The main problem to be solved is the way of how to move only a part of the pixels.

The first idea was the use of gradient vectors, which magnitude shows how great the change and therefore how sharp a border edge is, and correspondingly how small the change is, which leads to a smooth transition. A point therefore should be moved with a bigger step, if it lies on a smooth edge.

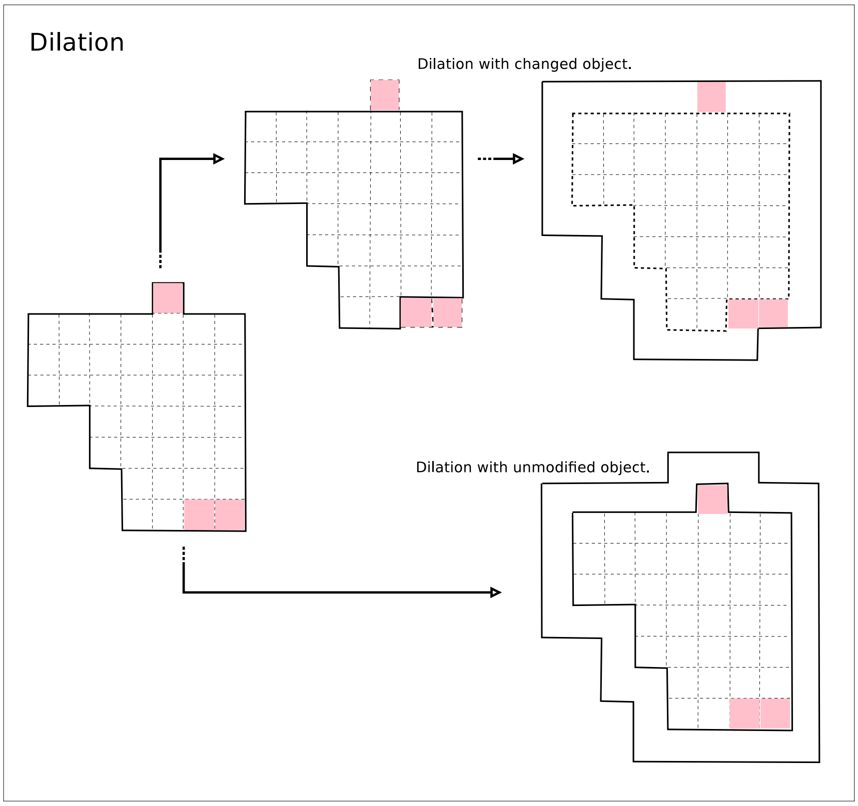
The problem, which occurred, namely that it is unknown in which direction the gradient vector points, was too intricate to solve. One possibility to check, in which direction the vector points, could be the classification into object or background pixel of that pixel, which the vector points at. However, the fact that hard exudates, for instance, usually appear in groups makes this approach quite unstable, as it is probable that the gradient vector points at another nearby exudate.

Therefore, a method was developed to handle the problem of moving just a part of the pixels. This method, illustrated in Fig.15, has the purpose to change a binary image, say the object to change contains only ones, the background only zeros, in such a way that only a part of the pixels is moved by erosion or dilation.

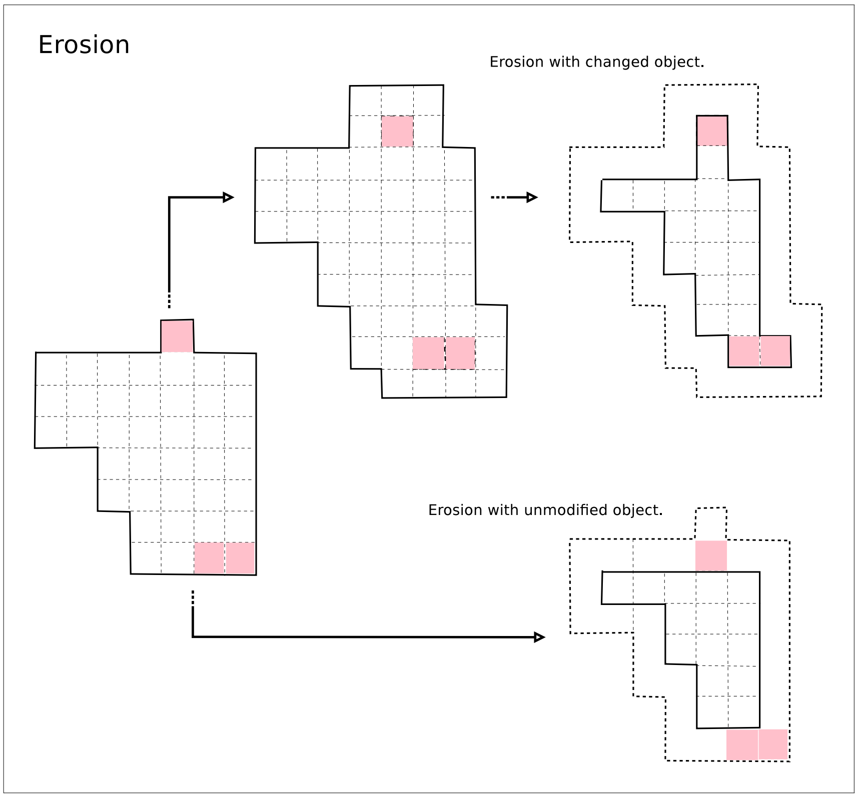
In the case that a dilation of a subset of the border pixels is desired, all the border pixels that are not wished to be moved are changed to a zero. As visible in Fig.15(a), this approach works quite reasonably, although there are some cases, in which the idea fails, e.g., as shown in Fig.16

If a partial shrinking of an object is wanted, the whole 3x3 neighbourhood around those border pixels not to move are turned to ones, before the erosion is applied, see Fig.15(b).

The output of the semi-automatic tool is consequently a set of the most accurate pixels of an object's border.



(a) The basic idea of the binary method for dilation.



(b) The basic idea of the binary method for erosion.

Figure 15: Two images illustrating the basic idea of the binary method.

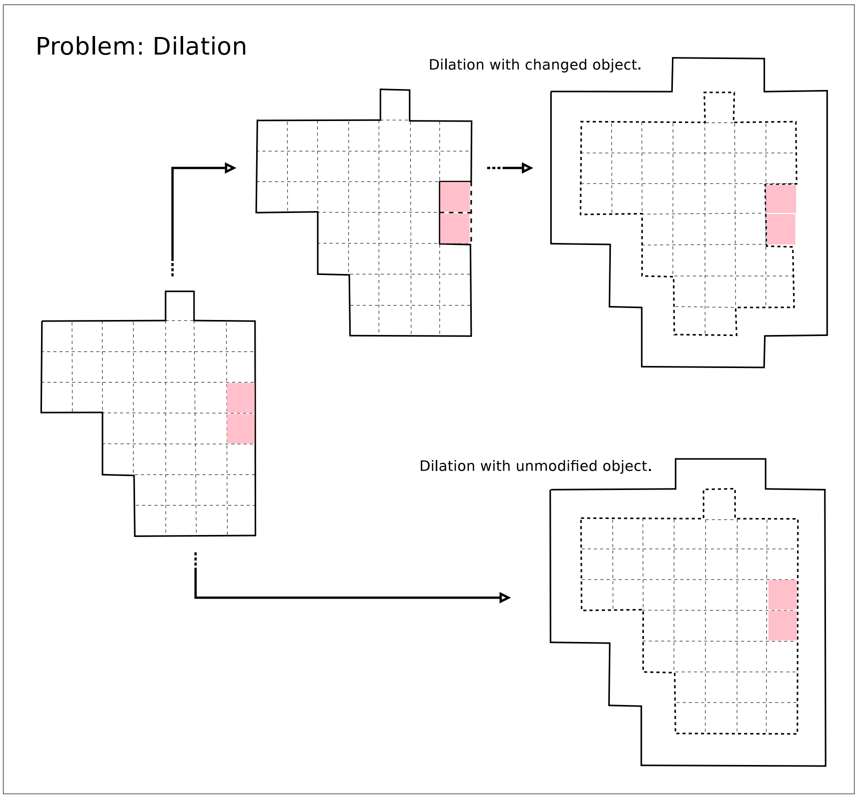


Figure 16: Despite changing the pixels, the binary method achieves the same result and every pixel moves.

