A Gaze-Contingent Display Compensating for Scotomata

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Abstract

A Gaze-Contingent Display (GCD) is developed in GLSL *to compensate for scotomata (loss of retinal visual acuity) such as brought on by Age-related Macular Degeneration (AMD). The compensatory GCD introduces a magnification ring slaved to the viewer's gaze point.*

Categories and Subject Descriptors (according to ACM CCS): I.3.3 [Computer Graphics]: Picture/Image Generation [Display algorithms] I.3.6 [Computer Graphics]: Methodology and Techniques [Ergonomics]

1. Introduction

Age-Related Maculopathy (ARM) is a central retinal disease and the major cause of permanent vision loss in adults over 50 years [Fei05]. Early in the disease process (early ARM) there is little or no vision loss and there are only slight retinal changes with abnormal deposits within Bruch's membrane. As the disease progresses (late ARM or Age-related Macular Degeneration, AMD) vision loss may be quite severe due to atrophy (dry AMD) or the development of chorioretinal neovascularisation (wet AMD). The disease effectively robs an individual of all but peripheral vision, leaving only a dim image or black hole at the center of vision—generally referred to as a *scotoma* (the blind spot, a feature of every mammalian eye, is a normally-occurring scotoma, located about 15° visual angle off-center).

By manipulating a computer display in real-time in relation to a viewer's point of gaze, gaze-contingent displays, or GCDs, can provide compelling visualizations of visual field defects such as scotomata [VAS08]. GCDs can thus be used to educate students, physicians and patients' family members about the perceptual and performance consequences of vision loss [GP02]. For example, Figure 1 shows a visualization of AMD (vs. normal vision shown) from a pamphlet issued by the American National Institutes of Health [NIH03]. To render such images, American National Eye Institute (NEI) doctors ask their patients with visual impairments what they see and try to get an in-depth description from them. Simulations are then created by computer staff and the doctors have them make changes until they feel that the information is correct [NEI04]. The GPU-based gaze-contingent display developed by Duchowski and Çöltekin [Dc07] can easily generate such a depiction given an appropriate spatiochromatic degradation function and fragment program (see below).

Figure 1: *Visual field simulation of Age-related Macular Degeneration (AMD), with image at right suggesting how a person with AMD may perceive the original image on the left [NIH03].*

Following maculopathy, patients can still use an intact peripheral portion of the retina to mediate meaningful perception [Mac99]. This strategy is known as *eccentric viewing*, but invoking it for prolonged periods of time can cause fatigue as it requires an "effort of will" [Hel25] to dissociate visual attention from the central point of gaze. Rehabilitation of AMD sufferers for reading often involves training them to use retinal areas below the scotoma (developing what is known as a preferred retinal location, or PRL). By simulating an artificial central scotoma, GCDs have been used in reading studies to show that normal-sighted viewers could develop this ability within five hours of training [Lin05, LSV08].

Although various computer displays have been used for assessing macular function [TKBHW03] as well as training eccentric viewing [FJN95], implementation details of gaze-contingent displays developed to aid eccentric viewing are thus far missing from the literature.

2. Background

Using a GCD to simulate an artificial central scotoma, experiments with normal-sighted readers suggest that increasing line-spacing leads to improved reading performance (e.g., 1.25× spacing yields a 5 word/min speedup) [BSC07]. Concomitantly, a gaze-contingent display was designed to deform text at the gaze point under the auspices of the *SOLAIRE* project [TBCK06]. The technique discussed here is similar but is image-based and therefore not limited to manipulation of text.

Because AMD is often diagnosed with the use of an Amsler grid, as shown in Figure 2, a gaze-contingent display can be designed to attempt to invert the perceived effect at the gaze point, e.g., in this case a magnification ring to compensate for the perceived foveal depression depicted in Figure 2 as a black hole. Inversion of the central scotoma depression by a magnification lens is not unlike a 3D pliable surface [CCF95] slaved to the viewer's gaze point. Such a gaze-contingent lens has been shown to improve visual search performance [ADS05]. In this paper, a similar lens is constructed in a GLSL fragment shader, with a central scotoma simulated at the gaze point. The resulting magnification ring can be interactively manipulated to affect the degree of magnification in the parafoveal region. It is conjectured that this new form of gaze-contingent display may be suitable for improving reading performance for ARM or AMD patients.

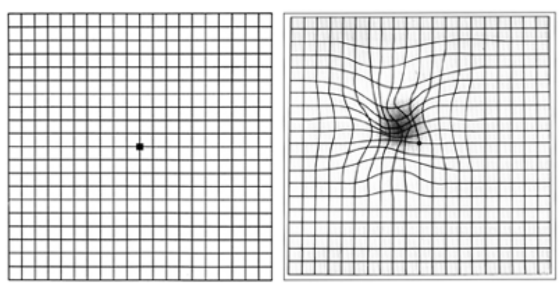


Figure 2: *Amsler grid, as seen by a person with normal vision (left), and as it may be viewed by a person with AMD (right) [NIH03].*

3. Implementation

Magnification is modeled by a function inspired by Libero Spagnolini's simulation of Apple's *PhotoBooth*'s "dent" effect [Spa08]. A pixel fragment is sampled from the underlying texture t at coordinates offset by scaling the fragment's distance r from the gazepoint p, $x = \|r\| = \|t - p\|$, via a function chosen for its degree of magnification, e.g., as plotted in Figure 3.

