

Visual Distortions in Macular Degeneration: Quantitative Diagnosis and Correction

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Large Seminar Room
University of California, Santa Barbara
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General Introduction

Macular Degeneration (MD or AMD) causes a patient's central field of vision to be spatially distorted.

This project's goals are to:

- Quantitatively measure the distortions perceived by the patient.
- Develop optical and computer-based methods to compensate for the perceived macular distortions as well as possible.

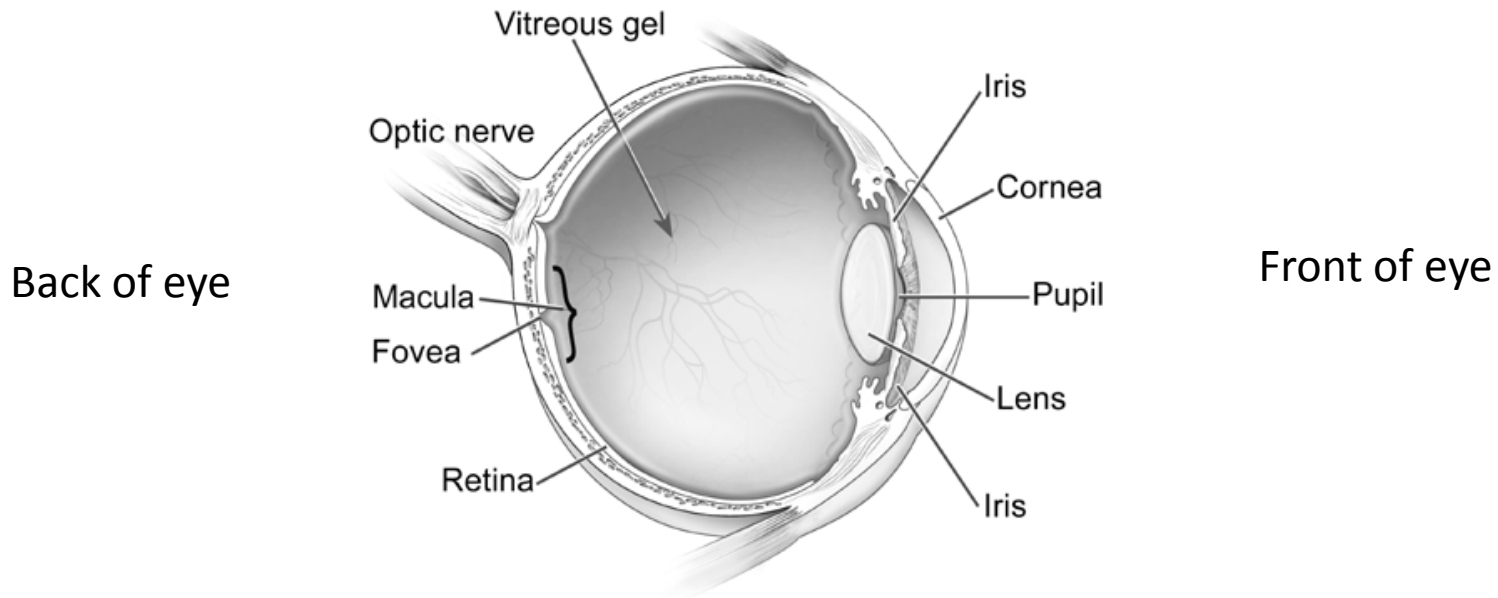


Figure 1: Diagram of the Human Eye

The Amsler Grid

- A useful, non-invasive, diagnostic tool for distorted vision (since 1945)
- Dimensions: Traditionally outer circumference $(10\text{ cm})^2$ enclosing 400 small squares $(0.5\text{ cm} \times 0.5\text{ cm})$. In our work also other sizes.
- The AG is presented 40 cm in front of the eye under examination, while the other eye is patched. The patient's head is fixed by a chin rest.
- The eye is aimed at the central red dot.
- A healthy eye perceives the Amsler Grid (AG) and its red center as shown in Figure 2.