8 Results

8.1 Border Pixel Tool

The tracking of the course of the border with artificial images without any noise and with an object with sharp edges is quite good, as seen in Fig.17. More detailed steps and results are attached in Appendix B.

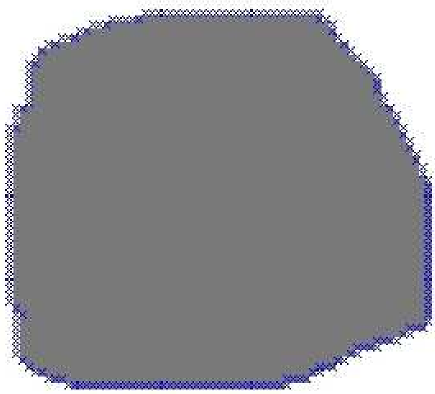
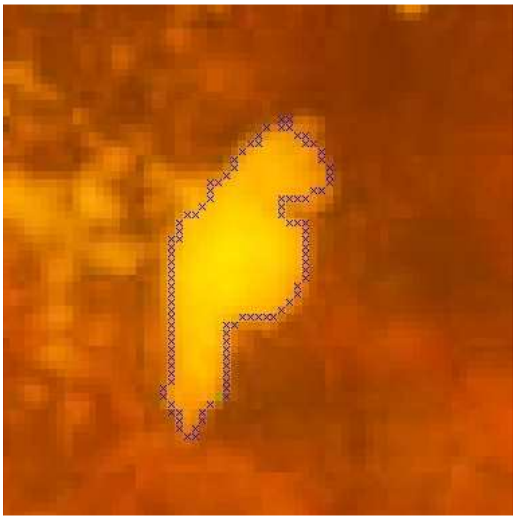


Figure 17: Result of the border pixel tool with an artificial image.

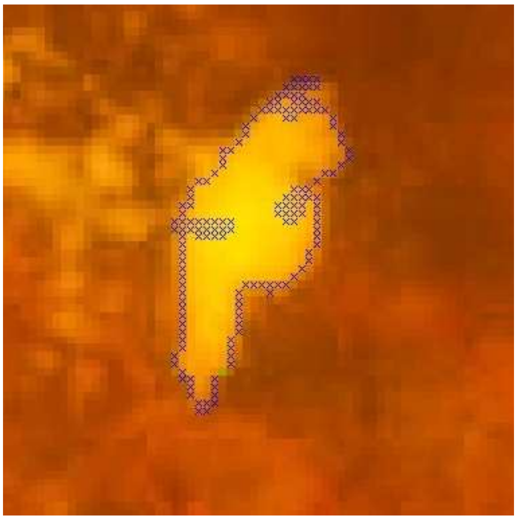
The only problem is that the tool is not able to decide between the background and the object pixels. Therefore, it only detects a set of border pixels which includes both object pixels and background pixels.

Nevertheless, much more interesting and important are the results, which can be achieved with real world images, namely fundus images.

The accurance of the border pixel tool depends primarily on the marked points by the user. If the markings are precise, the tracking can proceed in a quite exact way, for instance, as seen in Fig.18(a). If the marked points are, however, imprecise, the tool can also achieve results like Fig.18(b) with the same object to mark.



(a) Accurate tracking of the object's border.



(b) Inaccurate tracking of the object's border with pixel clusters.

Figure 18: Two different markings of the same object.

Hence, it is important that the person, who is using the tool, tries to make the markings as accurate as possible. Accuracy can be achieved by using the zoom functionality, which is integrated into the image annotation tool. Therefore, it is easier to decide which pixel belongs to the object and which to the background. On the other hand, marked points that are closer to each other assure a better result than points which are marked with quite large distances.

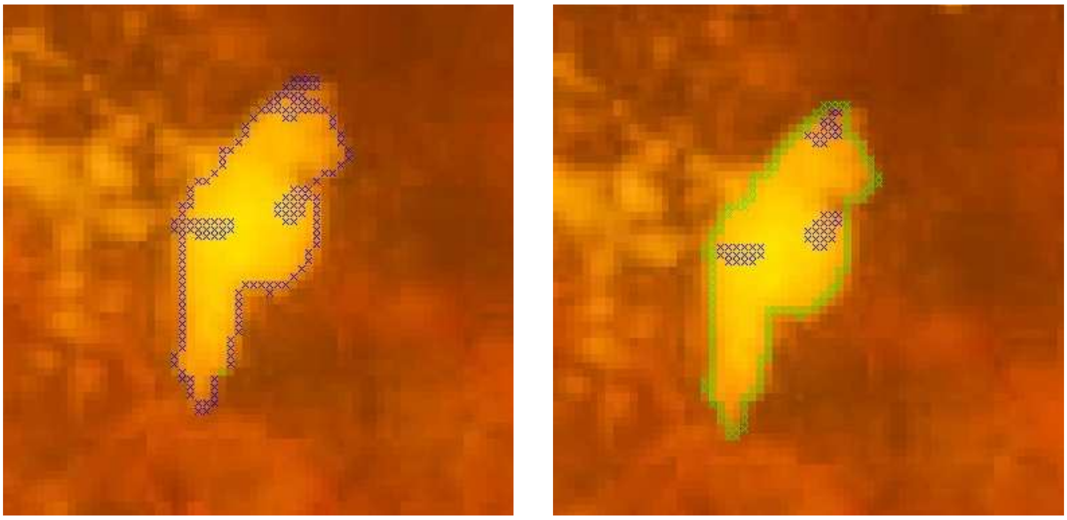
In addition, after a while the user gets quite fast used to the tool and develops a feeling for where to mark the points the best. The user will get an eye for difficult areas and learn to estimate which parts of the object border are hard to track.

However, the precondition to achieve proper results is to mark points that lie on the border of an object.

8.2 Semi-Automatic Tool

The semi-automatic tool achieves good results with artificial images. The afore-mentioned problem that the output pixels of the border pixel tool contain object pixels as well as background pixels can be solved quite easily with just one slider step. The user has, therefore, the possibility to choose between a set, which consists of exclusively background or object pixels, as shown in Fig.14.

The two mentioned problems, which can occur using the border pixel tool, namely the pixel clusters and the gaps between pixels can be solved quite good in both cases, as seen in Fig.19 and Fig.20.

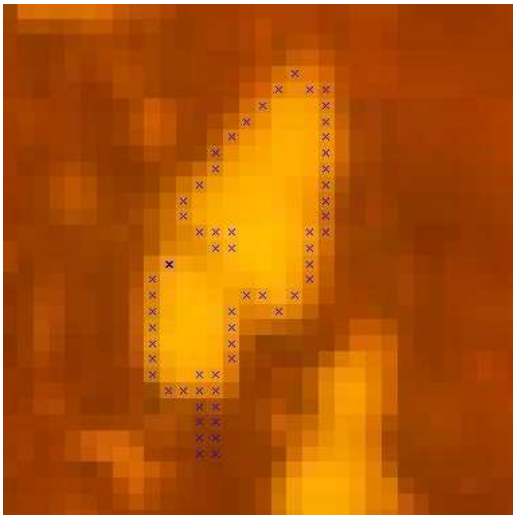


(a) Input pixels of the semi-automatic tool. (b) Initial step of the semi-automatic tool.

