Application of the *Golden Ratio* to 3D Facial Models

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ABSTRACT

In this paper we describe the application of the *Golden Ratio* to three-dimensional facial scans. The Golden Ratio is believed to be a blueprint for facial features that conform to beauty. Faces are scanned using the Minolta VI-700 range data scanner. The acquired 3D meshes are viewed and manipulated using 3DS Max and MAXScript. A Golden Mask, constructed based on the Golden Ratio is used to indicate the ideal positions and orientation of the features of the face. The mesh is morphed according to the ideal positions to suggest a new arrangement for facial features aligning them to the Golden Mask, resulting in more a beautiful face. This has many implications for a wide range of applications including plastic and reconstructive surgery, and can be used to quantify the beauty of a face. These techniques can be applied to modify characters to comply with the rules of the Golden Mask, thus making them more beautiful. Conversely, characters facial features can be modified to deviate from the Golden Mask resulting in less attractive characters.

Keywords
Computer Graphics, 3D Mesh, Mesh Manipulation, Golden Ratio, Character Development

1. INTRODUCTION

The Golden Ratio, (1.618:1), is believed to hold the key to the secret of beauty. The Golden Ratio originates as far back as the ancient Greeks and has been discovered in numerous patterns of nature, such as flowers, and many other designs, paintings and objects regarded as visually pleasing, Figure 1.

This suggests that our perception of beauty is not simply subjective, or "in the eye of the beholder", but may rely on how faithfully the Golden Ratio is echoed in the proportions. This may also be true of human beauty.
Dr. Marquardt [Mar02a] found that the parameters of an attractive face and the orientation of the

Figure 1: The aspect ratio of the Acropolis is the Golden Ratio. The individual florets of the sunflower grow in two spirals extending out from the centre. The first spiral has 24 arms, while the other has 35. The ratio, 24 to 35 is the Golden Ratio

features that are collectively recognized as an attractive face, can be described using a collection of lines and points selected from a composite of pentagons whose sizes are related by the Golden Ratio. Marquardt used such a collection of lines and points selected from a composite mask of pentagons to construct a *Golden Mask* [Mar94]. This Mask reflects the ideal distance between the elements of an attractive face. Overlaying this Mask on beautiful faces results in an exact fit [Mar02b]. The further the face deviates from the lines of these pentagons (the Golden Mask), the less attractive the face is considered to be, Figure 2.

In this paper we apply the Golden Mask to mould 3D facial scans to their ideal proportions, in an attempt to produce a more attractive face. Section 2 outlines related work. Section 3 describes how the initial 3D mesh is captured and stored and gives details of how the Golden Mask is constructed. In Section 4 we outline how the Mask is applied to the scanned meshes to generate the "ideal" corresponding facial mesh. Section 5 describes how the features are morphed. The results of applying the Golden Mask are illustrated in Section 7, and Section 8 concludes the work and discusses further avenues of research.

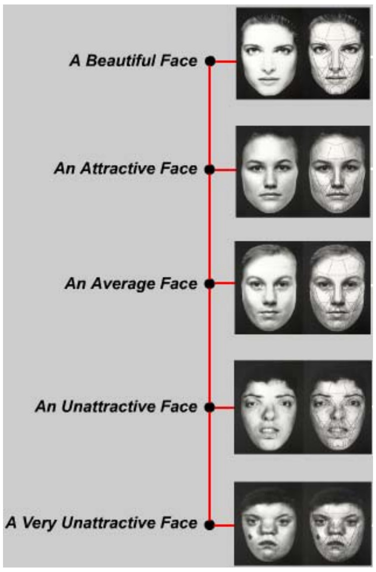


Figure 2: The closer the fit of the face to the mask, the more beautiful the face

2. RELATED RESEARCH

Computer simulations are a new tool in plastic surgery. [Pla03] provides a facility for potential clients to submit a photograph of themselves, along with a description of the surgery that they would like to have performed. The photograph is then morphed according to the surgical procedure and returned to the client, to give them an impression of the outcome of the surgery.

Some plastic surgeons currently use morphing programs in 2D. It is basically an "eyeball it" concept where the surgeon tells the patient what he plans to do for them and approximates it in the morphing program by modifying a photograph generally in the lateral view of their face e.g. removing a hump in the nose etc. The problem with this concept is that there is no "ideal" to adhere to - the surgeon only gives his subjective "opinion".