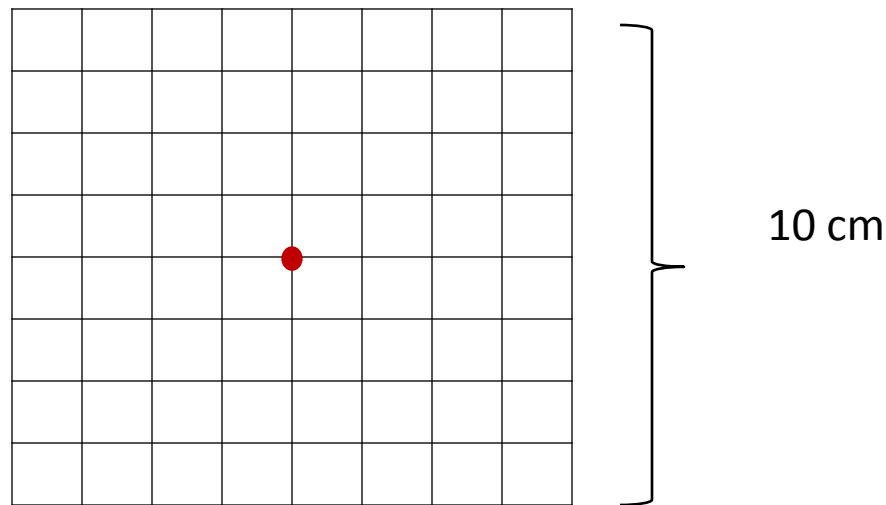


Fig. 2: A useful diagnostic tool in Ophthalmology.

Amsler Grid as perceived by a Patient with AMD

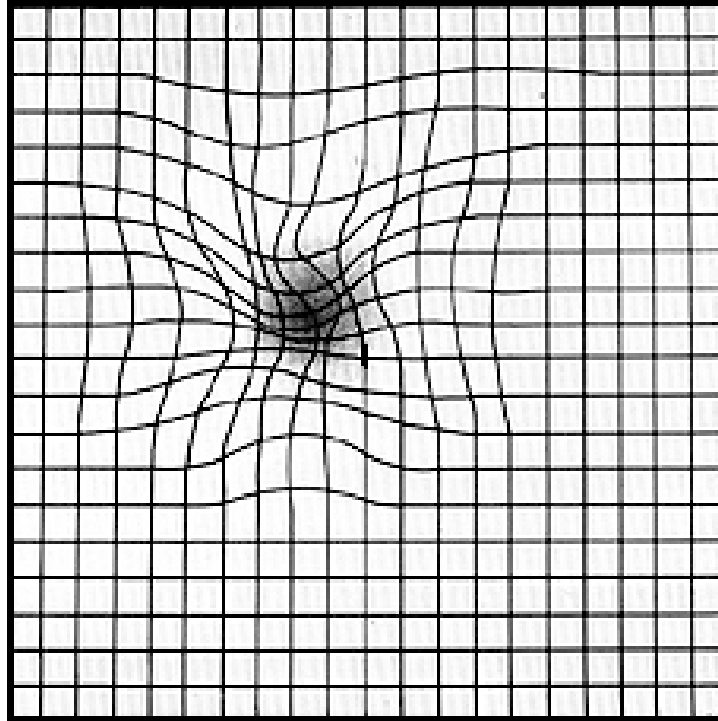


Figure 3: Showing two abnormal features:

- Distortions of AG lines near the center. (However peripheral AG lines are fairly *undistorted*)
- Dark area(s) with diameter ~1 cm

Diagnosis

- AMD Patient wears his normal reading glasses (if any).
- AG is presented to the patient on a computer monitor, 40 cm ahead of him.
- Head is fixed by a chin rest.
- Patient aims and maintains his gaze on the central red dot of the AG.
- The patient uses simple software and the mouse to straighten distorted vertical and horizontal lines, until he perceives the grid as 'perfect'. ~80% or better.
- During the straightening procedure, the computer records the displacements of all intersection points of the AG.
- These displacements constitute the spatial diagnosis of the distortions.