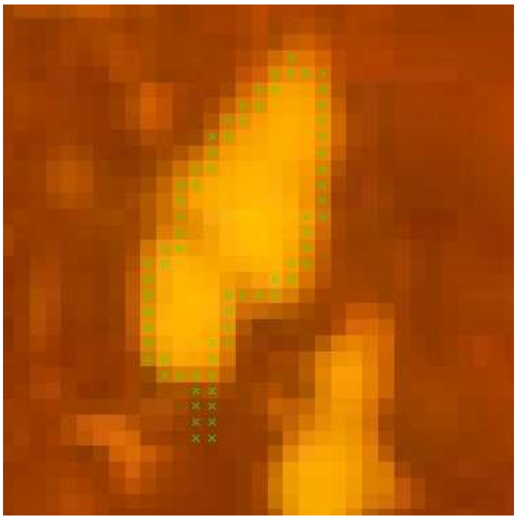
Figure 19: Input of the semi-automatic tool is a set of pixels including clusters. The initial step of the semi-automatic tool, namely computing an one-pixel thick and connected pixel set, solves the problem (visible as the green pixels).

Getting the exact borderline of an object depends on the given image and the input pixels and primarily on the classification which is made. There can be cases in which the program would classify a pixel to the background distribution, whereas the human would assign it to the object pixels.

A quite satisfying example for a result, the semi-automatic tool achieves with just one



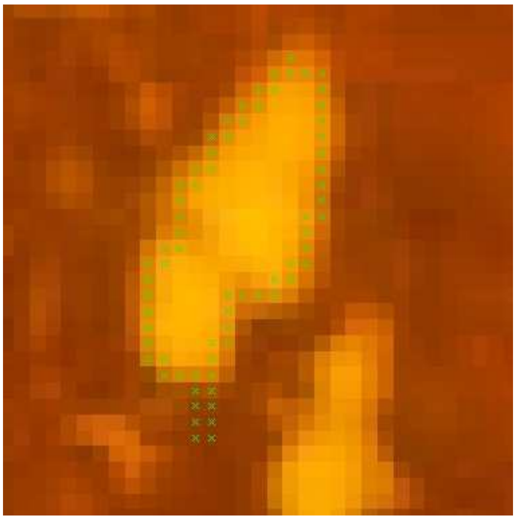
(a) Input pixels of the semi-automatic tool.



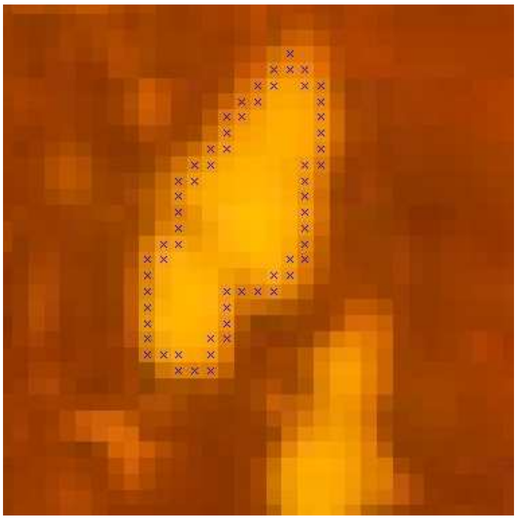
(b) Initial step of the semi-automatic tool.

Figure 20: Input of the semi-automatic tool is a set of not totally connected pixels. The initial step of the semi-automatic tool, namely computing an one-pixel thick and connected pixel set, solves the problem.

slider step, is shown in Fig.21, other examples are attached in Appendix B.



(a) Input pixels of the semi-automatic tool.



(b) After decreasing the slider value by one.

Figure 21: Quite good example by applying the semi-automatic tool once.

Especially difficult are the cases when an object has no sharp but blurry edges. Even for the human eye it is hard to say on which border the object ends and where the background begins.

9 Conclusions

Dealing with real world images raises problems in the tracking of the border as well as in the semi-automatic tool, whereas computing artificial images can lead to virtually perfect results.

The most relevant problems, which occure with fundus images, are the fact that a lot of abnormalities and objects to mark have a quite blurry edge, therefore it is hard to make the difference between object and background. Although hard exudates and the optic disc may be silhouetted against the background quite clearly in the green channel image, other objects like red small dots may be hard to detect.

However, the border pixel tool extends the image annotation tool not only with a new way of marking objects, but more important, with a different one.

Whereas the other markup tools give the user full control and responsibility to annotate the objects, the border pixel tool includes a tracking, which works semi-automatically.

In addition, the purpose of the new tools are distinguishable from the other tools, namely the possibility to try to find the exact border of an object, so that the marking encloses an area which contains exclusively object pixels.

While the other tools for marking objects were intended for making coarse and fast markings, the new tools provide the possibility to make more detailed annotations.

9.1 Future Work

Both the border pixel markup tool and the semi-automatic tool can be modified and enhanced in quite many ways:

Tracking of the object border:

- Possibility to undo last point, right now it is only possible, if no reasonable track between two marked points was found.
- Other possiblities to select the „best candidate“ for the next adjacent pixel than selecting the one with the greater gradient magnitude.
- Multiple tracking between the two marked points instead of following only one track.
- In case of a dead end, more options than the current ones, namely moving the last marked point and drawing a straight line. One possibility would be backtracking and different selection of border pixel.
- The tool should not work only based on the information the green channel gives, but possibly other options.

Semi-automatic tool:

- Other methods to move only a subset of the border pixels than the binary method, possibly the realisation of the gradient vector idea.
- Additional features for the classification into background and object pixels, which could enable an accurate classification
- Expanding the small interval.
- Computing every slider step separatly, since in the current implementation the several steps are once computed and stored, so that in the case that the user first expands and then shrinks, not the pixels that resulted from the expanding are used to compute a new shrinking, but the already computed pixels are taken.

A Appendix

In the following there are some suggestions for improvement listed:

1. **Flexibility** in the marking of objects

    - The possibility to redo/modify markings, which already had been fixed by providing an eraser functionality, for instance
    - When using the polygon markup tool, the option to cancel the last marked point

2. **Intuitivity and Interactivity**

    - Interactive sliders
    - Replacing and explaining the use of the region selection slider (missing label)
    - Improved automatic or semi-automatic support methods, while the user is annotating
    - Pointing out the meaning of the possible selection between HS and RG

3. **Smaller corrections**

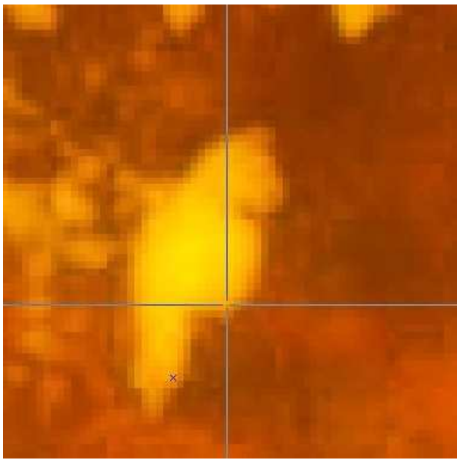
    - Higher lucidity and documentation
    - Fixed window size
    - „Remove object“ under „Add new object“, so that the structure is more logical
    - Change the marking of a selected object, currently the selected object is hard to find
    - It should be possible to change the object colour for a selection of objects, not only for all objects

- Status can easily be overlooked, change its position to another location, e.g., above the image
- If the user tries to define the representative point outside the area, a warning should pop up.

