The eyeBook

Using Eye Tracking to Enhance the Reading Experience

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Introduction

A rapid development of eye tracking technology has been observed in recent years. Today's eye trackers can determine the current focus point of the eye precisely while being relatively unobtrusive in their application.

Also, a variety of research and commercial groups has been working on this technology, and there is a growing interest for such devices on the market. Eye tracking has great potential and it can be assumed that it will advance further and might become a widespread technology used at a large number of personal or office computer workplaces. Approaches using simple webcams for eye tracking already exist, for example webcams integrated into laptop computers by default. Thus, they allow for new kinds of applications using eye gaze data.

However, not only eye tracking technology is advancing rapidly to an easily usable state. Additionally, during the past 100 years researchers gathered a considerable amount of knowledge on eye movements, why and how they occur, and what they might mean.

So, today, we have the technology and knowledge for tracking and analyzing eye movements, making an excellent starting point for sophisticated interactive gaze-based applications.

Naive approaches where gaze data is directly employed for interacting with the system, e. g., pressing buttons on the screen with the "blink of an eye" generally have serious problems. Because the eyes are organs used for perceiving the world and not for manipulating the world, it is hard and against human nature to control eye movements deliberately.

However, a highly promising approach is just to observe eye movements of the user during his or her daily work in front of the computer, to infer user intentions based on eye movement behavior, and to provide assistance where helpful. Gaze can be seen as a proxy for the user's attention, and eye movements are known to be usually tightly coupled with cognitive processes in the brain, so that a great deal about those processes can be observed by eye tracking. For example, by interpreting eye movements, reading behavior of the user can be detected, which most likely entails cognitive processes of understanding with regard to the currently read text.

In this paper we are focusing particularly on reading behavior since reading is probably the most common activity of knowledge workers sitting in front of a computer screen. We present an algorithm for online reading detection based on eye tracking data and introduce an application for assisted and augmented reading called the *eyeBook*.

The idea behind the eyeBook is to create an interactive and entertaining reading experience. The system observes, which text parts are currently being read by the user on the screen and generates appropriate effects such as playing sounds, presenting

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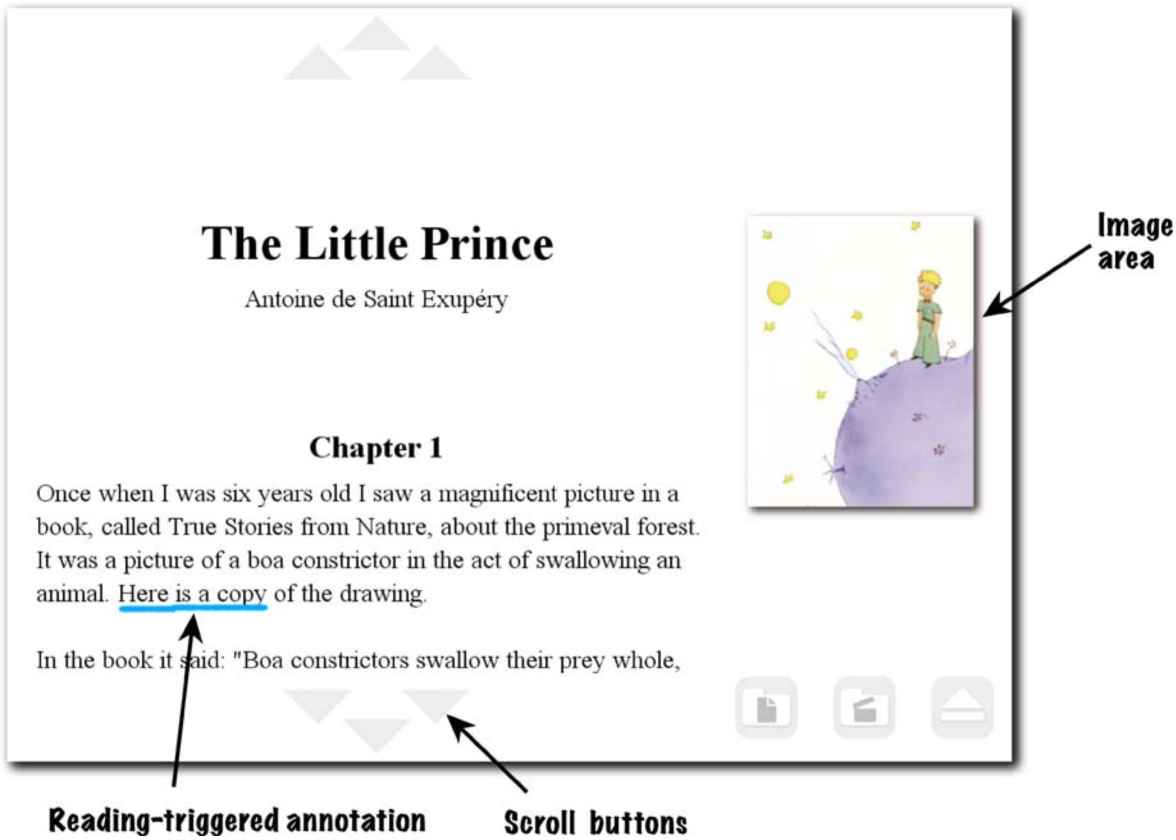