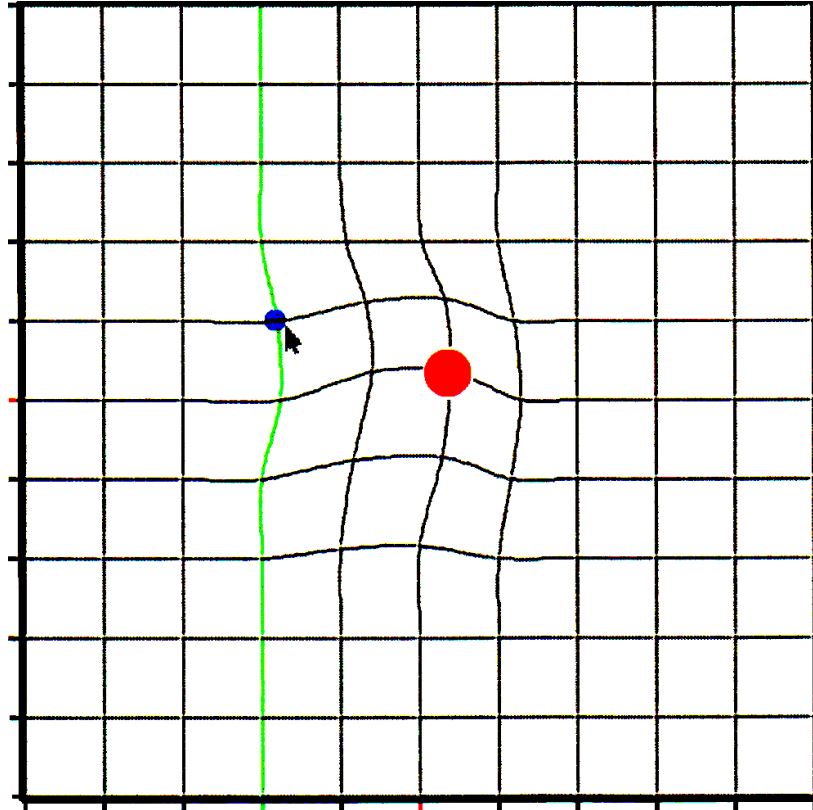


Figure 4: Using the computer mouse (black arrow cursor) to straighten a distorted line of the AG

Interpolation

- Displacement of Arbitrary Points Inside the AG.
- At the conclusion of the diagnostic/editing procedure, ideally the patient perceives the AG intersection points without distortions.
- Typical reading material consists of $\sim 10^3 \times 10^3 = \sim 10^6$ pixels or dots per page.
- Straightening out lines in reading material with 10^6 points is comparable to editing 10^6 AG grid intersection points - unrealistic.
- The 100 displacements supplied by the diagnosis can be used to obtain other points within the AG by standard interpolation using a cell phone-sized computer.

Dynamic Correction by Computer

- The reading material is scanned, photographed, or otherwise converted into an array of pixels.
- Computer software displaces each pixel using the displacements obtained from the diagnostic procedure (Figure 5a).
- The patient views the computer-corrected text at the appropriate distance of 40 cm. He perceives it as undistorted (Figure 5b).
- The text flows in a ticker tape fashion. The patient's eye remains fixed at the center of the white area.

Dynamic Correction by portable computer

- A stationary AMD patient views fixed reading material while moving the correcting device such as shown in figures 6a and 6b.
- The dynamic compensating distortions are applied in real time
- To a reader, with a healthy eye, the image on the camera will appear distorted. To the AMD patient, the image on the camera will appear undistorted.



Figure 6a A small computer and video camera are built into the nosepiece. The computer applies the correcting distortions while the viewer moves his head. The result is displayed by the video glasses.

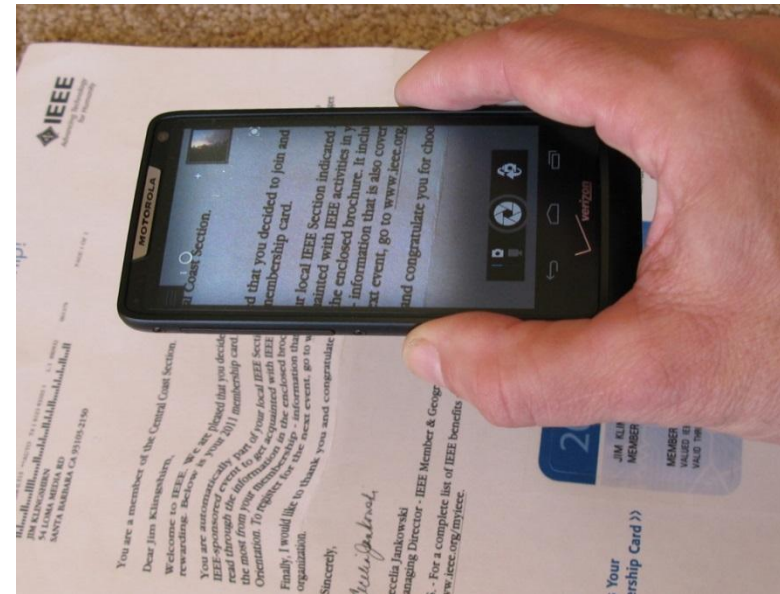


Figure 6b. Correction applied in real time by a hand-held computer, as the reader looks through the device.