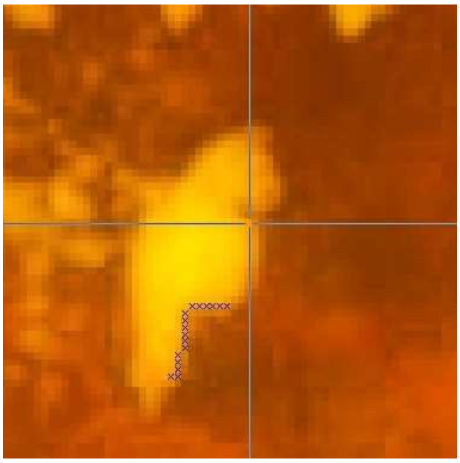
4. **Bugs**

- Incorrect display of some images (reason: conversion into HSV)
- The program freezes, when you use the circle or ellipse markup tool, and mark an area, which crosses the lower borders of the image
- The option to shut down the program, even if a current job is running, should be possible
- Definition and removal oExample 1: borderpixel tool step 1.f a class only possible by writing in the corresponding files. Use of the menu-item „Classes“ → „create new class“ only creates a new class for the current job. If you mark a point with the new created class, it's saved, but it's only defined for this special image, not for the others.

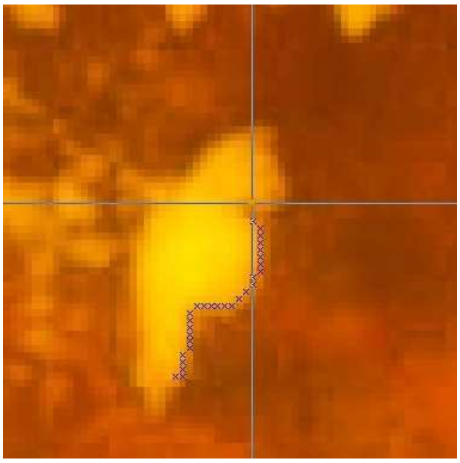
B Appendix



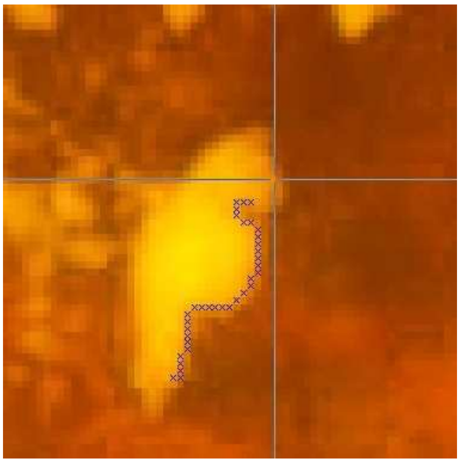
(a) Border pixel tool, example 1: First step.



(b) Border pixel tool, example 1: Second step.

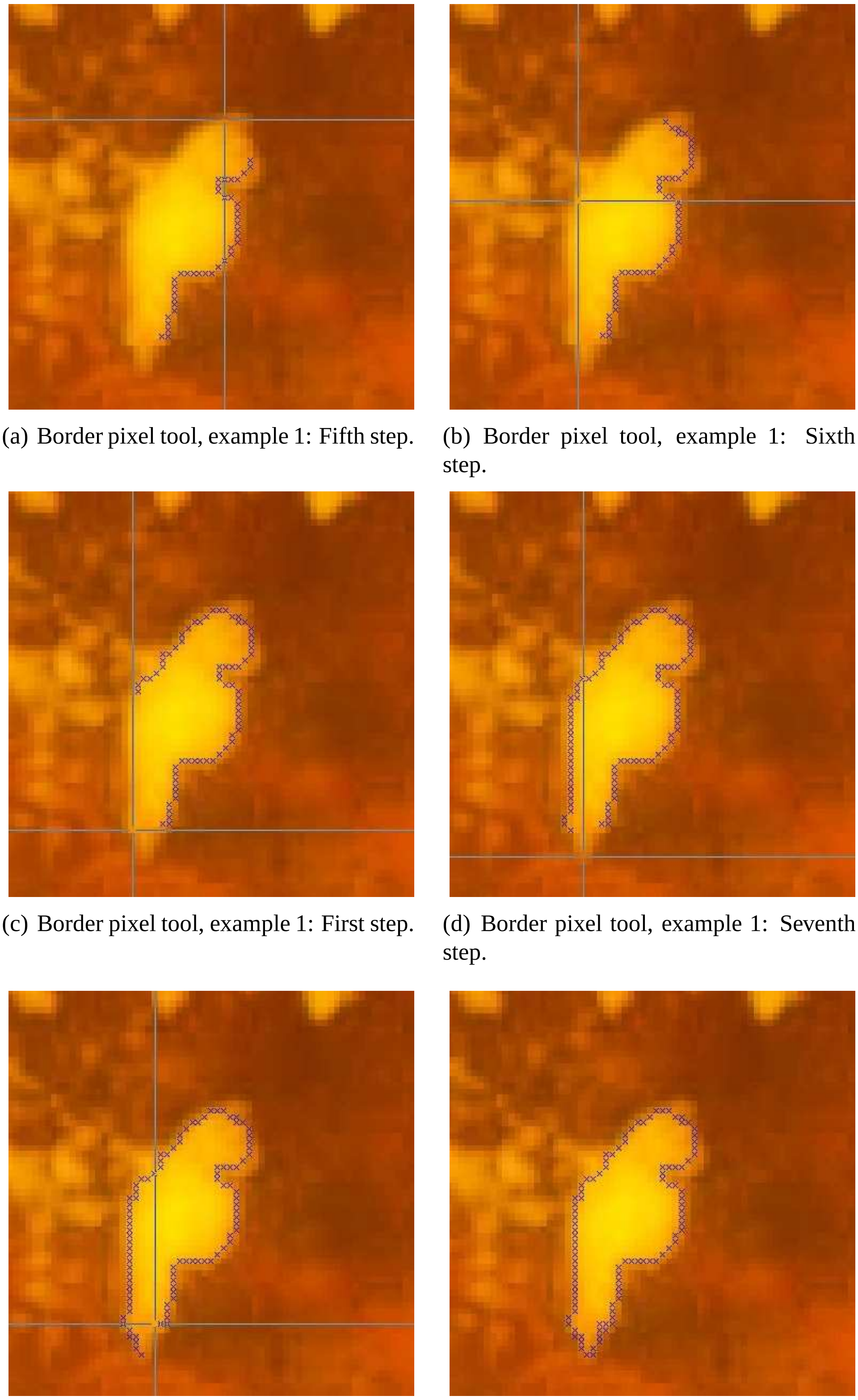


(c) Border pixel tool, example 1: Third step.



(d) Border pixel tool, example 1: Fourth step.

Figure 22: Border pixel tool, example 1: Steps 1-4.



(a) Border pixel tool, example 1: Fifth step.

(b) Border pixel tool, example 1: Sixth step.

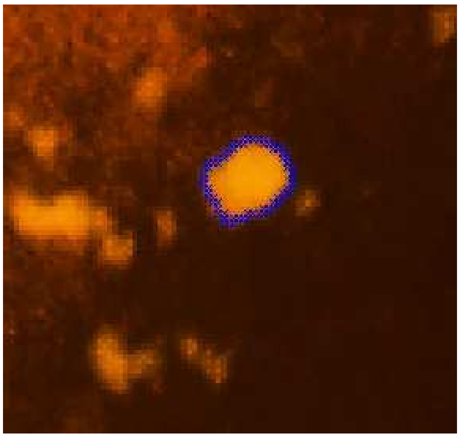
(c) Border pixel tool, example 1: First step.