Fig. 1 User interface of the eyeBook. If the reader passes the marked position, a sound can be heard and a new image is shown

pictures, or changing the color scheme. An example of the eyeBook interface is presented in Fig. 1. It is an entertaining application introducing a new kind of story telling experience, and the eyeBook technology has the potential to be used for information assistance purposes.

Eye Tracking Technology

For the past hundred years some interesting advances have been observed concerning the analysis and study of eye movements both with respect to eye tracking techniques and their applications. Here, we give a brief overview on how modern eye trackers work and what kinds of applications eye trackers are mostly used for today.

Starting from the manual observation of the eye for the purpose of understanding eye movements during reading to interactive systems reacting on just the *flick of an eye*, a diversity of measurement systems, scenarios and programs have been developed addressing one main question: *What can be read from eyes?*

Modern Remote Eye Tracking

While even today many different classes of eye tracking devices exist, the trend in end user devices, e. g., used by disabled users, research, and usability labs, goes to remote eye tracking. This technique usually works by illuminating the eye with one or more infrared light sources, and the reflection on the eye is in turn recorded by one or more cameras. One of the advantages of infrared light is its invisibility to the user, and therefore it does not distract people while working with the eye tracker.

The exact mechanisms used by proprietary devices (like the eye tracker shown in Fig. 2) are disclosed, but published techniques often work by computing the center of the pupil and the center of the corneal reflection, called glint, and determining their relative position to each other. Yet, some eye trackers also consider further reflective zones of the eye to gain a higher tracking precision (compare Fig. 3). These relative positions can then be used in conjunction with reference points to compute the on-screen gaze position for a fixed head orienta-

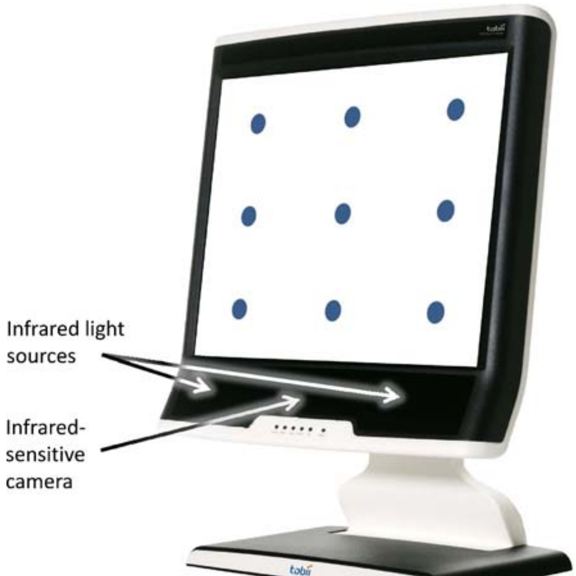

Fig. 2 A modern desk-mounted eye tracker (Tobii T60) with an integrated camera below the screen