Correction by a Refractive Material

- Using the results of our diagnostic procedure, smooth, moderate macular distortions can be corrected or significantly reduced by a suitably patterned slab of optical material.
- The slab is made of glass or optical quality plastic, with typical dimensions of 10cm x 10cm x 2cm.
- The pattern on the top surface and the plate thickness at its upper edges are chosen, with the aid of a computer, so as to optimally reduce the distortions created by the patient's macular degeneration.
- The reader slides the slab over horizontal reading material. The top surface is custom-drilled downward for each patient to a maximum depth of 1-2cm.

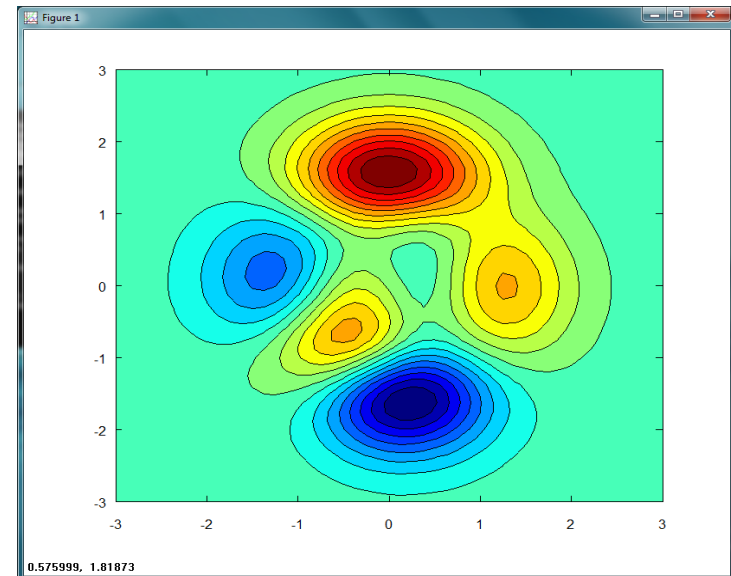
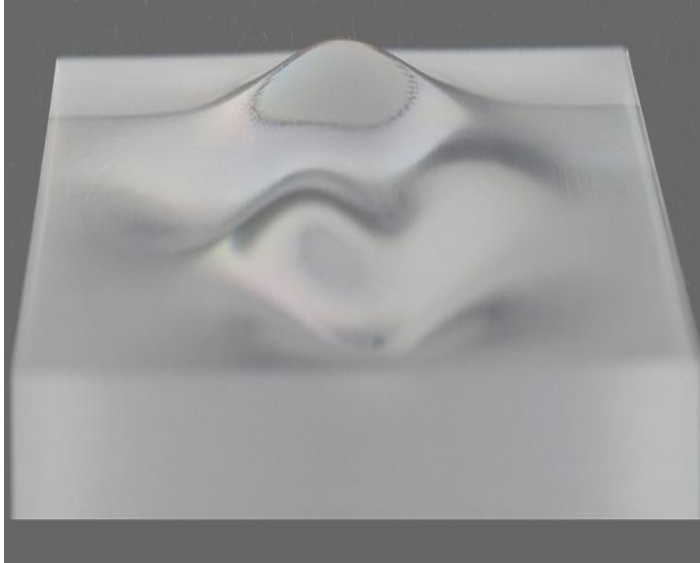


Figure 7a: A refractive contoured slab for correcting macular distortion, created by UCSB Machine Shop

The Correcting Slab Pattern

- Any arbitrary, sufficiently regular slab surface $z(x,y)$ which vanishes at the boundary of a square, $0 \leq x,y \leq L$, can be represented as a convergent, weighted series of products of sine functions. (A 2D sine Fourier series):

$$z(x,y) \quad 0 \leq x,y \leq L \quad (1a)$$
$$z(x,y) = \sum_{m=1}^N \sum_{n=1}^N P_{mn} \sin\left(\frac{mx}{L} * \frac{\pi}{2}\right) \sin\left(\frac{ny}{L} * \frac{\pi}{2}\right)$$

- Any particular choice of amplitudes P_{mn} , generates a specific surface structure $z(x,y)$. A trial and error procedure using optical raytracing is used to find the surface that optimally corrects the patient's AMD.