(d) Border pixel tool, example 1: Seventh step.

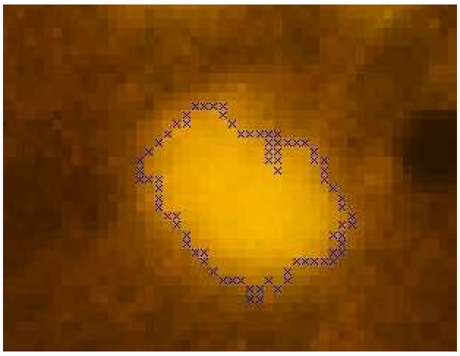
(e) Border pixel tool, example 1: Eighth step.

(f) Border pixel tool, example 1: Last step.

Figure 23: Border pixel tool, example 1: Steps 5-9.

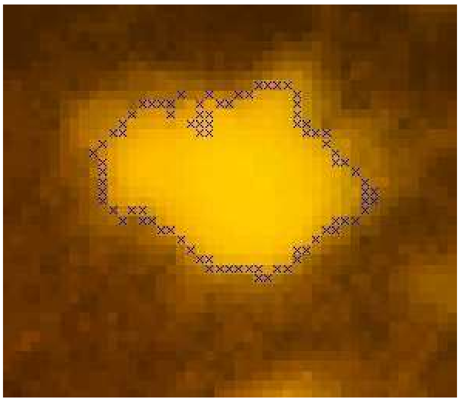


(a) Border pixel tool, example 2: Result.

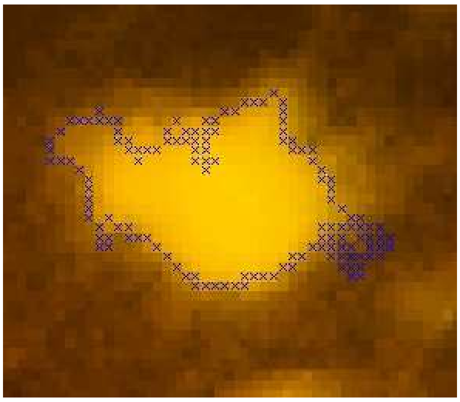


(b) Border pixel tool, example 3: Result.

Figure 24: Border pixel tool, two example results.

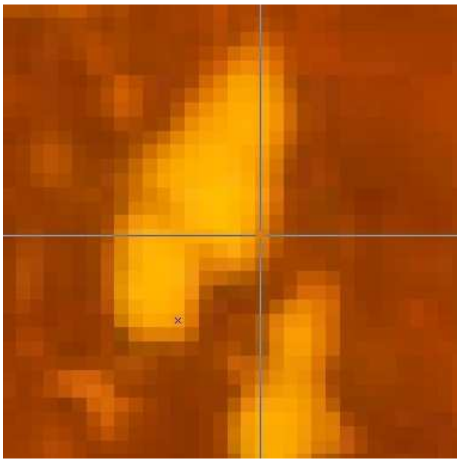


(a) Border pixel tool, example 4: Result.

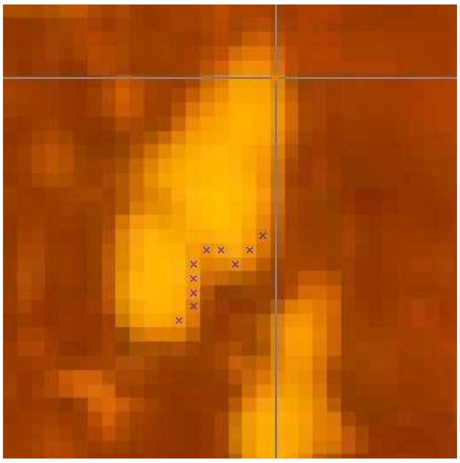


(b) Border pixel tool, example 5: Result.

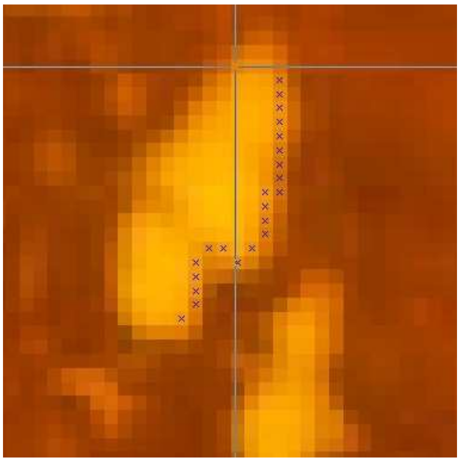
Figure 25: Border pixel tool, two example results: Same object, but different results.



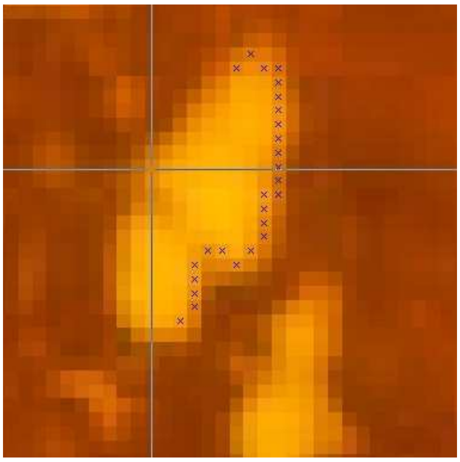
(a) Border pixel and semi-automatic tool, example 1: First step.



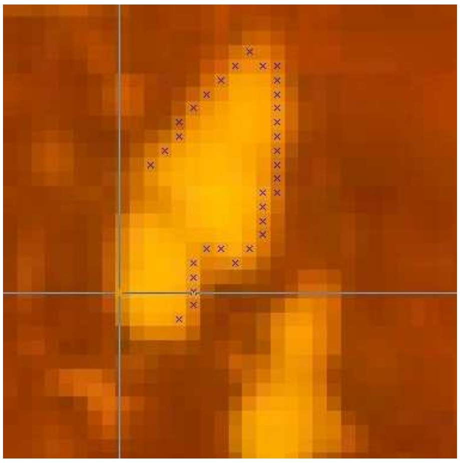
(b) Border pixel and semi-automatic tool, example 1: Second step.



(c) Border pixel and semi-automatic tool, example 1: Third step.

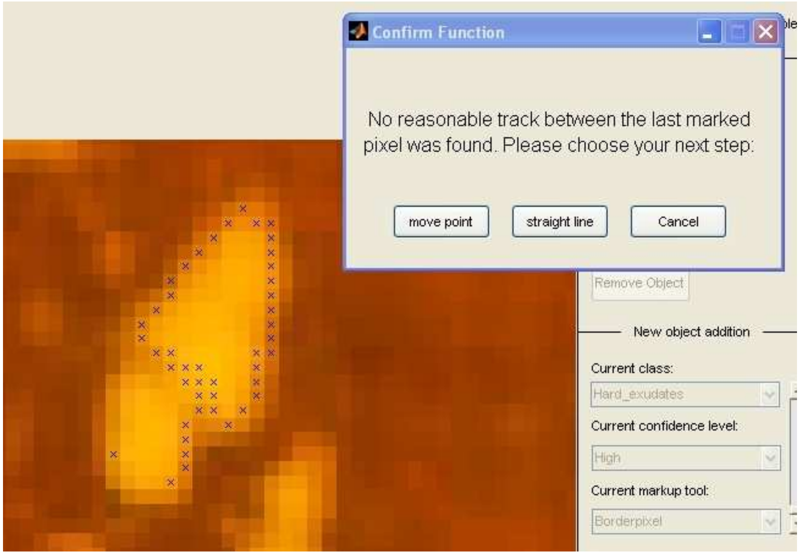


(d) Border pixel and semi-automatic tool, example 1: Fourth step.