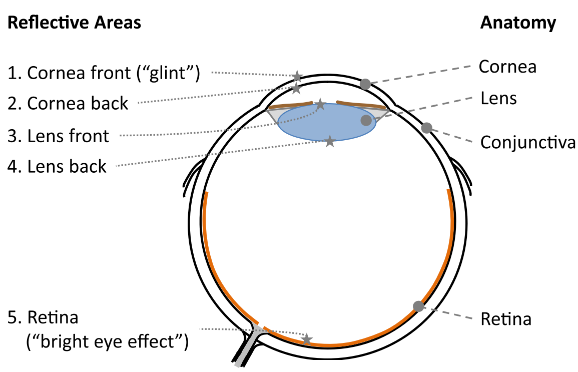

Fig. 3 Schema of an eye. Different locations of light reflections used for eye tracking are marked with asterisks

tion. The reference points are obtained in a process called *calibration* where the user usually has to focus on a small number of different locations on the screen for a short time (e. g., the 9 different locations depicted in Fig. 2).

Based on these computations the device usually delivers raw gaze data to the application. This data may include gaze positions of the individual eyes in screen coordinates and optionally additional information such as the head position in x-, y- and z-coordinates and the observed pupil size. The raw gaze values, however, are rarely used directly and are usually further filtered and post-processed since they are subject to random noise, such as measurement errors, systematic errors and drift from calibration.

So, given that the computer knows where people look on the screen, how can this information be used?

Present Applications of Gaze

The application of gaze data can be distinguished as being either diagnostic or interactive [7]. Because computer equipment was not available a century ago, diagnostic usage was historically the first to emerge and it has kept its importance to the present day. Interactive applications on the other hand address new ways of human–computer interaction using gaze input.

Diagnostic Applications. Diagnostic applications cover a wide range of domains. One of the first usages of eye tracking was the examination of reading and information processing, a topic that is still of interest today, as the rest of this article shows.

As we are confronted with a constantly changing environment, it is reasonable to ask how we visually perceive our surroundings – a field generally called scene perception. One of the main applications in this area is the analysis of advertisements. Companies investing several thousand Euros into the distribution of a billboard have a keen interest to objectively verify that customers actually notice what it was designed for, e. g., to notice the brand or company name.

A different diagnostic domain is the study of Human-Machine-Interface-related tasks. Experts solve problems differently to novices. Their actions, but also their focus of attention, vary from those of untrained operators. A comparative gaze analysis can uncover the potential for optimization or refinement of training, for example in aviation, driving or the interpretation of medical images.

Furthermore, within the automobile industry for example, there is ongoing research regarding the integration of eye tracking systems for driver assistance. Drowsiness is a significant cause of accidents and a real-time diagnosis alerting the driver of his or her potentially hazardous state will help to avoid that danger.

Interactive Applications. In contrast to diagnostic purposes, interactive applications facilitate gaze as an input to alter the runtime behavior of the system. Most notably this category comprises selection applications, where the user actively uses his or her gaze to control or perform a certain action.

As previously stated, the use of gaze in order to manipulate user interfaces creates new problems (especially when considering that eyes mainly evolved as organs to perceive information), for example those of accidental manipulation. One noteworthy problem in this regard is called the *Midas Touch*, referring to the mythical king who turned everything he touched into gold. In the domain of eye tracking, this term denotes the difficulty to infer an intent of manipulation from the purely two dimensional position of the user's gaze. One workaround concerning a selection process is dwell time: a button or control element is charged by gaze time until a certain threshold is reached. Looking away from the element before activation will discharge it. However, while a sufficiently long dwell time could effectively eliminate the Midas Touch, the systems would then be rendered unusable because it would just take too long to interact with them.

Another category of interactive gaze-based applications not only serves the purpose of aiding handicapped users. Starker and Bolt [18] for example created an interactive narrator which provides additional information about items gazed upon in a three-dimensional world by speech synthesis. Yet even more directly, eye-tracking control of 3D-applications such as ego-shooters, World of Warcraft or Second Life was implemented recently with varying success. But also 2D applications can benefit from gaze data: Learning environments [12], for example, present related information, dictionaries show unknown vocabulary [8] or text windows scroll automatically [10].

Eye Movements and Perception

As we have seen, gaze data can easily be recorded nowadays. Yet, what do typical eye movements look like and what do they tell us?