Correcting Slab Displacement Vectors

- The MD patient is presented with a perfect AG (as seen by the technician). The patient perceives it as distorted. The intersection points of the AG, \mathbf{r}_{mn} , are shifted by the MD by the addition of displacement vectors, $\mathbf{d}_{mn}^{\text{MD}}$, which are recorded

$$\mathbf{r}_{mn} \rightarrow \mathbf{r}_{mn}^{\text{MD}} = \mathbf{r}_{mn} + \mathbf{d}_{mn}^{\text{MD}}$$

- Obviously, a patterned slab, interposed between the AG and a healthy eye, will also cause displacements, $\mathbf{d}_{mn}^{\text{SLAB}}$.

$$\mathbf{r}_{mn} \rightarrow \mathbf{r}_{mn}^{\text{SLAB}} = \mathbf{r}_{mn} + \mathbf{d}_{mn}^{\text{SLAB}}$$

- Provided that $\mathbf{d}_{mn}^{\text{MD}}$ and $\mathbf{d}_{mn}^{\text{SLAB}}$ are weak enough, the combined effects of the MD and of the patterned slab are algebraically additive.
- In these circumstances, the objective of the glass correction procedure is therefore simply to find *that* slab pattern for which

$$\mathbf{d}_{mn}^{\text{SLAB}} = -\mathbf{d}_{mn}^{\text{MD}}$$

Optical Raytracing Procedure

$$z(x, y) \quad 0 \leq x, y \leq L$$
$$z(x, y) = \sum_{m=1}^N \sum_{n=1}^N P_{mn} \sin\left(\frac{mx}{L} * \frac{\pi}{2}\right) \sin\left(\frac{ny}{L} * \frac{\pi}{2}\right) \quad (1b)$$

- For each candidate surface, a set of rays are traced numerically, each starting from its source on an AG intersection point, through the slab, and continuing through a pinhole pupil, to the macula.
- The values of the weights P_{mn} are chosen, to minimize $(\sum D_{mn}^2)^{1/2}$, the sum of square difference between the candidate surface and the patient's diagnosis.
- We require the surface $z(x,y)$ to be sufficiently smooth so that the infinite series expansion for z can be cut off after about 50 terms, with both m and n less than 7. This limits the number of candidate surfaces to 50.
- Rays for 100 intersection points (10x10 AG) are traced for each candidate surface. This entire minimization procedure can be completed in a few minutes on an ordinary computer.

Construction of the Correcting Slab

- The correcting slab starts as a perfect parallelepiped, $0 \leq x, y \leq L$ and $-h \leq z \leq +h$, where L is typically 5 cm or 10 cm and h is typically 1 cm or 2 cm. We call the total number of small squares N^2 . For example in Fig.4 $N=10$. Each small square is labeled by the integral coordinates m and n along the x -and y axes respectively. The set of amplitudes A_{mn} with $1 \leq m, n \leq N$ defines a candidate correcting slab. The top surface is patterned as follows:

$$z(x, y) = \sum_{m=1}^N \sum_{n=1}^N A_{mn} \sin\left(\frac{mx}{L} \times \pi\right) \sin\left(\frac{ny}{L} \times \pi\right) \quad (1a)$$

$$z(x, y) \quad 0 \leq x, y \leq L \quad (1b)$$

- The following trial and error procedure is now used to find that surface which optimally corrects the AMD distortions perceived by the patient