Koch et al [Koch02] have computed the mechanical behavior of the underlying soft tissue of the face, in order to simulate common facial surgery procedures. These realistic images of the post-surgical appearance of the patient's face are of great importance to relax patient's fear.

M.A.I. (Marquardt Aesthetic Imaging, Inc.) [Mar02a] is developing a program where the surgeon can use the computer to analyze the 2D photo of the patients face by comparing it to the Golden Mask that they have developed. The program will then morph the photograph of the face to approximate the mask in any area desired (nose, chin, eyebrows, etc.).

This paper extends the above idea by *automatic* morphing of the features to fit the mask, and by using actual 3D meshes, which represent the individual face, instead of photographs.

3. THE GOLDEN MASK

To acquire the initial models, facial scans were captured using a Minolta [Min02] VIVID-700 3D laser scanner, Figure 3.

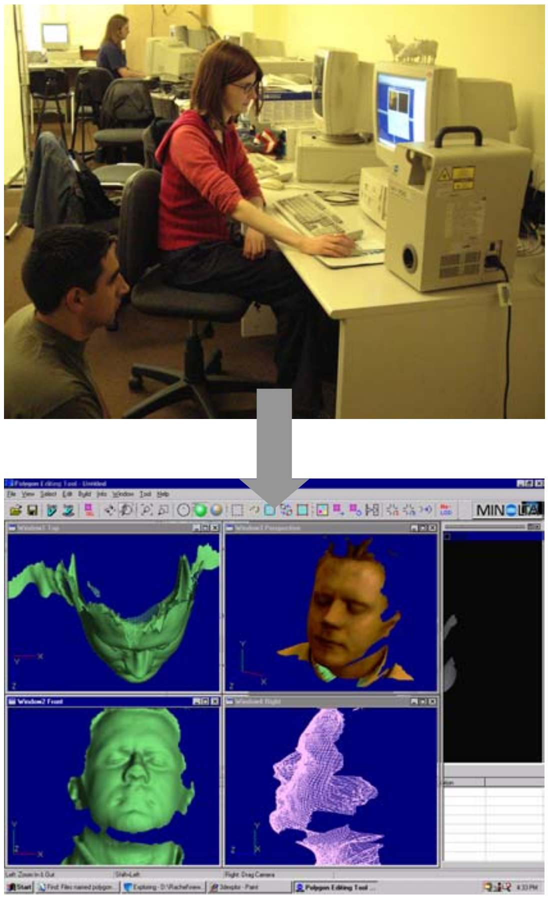


Figure 3: 3d scanner is attached to the computer and records an image of the test subject

The scanner is a non-contact 3D laser scanner; this means that it can infer depth information from a 3D object without using a measuring needle to contact the surface of the object. When taking the facial scans, the person kept their eyes closed while the lasers were running over their face, to prevent any damage to the retina. The scanner records a detailed mesh and a CCD photograph of the face. The output is exported to 3DS Max 4.

Extremely detailed mesh models can be displayed and manipulated in 3DS Max 4, resulting in a highly realistic model of a human face.

3DS Max 4 and its scripting language (MAXScript) were used to construct the 3D mask. MAXScript [Bic01] is specifically designed to complement 3DS Max software. It has several special features and constructs that mirror high-level concepts in the software user interface.

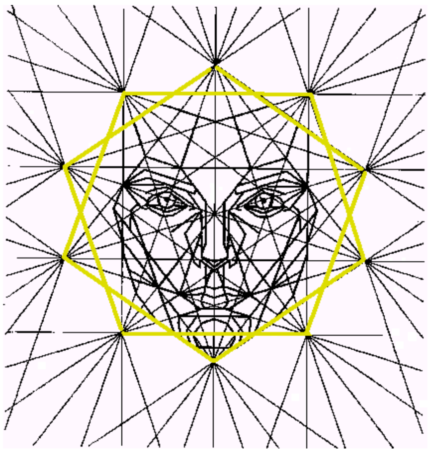


Figure 4: Pentagons and radials positioned over the face

3. FINDING IDEAL PLACEMENT OF FEATURES

To determine the correct positioning of the ideal positions of facial features, Dr. Marquardt's Golden Mask was implemented using MAXScript. This was achieved by placing a pentagon complex over the face, Figure 4. The pentagon complex consists of 2 Golden Pentagons, with 20 lines (spaced evenly over 360°) projecting from each vertex. Dr Marquardt also developed a Golden Mask for the side view (lateral view) of the face. This lateral Golden Mask is made up of pentagons and radials and was implemented in a similar manner to the frontal Golden Mask, Figure 5.