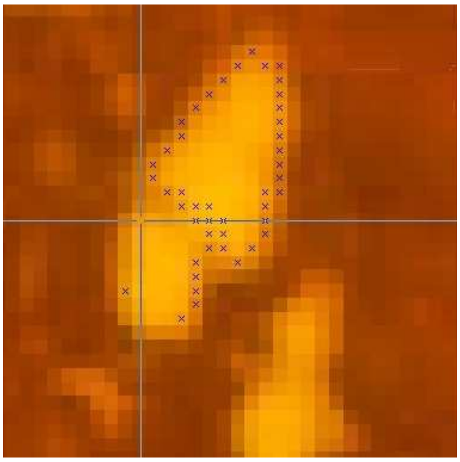


(e) Border pixel and semi-automatic tool, example 1: Fifth step.

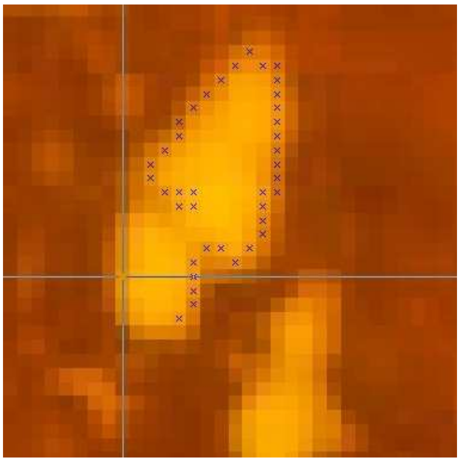
Figure 26: Border pixel and semi-automatic tool, example 1: Steps 1-5.



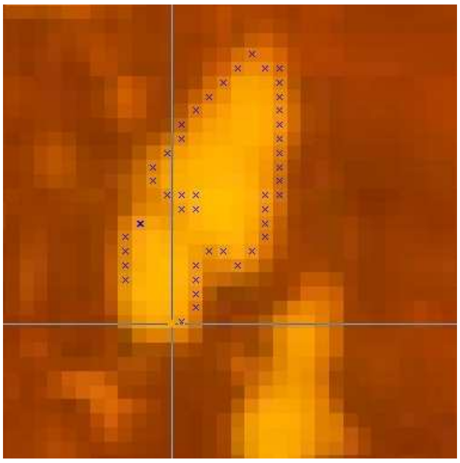
(a) Border pixel and semi-automatic tool, example 1: Sixth step, choose to move point.



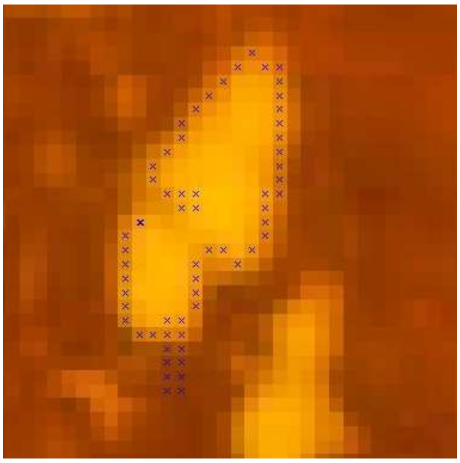
(b) Border pixel and semi-automatic tool, example 1: Seventh step.



(c) Border pixel and semi-automatic tool, example 1: Eighth step.

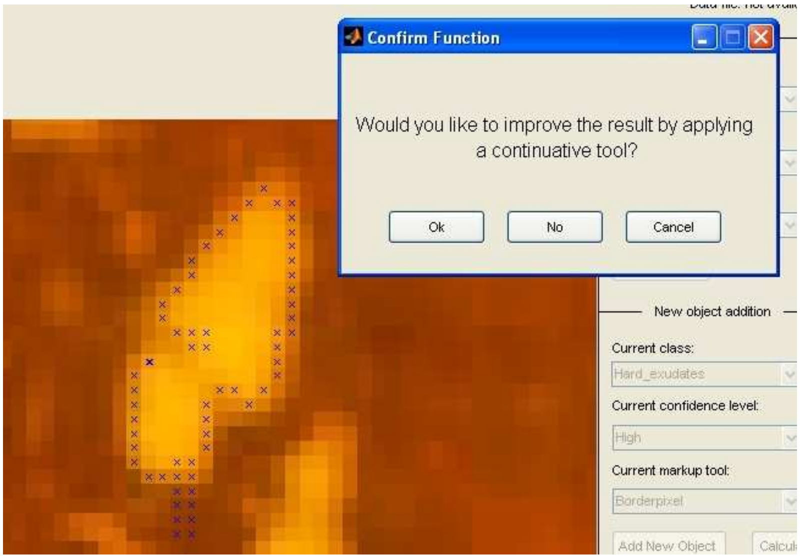


(d) Border pixel and semi-automatic tool, example 1: Ninth step.

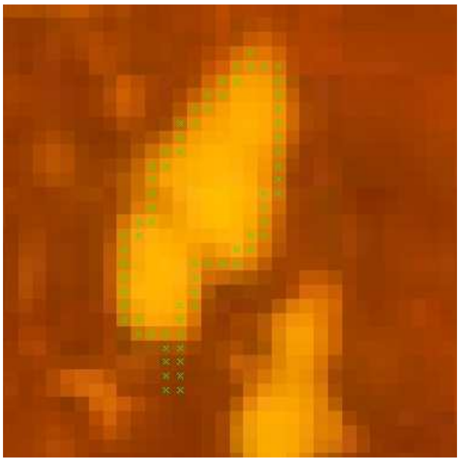


(e) Border pixel and semi-automatic tool, example 1: Tenth step.

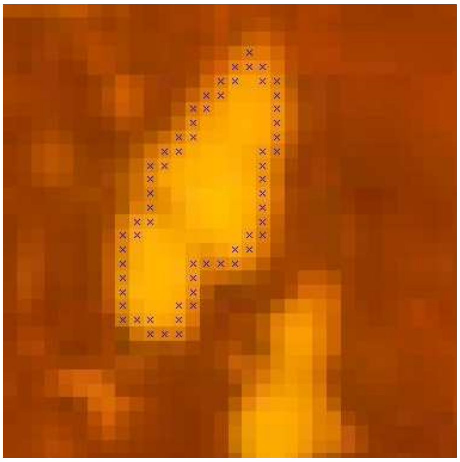
Figure 27: Border pixel and semi-automatic tool, example 1: Steps 6-10.



(a) Border pixel and semi-automatic tool, example 1: Eleventh step, applying continuative tool.

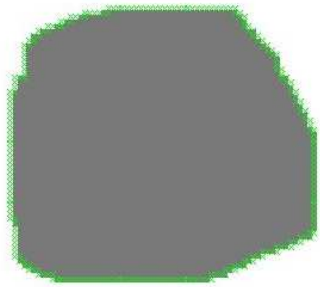


(b) Border pixel and semi-automatic tool, example 1: Twelfth step.

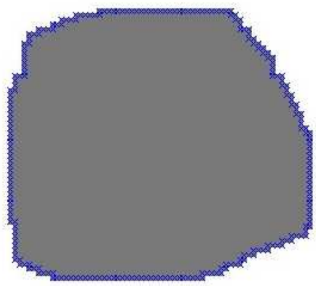


(c) Border pixel and semi-automatic tool, example 1: Last step.