Typically, while awake, the eyes move rapidly with a frequency of around four times a second in order to focus on different parts of the current visual scene. Eye movements are most often coupled with cognitive processes in the brain, so that it is possible to derive information about those processes by observing and interpreting eye movements.

Here, we give a short overview of general physiological characteristics of the eyes and how their movement is controlled especially during reading behavior.

Characteristics of the Human Eye

Human eyes can only perceive a limited fraction of the visual world at one point in time. During a fixation (i. e., when the eyes are steadily looking at one spot in the visual scene), both eyes together provide a roughly elliptical view of the world which is approximately 200° of visual angle wide and 130° high [9]. However, not all parts of this view are perceived with equal acuity because the *retina* of the eye has a varying structure and composition. Generally, it is composed of two types of visual receptors, i. e., *rods* and *cones*, that are unevenly distributed.

As depicted in Fig. 4, the *foveal area* is a small central region of the retina of around 2° to 3° of visual angle where visual acuity is maximal [9, 15]. It lies in the center of the retina and covers the area around the fixation point of the eye. It is almost completely composed of cones which are specialized in processing detail, for acuity, and which also serve to distinguish between colors.

With increasing distance from the foveal area, the composition of the receptors on the retina changes: the density of cones decreases while the density of rods increases. Rods are specialized in discriminating different levels of brightness and also in detecting movement. In accordance with the change in composition, visual acuity decreases by 50% at a distance of 5° from the fovea and by 90% at 40° [9]. The area around the foveal area up to 10° of visual angle is called *parafoveal area*. The remainder around the parafoveal area is called *peripheral area*.

In order to achieve the most accurate visual impression of a visual scene, the eyes rapidly move in mostly ballistic jumps (i. e., saccades) from one spot to another, fixating each spot only for a short while of around 250 ms.

Among those rather large saccadic eye movements that an attentive person can easily observe from his or her own experience there are three different, much smaller types of eye movements, i. e., fixational eye movements like tremor, drift, and microsaccades [11]. Their function is to avoid saturation effects of the visual receptors on the retina which would lead to fading perception. However, people are unaware of those tiny movements

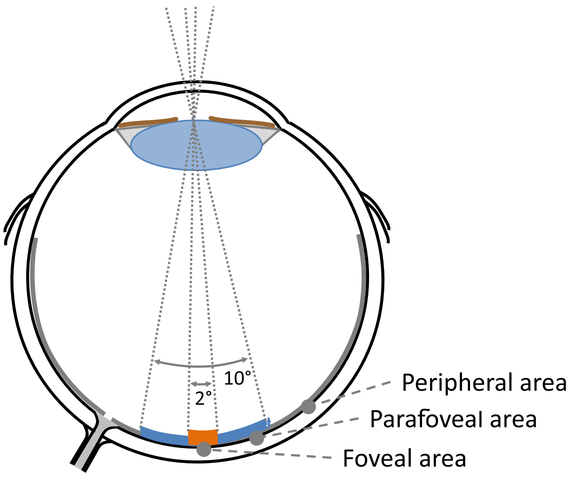

Fig. 4 Foveal, parafoveal, and peripheral regions on the retina

and they can hardly be detected by state-of-the-art unobtrusive eye trackers.

Reading Psychology

During the last one hundred years a lot of research has been conducted concerning eye movements while reading. When silently reading an English text, as summed up by Rayner [14], the eye shows a very characteristic behavior composed of fixations of about 200–250 ms and saccades in specific directions. The mean left-to-right saccade on a line of text has a distance of 7–9 letter spaces. Approximately 10–15% of the eye movements during reading are regressions, which are saccades to the left along the current line or to a previously read line. Short regressions mostly occur due to oculomotor errors or due to problems of the reader with the previously fixated (e. g., unknown) word. There is evidence that longer regressions (more than 10 letter spaces to the left of the currently focused line or to a previous line) occur because the reader did not understand the content of the text.

Words can be identified only during fixations (not during saccades), namely up to ca. 7–8 letters spaces to the right of the fixation point (i. e., foveal vision). However, the total perceptual span, where at least some useful information about the text can be extracted, extends about 14–15 letter spaces to the right of the fixation point.

The factors influencing where, when, how and why eye movements are performed during reading are accounted for in the E–Z reader model of eye movement control in reading [16] in great detail.