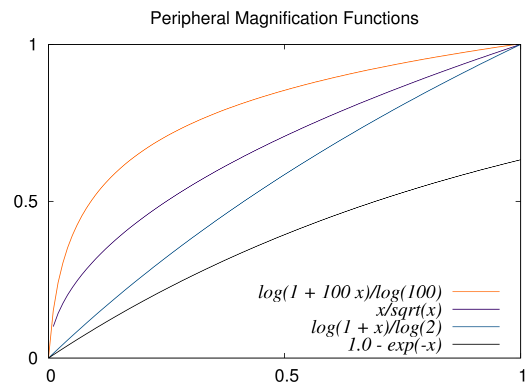
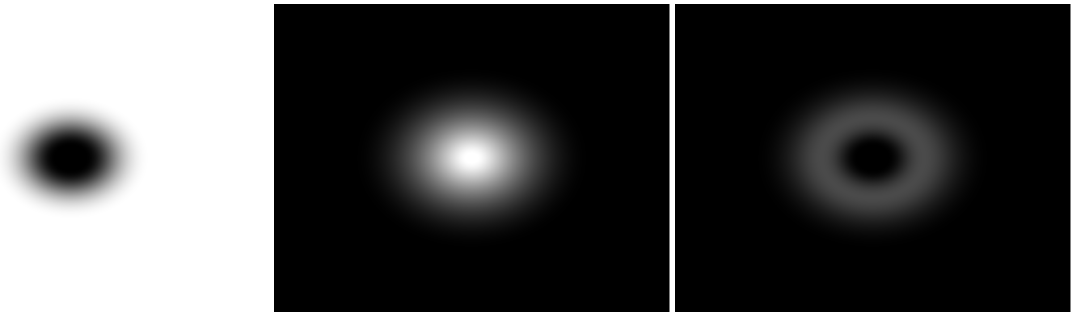


Figure 3: *Peripheral magnification functions potentially suitable for AMD compensation.*

Foveo-peripheral magnification is a composite of center and surround masks, or visual fields. The surround mask is defined by the root of the normalized distance r of the pixel fragment to the gaze point $d = (\|r\|/\sqrt{2.0})^{\frac{1}{2}}$ subject to Hermite interpolation via GLSL's smoothstep function (see fragment shader given in Listing 1). The result is a smoothly decreasing greyscale function centered at the point of gaze that controls the height of the magnification lens and peripheral extent. The center mask is similarly defined and controlled by a smoothstep function and is meant to be limited concentrically within the surround region. The center mask's function is to "punch out" a central hole within the magnification lens nullifying the magnification effect within the central region. The result is a magnification *ring* with no magnification in its center. The center, surround, and composite ring are shown in Figure 4. Ring shape is controlled interactively by manipulating the min and max arguments to smoothstep.