$$A_{mn} =$$

Displacements of AG Intersection Points and Text by AMD

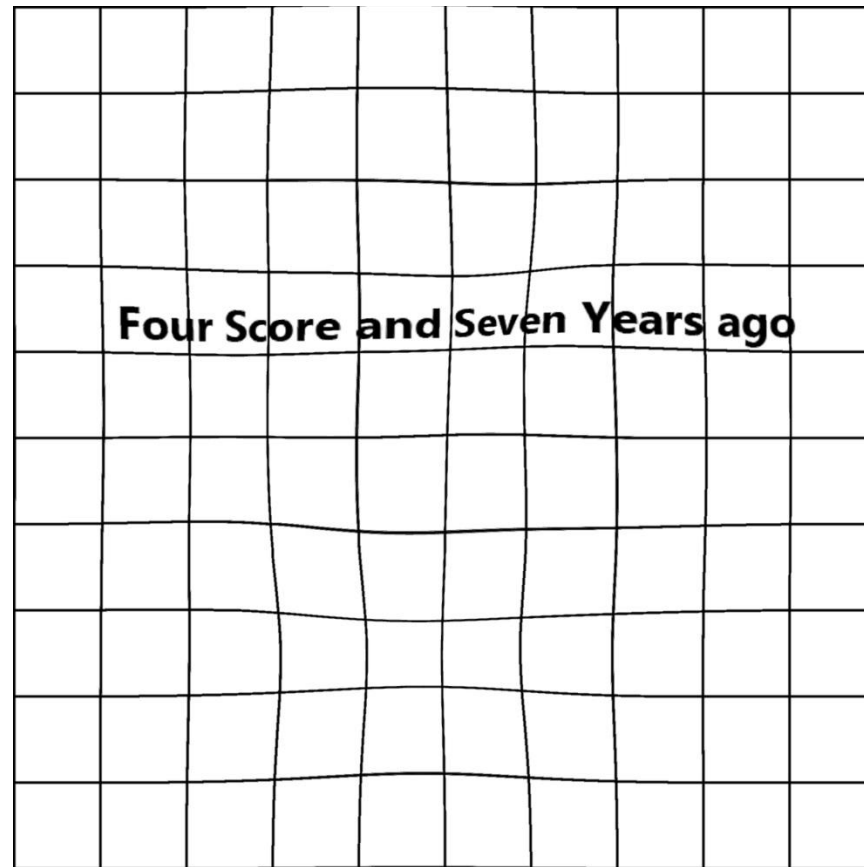


Figure 9: As perceived by an AMD patient (Requires correction)

Compensating Displacements of AG Intersection Points

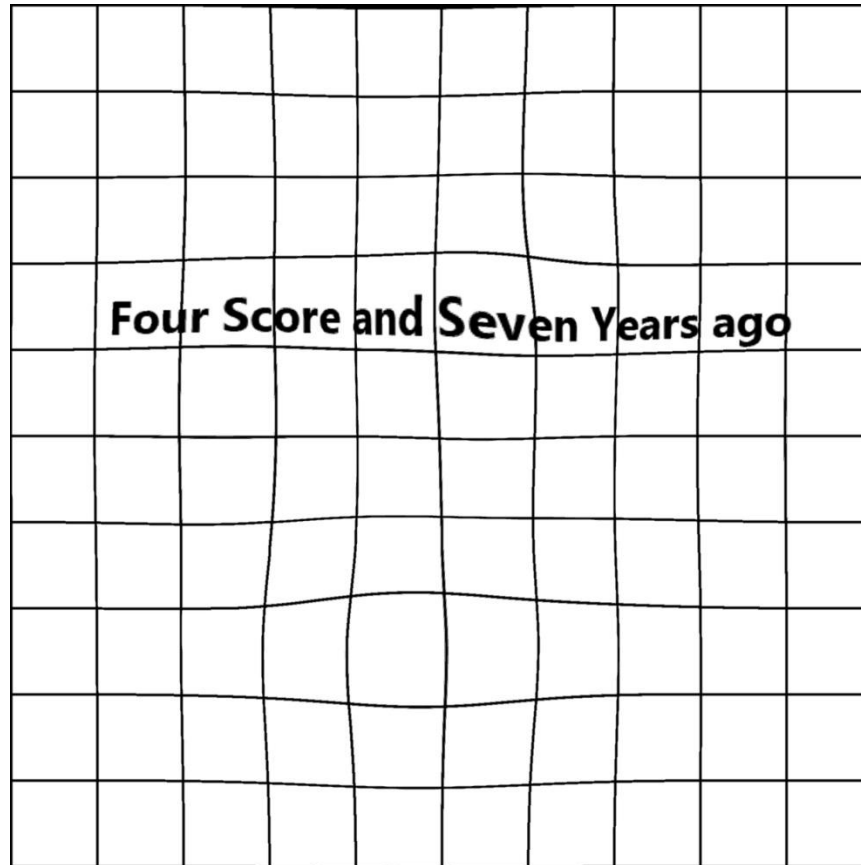


Figure 10: Perception of a person *without* AMD through the correcting device.

Corrected AG and Text

		Four	Score	and	Seven	Years	ago		

Figure 11: Corrected perception of a patient *with* AMD through the correcting device.

CURRENT STATUS

- Analysis of the diagnostic procedure is complete.
- A computer program that creates a dynamic (time dependent) spatial correction has been implemented.
- Prototype optical slabs, providing significant correction, have been fabricated.

OUTLOOK

- Age –Related Macular Degeneration (AMD), a widespread progressive eye disease, is the primary cause of blindness of aged persons, about 65 years or older. A principal element of AMD is **distortion** of visual perceptions. We expect further rapid progress in the reduction of AMD-created visual distortions.