Note that there is a high variability of the above-mentioned average values, both concerning individual differences between readers and also concerning document-induced differences for the same reader. For example, the fixation durations for the same reader can vary between ca. 100–500 ms, while the saccade sizes can range between 1 and 15 characters. Amongst others, this variability is influenced by features of the text such as difficulty and word predictability [6], as well as by characteristics of the reader, like background knowledge and reading strategy. For example, there is evidence that if a text becomes more difficult then fixation duration increases, saccade length decreases, and regression frequency increases [15].

Reading Detection

Having this knowledge on the physiological characteristics of the human eye and how and why we control eye movements in mind, it is possible to detect reading behavior based on the very specific sequence of saccades involved. Knowing when the user is reading and which text parts he or she is reading is highly valuable information that can be used as implicit feedback for the computer system. Since reading behavior most often entails cognitive processes of understanding in the user's mind, a computer system might use this information for estimating the user's current topical interests and for providing assistance during reading. Thus, using gaze data for rather indirect reading detection and not for direct interaction with a computer (creating problems like Midas Touch) seems to be a very promising field of application. Since eye trackers of today have sufficient tracking accuracy and are relatively unobtrusive in their application, it seems possible in the future to acquire information about what the user has read on the screen.

What is generally meant by "reading" can be quite different. When people look at a map, study an overview of the latest soccer results in a newspaper, scan through programming code to find an error, all of these could be called "reading" in general. Yet, according to Rayner and Pollatsek [15], we narrow down the meaning of reading by focusing on skilled reading which occurs when reading a text book (or this article) in order to understand its content. An example of fixation placement during such reading behavior is given in Fig. 6.

Based on the knowledge about eye movement behavior during reading, we designed an algorithm that can detect such behavior. Since the two concepts "reading" and "skimming" exist in common language usage, we also introduced a functionality that roughly differentiates between them.

Reading Detection Algorithm

The general idea of the algorithm is related to an algorithm by Campbell and Maglio [5] and ideas by Beymer and Russell [1] and works as first described in [2]:

First, fixations are detected. A new fixation is detected if successive nearby gaze locations within a time interval of 100 ms can be observed from the eye tracker. 100 ms is the minimum fixation duration according to the literature. Gaze points are considered nearby when they fit together in a circle with a diameter of 30 pixels (compare Figs. 5 and 6: classification of raw gaze locations produced by the eye tracker into fixations. The diameter of the circles in Fig. 6 corresponds to the fixation durations).

Second, each transition from one fixation to the next (i. e., each saccade) is classified according to its length and direction. This results in features describing saccades that occur more or less often during reading or skimming, e. g., saccades to the right or left with different distances. A list of all possible features is given in Table 1.

Third, scores associated with the features are accumulated. In order to differentiate between reading and skimming behavior, we apply two different sets of scores as shown in Table 1, one used by a reading detector, and one used by a skimming detector.

Finally, it is determined whether thresholds for "reading" and "skimming" behavior are exceeded.