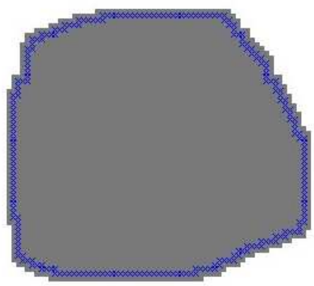
Figure 28: Border pixel and semi-automatic tool, example 1: Steps 11-13.



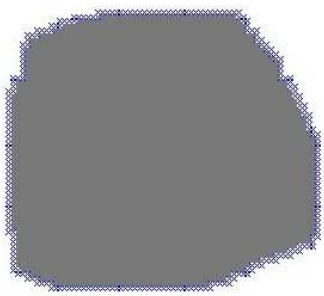
(a) Semi-automatic tool, example 1: Initial step.



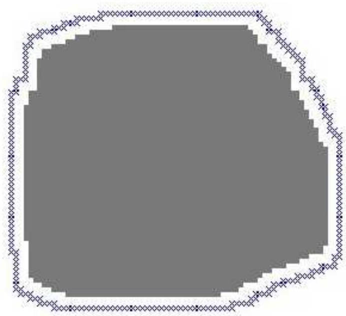
(b) Semi-automatic tool, example 1: Decrement slider value by one.



(c) Semi-automatic tool, example 1: Decrement slider value by two.

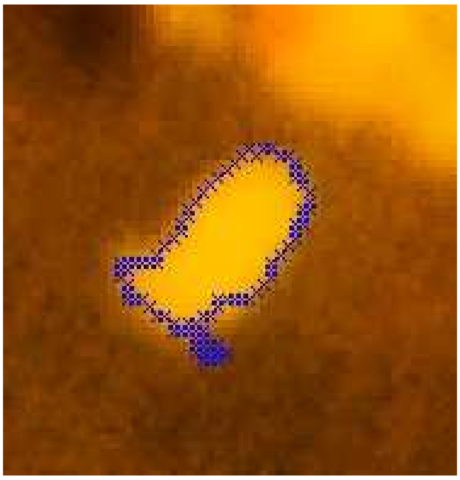


(d) Semi-automatic tool, example 1: Increment slider value by one.

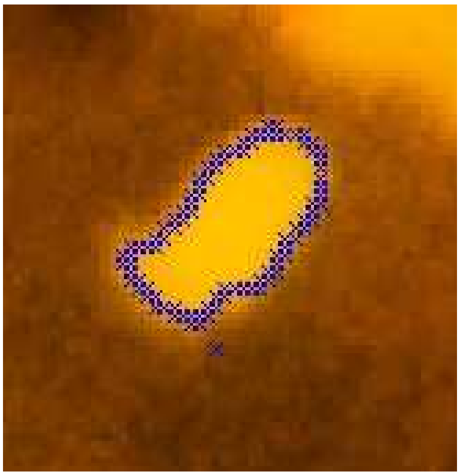


(e) Semi-automatic tool, example 1: Increment slider value by two.

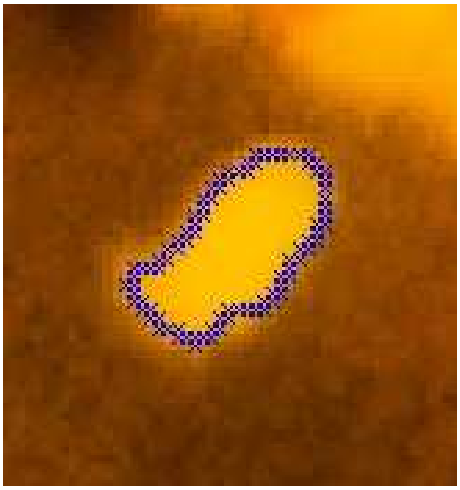
Figure 29: Semi-automatic tool, example 1 with an artificial image.



(a) Semi-automatic tool, example 2: Input pixels.

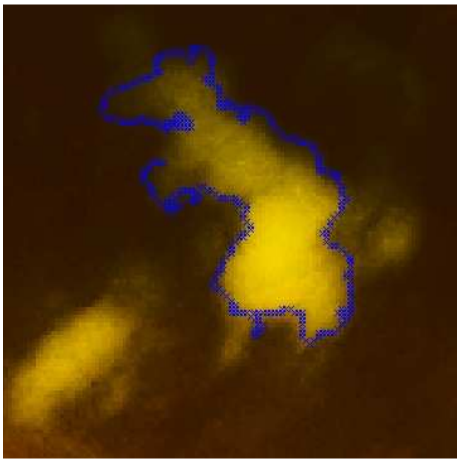


(b) Semi-automatic tool, example 2: Decrement slider value by one.

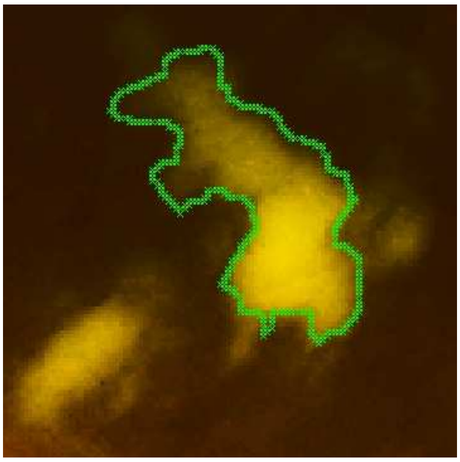


(c) Semi-automatic tool, example 2: Decrement slider value by two.

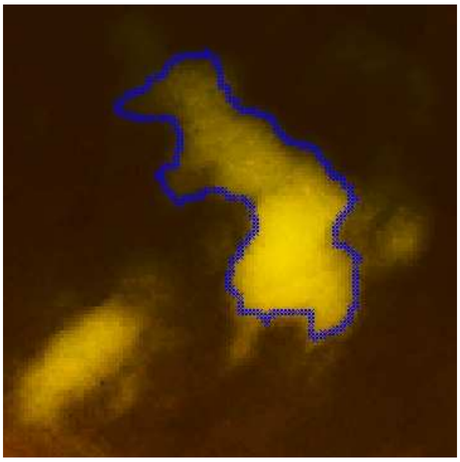
Figure 30: Semi-automatic tool, example 2: At the last step, only one pixel moves.



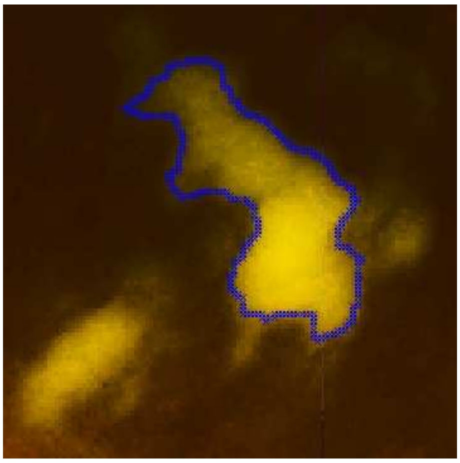
(a) Semi-automatic tool, example 3: Input pixels.



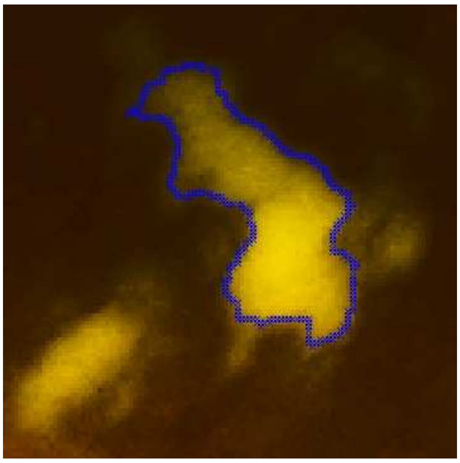
(b) Semi-automatic tool, example 3: Initial step.