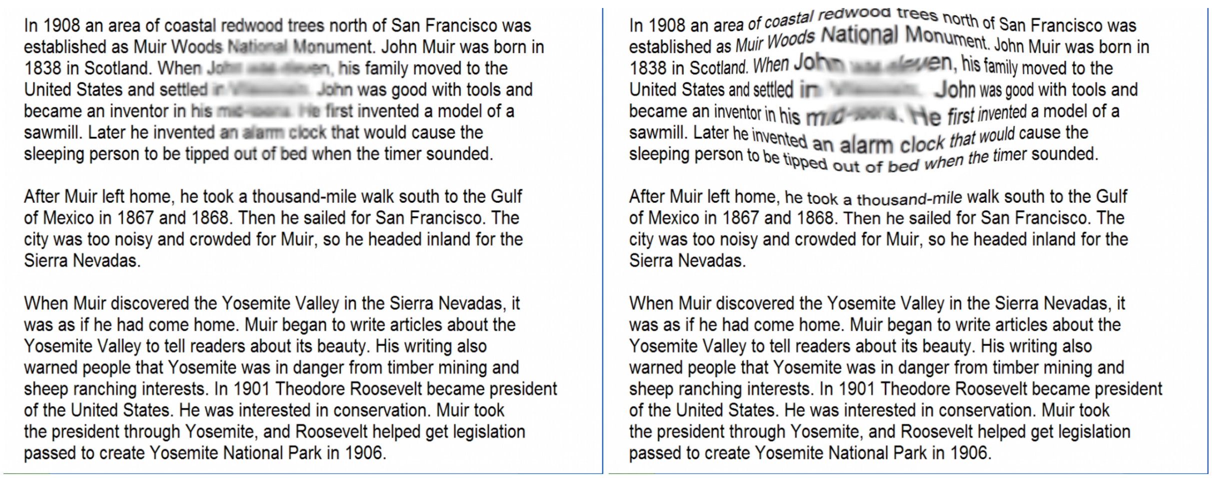
4. Results

The gaze-contingent ring has been implemented and tested with real-time gaze point coordinates obtained from a Tobii ET-1750 eye tracker (see Figure 5). The current sampling rate of the eye tracker (50 Hz) appears sufficiently fast for gaze-contingent steering of the lens. Anecdotal observations indicate that application of a short smoothing filter to gaze point coordinates is necessary to ameliorate lens jitter stemming from the noisy characteristics of gaze data [ADS05]. Interactive control has been provided to vary the width and degree of magnification. At this point, however, it is not yet known which parameter settings are best for sufficient (peripheral) preview benefit to compensate for scotomata.



(a) (b) (c)

Figure 4: *Concentric center-surround masks (or visual fields) used to effect the gaze-contingent magnification ring: (a) center (min = 0.09, max = 0.87), (b) surround (min = 0.54, max = 0.90), (c) center-surround composite.*



In 1908 an area of coastal redwood trees north of San Francisco was established as Muir Woods National Monument. John Muir was born in 1838 in Scotland. When John was eleven, his family moved to the United States and settled in Wisconsin. John was good with tools and became an inventor in his mid-teens. He first invented a model of a sawmill. Later he invented an alarm clock that would cause the sleeping person to be tipped out of bed when the timer sounded.

After Muir left home, he took a thousand-mile walk south to the Gulf of Mexico in 1867 and 1868. Then he sailed for San Francisco. The city was too noisy and crowded for Muir, so he headed inland for the Sierra Nevadas.

When Muir discovered the Yosemite Valley in the Sierra Nevadas, it was as if he had come home. Muir began to write articles about the Yosemite Valley to tell readers about its beauty. His writing also warned people that Yosemite was in danger from timber mining and sheep ranching interests. In 1901 Theodore Roosevelt became president of the United States. He was interested in conservation. Muir took the president through Yosemite, and Roosevelt helped get legislation passed to create Yosemite National Park in 1906.

Figure 5: *Simulation of AMD (left) with a gaze-contingent moving mask modeled by an inverted 1-center, 0-surround Gaussian function* $1 - exp((x^2+y^2)/(-2\sigma^2))$ *with* $\sigma = 100$ *and augmented by the gaze-contingent magnification ring (right) with* $\log(1+x)/\log(2)$ *magnification and center-surround parameters as given in Figure 4. In both instances of this example passage on the life of John Muir, the reader is fixating the word* Wisconsin *(obscured by the simulated central scotoma). AMD patients trained in eccentric viewing are likely to use a preferred retinal location below the scotoma, e.g., attending to the word* alarm. *The two display versions show the entire page of text that can be used in a reading task designed to test the efficacy of the GCD. The GCD magnification ring would only be provided in the treatment condition. The artificial scotoma, moving in tandem with one's gaze point, would be present in both control (left) and treatment (right) conditions for normal-sighted viewers.*

5. Conclusion & Future Work

A gaze-contingent ring has been developed that holds potential for providing peripheral preview for patients suffering with scotomata (e.g., associated with ARM or AMD, but not necessarily central scotomata—the lens may easily be offset to any position relative to the gaze point). The GPU-based technique is easy to implement and should provide a performance benefit to readers trained in eccentric viewing.

The next step in this research requires testing either with patients with scotomata or with normal-sighted individuals viewing a simulated scotoma, as shown in Figure 5. The experimental design for such a study can involve a reading task, as depicted, with dependent variables of words per minute (speed), comprehension (accuracy), and perception of fatigue (subjective impression).

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```
uniform sampler2D img_tex;    // texture
uniform float ex,ey;          // gaze point coords
uniform float c_min, c_max;   // center extent
uniform float s_min, s_max;   // surround extent

void main(void)
{
  // shorthand
  vec2 tex = gl_TexCoord[0].st;
  vec2 pog = vec2(ex,ey);

  // distance to gaze point
  vec2 r = tex - pog;

  // root of normalized diagonal distance
  float d = sqrt(length(r)/sqrt(2.0));

  // surround modeling peripheral magnification
  float s = smoothstep(s_min,s_max,1.0 - d);

  // center modeling the scotoma
  float c = smoothstep(c_min,c_max,1.0 - s);

  // distance from fragment
  float x = length(r);

  // magnification effect
  r *= log(1.0 + x)/log(2.0);

  // linear interp between center/surround
  r = (s*c) * r + (1.0 - s*c) * vec2(tex - pog);

  // if r is untouched, no magnification effect
  tex = pog + r;

  // return final composite
  gl_FragColor = texture2D(img_tex,tex);
}
```

Listing 1: *Peripheral magnification at gaze point.* GLSL *code for scotoma simulation is found elsewhere [Dc07].*

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