Fig. 5 Raw gaze data during reading as produced by the eye tracker

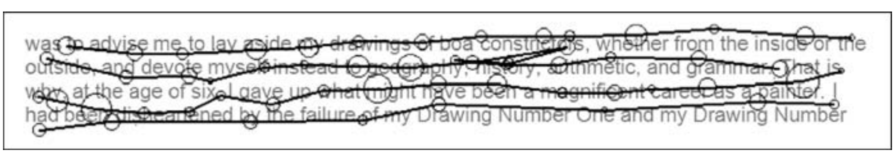

Fig. 6 Fixations and saccades during reading behavior

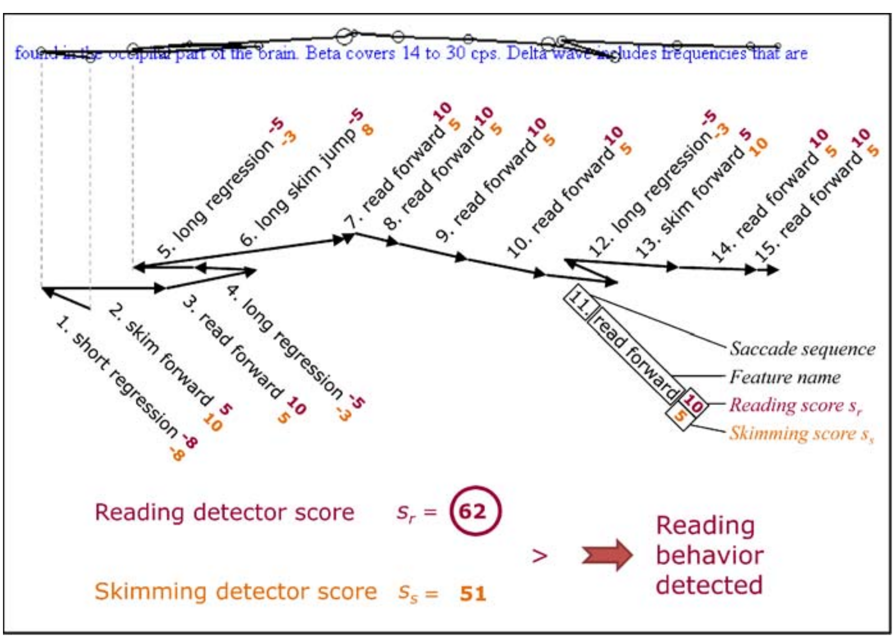

Fig. 7 Reading detection on a saccade sequence

Table 1

Saccade classification and detector scores

Horizontal saccade distance x and direction in letter spaces	Feature name	Reading detector score s_r	Skimming detector score s_s
0 < x <= 11	Read forward	10	5
11 < x <= 21	Skim forward	5	10
21 < x <= 30	Long skim jump	-5	8
-6 <= x < 0	Short regression	-8	-8
-16 <= x < -6	Long regression	-5	-3
x < -16 and y according to line spacing	Reset jump	5 and line delimiter	5 and line delimiter
All other movements	Unrelated move	Line delimiter	

If this is the case then the respective most plausible behavior is detected as shown by an example in Fig. 7.

The eyeBook

The eyeBook is an intelligent book that facilitates gaze to offer a new, multimedia experience of reading. It won first prize in the COGAIN Competition: Creative Gaze[1].

Basic Concepts

This section outlines two parts: Our application framework, called eyeBook framework, which is a system that reads *book-bundles*, loads additional multimedia content, renders the result on the screen and interprets gaze, compare Fig. 1. We also present the individual books created for this reading engine and their format. They are called eyeBooks as well. These books form a bundle of raw text, annotations (also called markers) and multimedia files such as images or sounds along with meta information.

Book-bundles are basically similar to zip-archives with a specific internal structure. A main configuration lists which files actually compose the text of the given book and which page should be opened upon the first reading session. The pages are described by a markup-language derived from HTML. The language contains additional elements like event handlers dealing with specific eye movement patterns of the user and action elements for modifying the user interface or playing sounds. Thus, most[2] valid HTML files are, in fact, valid eyeBook files.

[1] http://www.cogain.org/competition/creative-gaze.html, last access 3 September 2009

[2] With some exceptions of the usage of JavaScript and CSS that are not fully supported by the rendering engine.

From Reading to Sound

The eyeBook framework, like any other HTML viewer, transforms strings from its book files into rendered text on the screen. The available screen size is evaluated, styles are applied and eventually text is put into layout and rendering, hence associating string positions with areas on the screen.

Calculating a text position for a screen coordinate enables us to perform the next step, integrating the aforementioned algorithms into the eyeBook: If we detect reading we associate the momentarily viewed position with it, thus we are able to flag elements of our book file as read and evaluate corresponding annotations (as depicted in Fig. 8). If there are annotations for reading events for the text section currently being read, then those events are executed.

These annotations can principally be divided into two types: singular markers and block markers. Singular markers span a certain short amount of text and are only executed once during normal operation. Depending on their position in the text, for example at the beginning of a line, singular markers may be expanded to cover more than their initial area, in order to increase the likelihood of an activation by eye gaze. Block markers in contrast usually annotate several lines of text, if not whole sections. Events associated will be executed randomly while the user reads in the area they cover.