(c) Semi-automatic tool, example 3: Decrement slider value by one.

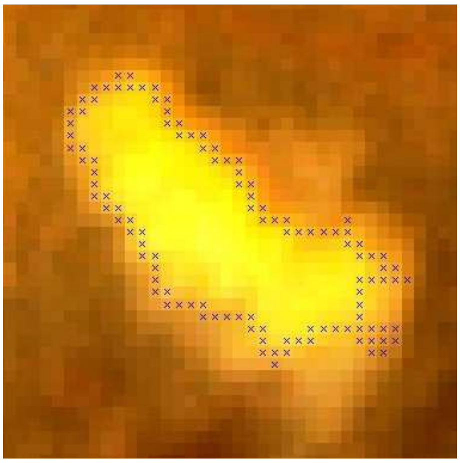


(d) Semi-automatic tool, example 3: Decrement slider value by two.

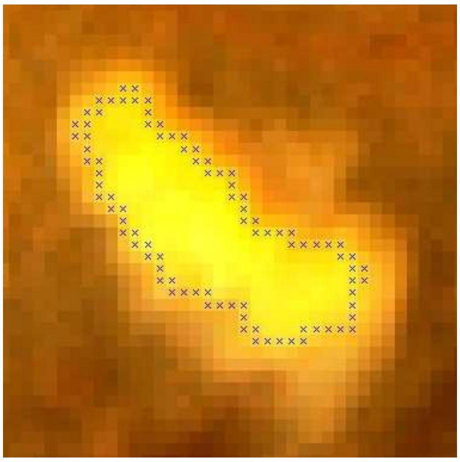


(e) Semi-automatic tool, example 3: Decrement slider value by three.

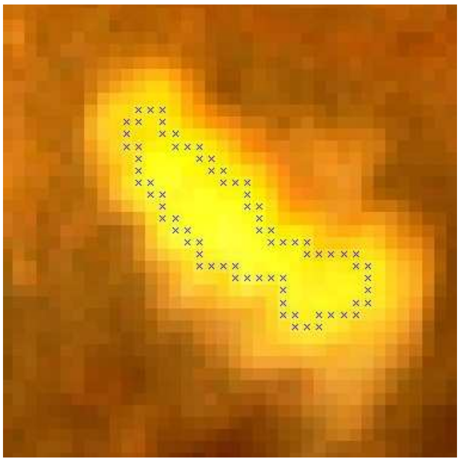
Figure 31: Semi-automatic tool, example 3 with a real image.



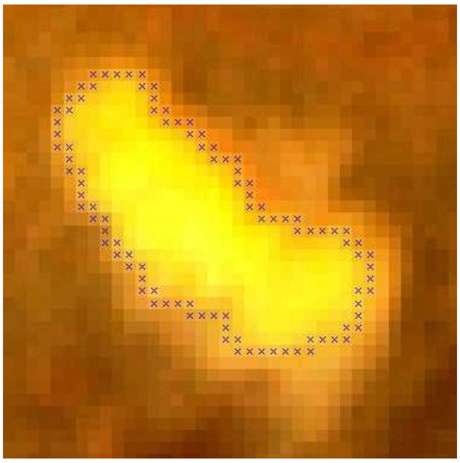
(a) Semi-automatic tool, example 4: Initial step.



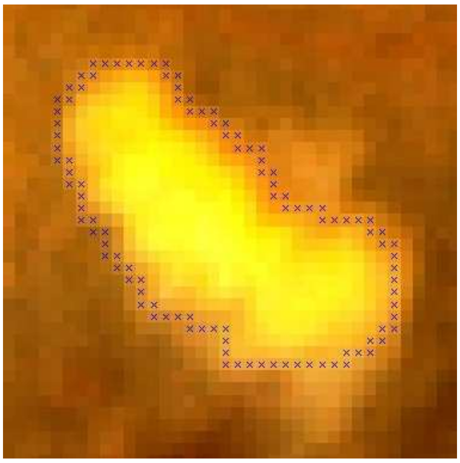
(b) Semi-automatic tool, example 4: Decrement slider value by one.



(c) Semi-automatic tool, example 4: Decrement slider value by three.



(d) Semi-automatic tool, example 4: Increment slider value by one.



(e) Semi-automatic tool, example 4: Increment slider value by three.

Figure 32: Semi-automatic tool, example 4 with a real image.

List of Figures

REFERENCES

[1] Alireza Osareh. *Automated Identification of Diabetic Retinal Exudates and the Optic Disc*. PhD thesis, University of Bristol, January 2004.

[2] DEHKO. *Development Programme for the Prevention and Care of Diabetes in Finland 2000-2010*. Finnish Diabetes Association, 2001.

[3] Klas Niemi, Marja; Winell. *Diabetes in Finland - Prevalence and Variation in Quality of Care*. Finnish Diabetes Association, Tampere, 2006.

[4] Pirjo; Haapa Etu-Seppälä, Leena; Ilanne-Parikka, editor. *Programme for the Prevention of Type 2 Diabetes in Finland*. DEHKO, 2003.

[5] Markku Kuivalainen. Retinal image analysis using machine vision. Master's thesis, Lappeenranta University of Technology, June 2005.

[6] Heikki Kälviäinen. Diabetes and retinal image analysis using machine vision.

[7] Imageret, optimal detection and decision-support diagnosis of diabetic retinopathy. website: http://www.it.lut.fi/project/imageret/ (referenced 5th october 2007).

[8] Gunvor von Wendt. *Screening for Diabetic Retinopathy - Aspects of Photographic Methods*. PhD thesis, St. Erik's Eye Hospital, Stockholm, 2005.

[9] Sightsavers international. website: http://www.sightsavers.org/ (referenced 26th september 2007).

[10] Robert M. Kaiser, Peter K.; Boynton. *Human Color Vision*. Optical Society of America, 2 edition, 1996.

[11] Julie Parry. *Screening for Diabetic Retinopathy in Europe 15 years after the St. Vincent Declaration, The Liverppol Declaration 2005 (Website: www.drscreening2005.org.uk)*. 18th January 2006.

[12] Wikimedia commons. website: http://commons.wikimedia.org/wiki/ (referenced 7th october 2007).

[13] Tekes, national technology agency of finland. website: http://www.tekes.fi/eng/ (referenced 1st october 2007).

[14] Abhay Sharma. *Understanding Color Management*. Thomson, Delmar Learning, United States, 2004.

[15] Konstantinos N. Lukac, Rastislav; Plataniotis, editor. *Color Image Processing: Methods and Applications*. CRC Press, Taylor & Francis Group, 2007.

[16] Andrew Rodney. *Color Management for Photographers*. Elsevier Inc., 2005.

[17] Alan Ford, Adrian; Roberts. Colour space conversions. August 1998.

[18] Robert Berdan. Digital printing workshop. *Science & Art Multimedia*, 2005.

[19] Richard E. Gonzalez, Rafael C.; Woods. *Digital Image Processing*. Prentice-Hall, Inc, New Jersey, 2 edition, 2002.

[20] Bryan S. Morse. Lecture 16: Segmentation (edge based, cont'd). Technical report, Brigham Young University, 2000.

[21] Wolfram mathworld, the web's most extensive mathematics resource. website: http://mathworld.wolfram.com/ (referenced 7th october 2007).