While it is imaginable that plenty of effects can be produced upon reading, we focus on a basic set for multimedia: The ability to play sound, music, display images and change the color theme. Usually there is one audio track acting as background music throughout the reading session. It is faded in smoothly and kept running until explicitly terminated. Starting a new music track will cross-fade from the old one. Sound effects in contrast can be played simultaneously and, depending on the book, there are up to three sound layers in parallel: ambient effects like wind or water, foreground sounds most frequently directly connected to the actual text currently focused on by the user (like a howling wolf, as can be seen in Fig. 9) and interface feedback sounds like a short click sound on scrolling.

The remaining two effect classes are images and themes. Images are faded into a separate picture area on the right side of the screen and remain there until a new image has to be displayed. Themes are basically color sets for the background and the fore-

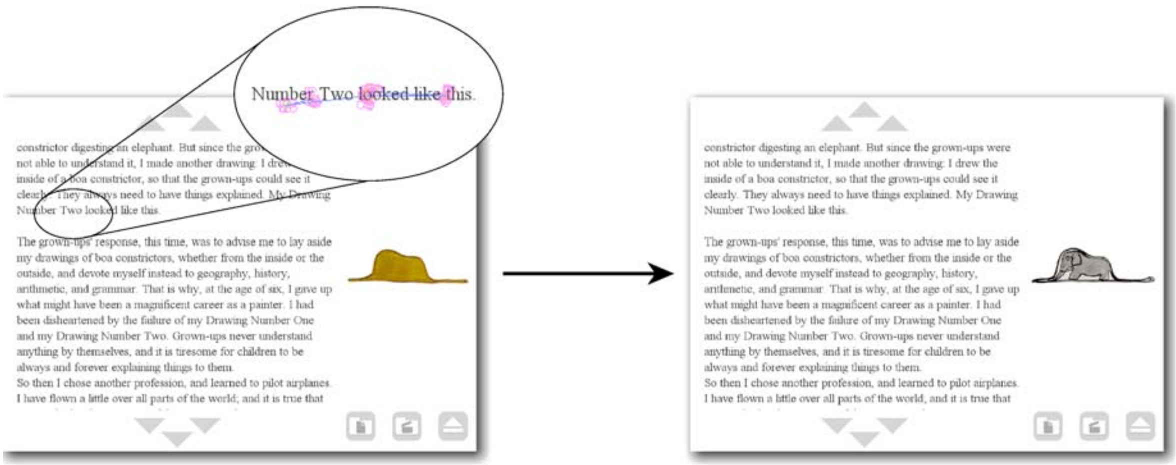

***Fig. 8** If the user reads over an annotation its corresponding event will be executed. In this case the image is changed*

```
Then, far off in the distance, from the mountains on each
side of us began a louder and a sharper @{CMD="play"
file="sounds/wolf.ogg" type="effect" volume="0.15"}
howling, that of wolves, which affected both the horses
and myself in the same way.
```

***Fig. 9** Example of an eyeBook markup. The element will react if its surrounding area has been read*

ground of the text which are intended to intensify the mood of the currently read scene.

Augmented Books

At the moment, there is a set of three eyeBook instances: annotated versions of *Dracula*, *The Little Prince* as well as a *Making Of.*

The first six chapters of *The Little Prince* were augmented with multimedia effects for reading. The book starts with the author making acquaintance with the prince. The music is rather melancholic and audio effects happen less frequently, also attributed to the book's stream of consciousness. Images displayed were taken from the ones drawn by Saint-Exupéry himself and appear exactly at the location they are referenced. For example in the text

> *"And after some work with a colored pencil I succeeded in making my first drawing. My Drawing Number One. It looked something like this."*

the end of the first sentence was annotated with a sound of a pencil scribbling on paper, while the middle of the third sentence was linked to an image of the Drawing Number One (i. e., the *hat*).

For *Dracula* we decided to use some of the first days of Jonathan Harker's diary, a scene outside in which he takes a ride in a caleche at night through a mountain area, surrounded by wolves and eventually arrives at the Count's residence. The book is kept very dark, the background color is almost set to black, the music was taken from the movie soundtrack, and numerous ambient sounds found on freesounds.org were integrated. Wolves can be heard howling or the caleche's driver is whispering when the user is reading over the appropriate parts of the text. At the same time in the background the wind roars constantly. Images taken from the movie were artistically converted into stills and shown at appropriate locations.

Explicit Interaction

During normal operation, interaction with the application is purely gaze-controlled. After startup, a user identification takes place and personal settings are loaded including the previous reading progress at word level. After selecting a book to read, the chosen title is opened with a small visual cue at the last read position (if any) and the background music, the color theme, and the sidebar images are restored.

While gaze operation is the default setting, mouse emulation is also possible for demonstration and debugging purposes. With its help the reader may use the mouse to follow his or her gaze in order to trigger reading annotations or activate controls.

All buttons inside are dwell-time-based, but exhibit learning behavior. This pays tribute to the balancing problem of the Midas Touch: Buttons which are gazed upon the first time get activated slowly, but decrease their required time with ensuing operations. This time is also dependent on the impact of the targeted control. Scrolling text, for example, is performed with the help of two areas around the upper and lower border of the screen that have a very low initial activation time: In case of an accidental activation the reading flow is interrupted only minimally and the inverse operation (e. g., *scroll up*, when the previous command was *scroll down*) is instantly accessible. The *quit-control* on the other hand has a high initial activation time, as an accidental execution stops the application and manual interaction is required to start it up again.

Outlook

We will perform more research on *augmented text* and *augmented reading*. With *augmented text* we denote text which reacts to reading, and consider the eyeBook engine as one of its instances. *Augmented reading*, on the other hand, is the process of enhancing reading by the gaze input of eye tracking devices. Both domains offer plenty of ideas worth investigating, not only bound to entertainment.

Reading annotations, for example, can be used for recontextualization purposes [3]: It often happens that one re-opens a document after some time in order to find exactly the same information as during the last time in order to resume a task where it was suspended before. In that case information about which parts have been read before can be used as a search filter applied to documents to find relevant passages quickly and accurately.

This is closely related to the field of personalization in information retrieval: If two different users pose the same query to the search engine, then often the same result list is returned to them. However, users have different individual background knowledge, interests, and information needs so that they expect to find different pieces of information depending on their situation. In this respect, eye tracking and the analysis of reading behavior is a very promising feedback technique. For example, it can then be used to disambiguate the user's query by adding terms that describe the background and current topical context of the user [4].

It is also possible to analyze how exactly the user is reading a text with respect to eye movement measures like fixation duration, saccade length, etc., in order to determine whether the contents of the text seems relevant or interesting to the user or not. This line of research has also produced some very promising results so far (compare [2, 13, 17]).

Other researchers showed that difficulties of understanding when reading text in foreign languages can be recognized and addressed [8] by providing translation on the fly. In a more generalized approach, additional information may be provided down to word level, read or skimmed text may be analyzed, stored or shared, yet collaborative approaches within workgroups – *collective reading* – are conceivable. Education and edutainment are other promising fields, particularly with respect to learning languages.

In the long term, the prevalence of these techniques will depend on how common eye tracking devices become. We think that if these devices become as miniaturized, reliable, and mainstream as webcams are today, then the emergence of augmented reading will be likely because it provides several advantages. However, it might also be imaginable that those devices, which would commonly serve as eBook readers of the future, will contain embedded eye trackers. We anticipate that in this case it is less a question of *if* augmented text will serve as an artistic instrument, but rather *to what extent*?

Conclusion

Overall, we have shown some great future potentials of eye tracking. First, the necessary hardware advanced to an easily usable state and can provide data about the focus point of the eyes with sufficiently high precision for many applications. Given the current commercial interest and competition and the rising interest on the market, it can well be assumed that such devices become more widespread in the future.

Second, today, we can look at a vast amount of research results from over 100 years in the area of cognitive science, particularly from the fields of eye movement and reading research. This knowledge enables us today to build applications making use of gaze data in a reasonable way. One application of that knowledge is the detection of reading behavior for which we presented a robust, online detection algorithm.

Third, the eyeBook application demonstrates the great future potentials for an augmented multimedia reading experience of a new kind. Furthermore, the technologies used are well-suited for additional applications in personal or office computer workplaces, such as applications for information assistance.

In general, there are a great many possibilities open to eye tracking and their applications which might have a considerable impact on the day-to-day work in front of computer screens.

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