People's faces vary in size. Different pentagons are fitted to each individual face. Using the distance between the eyes as a base, the correct pentagons for the individual are computed. Simple geometry rules are used to find the

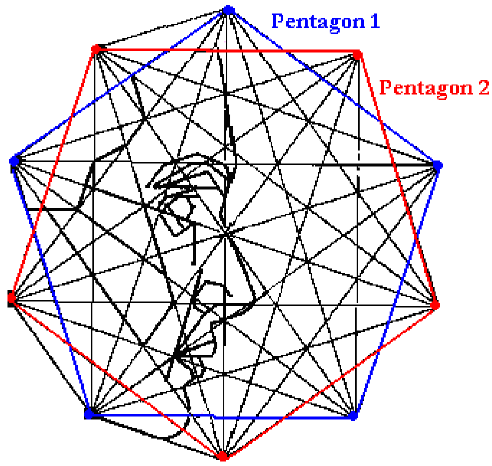


Figure 5: Lateral positioning of pentagons and radials over the face

positions and sizes of the pentagons, Figure 6. The other four vertices of the pentagon are then calculated using trigonometry, Figure 7. Projecting out of each vertex of a pentagon are ten lines or "radials". The intersections of these radials indicate the positioning of the ideal features of the face, Figure 8

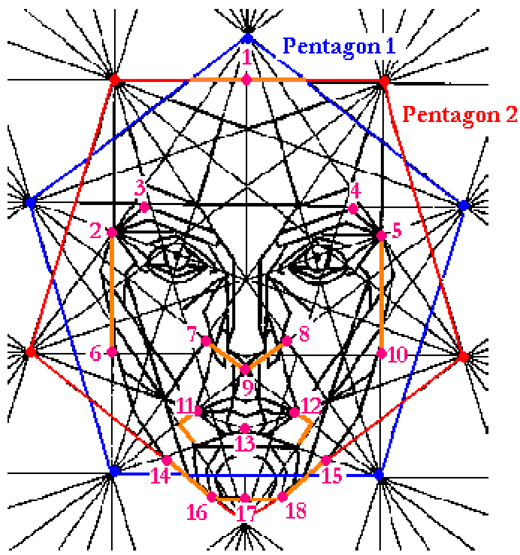
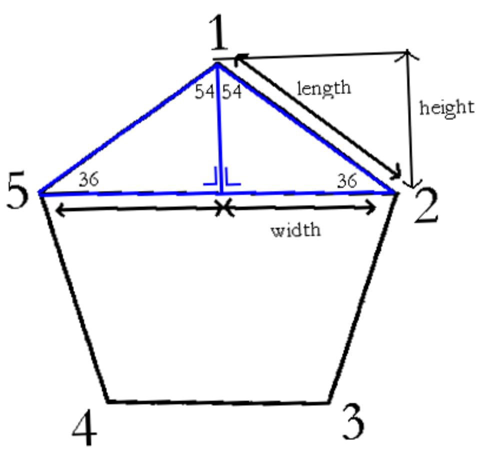


Figure 8: Intersection points of radials that correspond to ideal feature points

```
vert1=(getvert faceMesh right_pupil_point) //returns the
//coordinates of the right pupil point on the face mesh
vert2=(getvert faceMesh left_pupil_point) //returns the
//coordinates of the left pupil point on the face mesh

x=dist vert1 vert2 //returns the distance between vert1 and vert2

phi_x=(1.618 * x) // returns phi times x

pentagon_linelength=(2*phi_x)/(1.618) //calculates the length of
//each side of the pentagon

midPupils=midPt vert1 vert2 //returns the midpoint between vert1
//and vert2

h=(phi_x*(sin 72)) //calculates the length of h

top_vertex=[midPupils.x, (midPupils.y)+h, midPupils.z+10]
//assigns the coordinates of the top vertex of the pentagon
```

Figure 6: MAXScript code for finding the top vertex of the pentagon, and the length of the sides



Coordinates of vertex 1 = [x, y, z]

Length = pentagon line length (previously specified)

Sin 54° = width / length //Sin = Opposite/Hypotenuse

Width = length * sin 54° //Rearrange equation

Sin 36° = height / length

Height = length * sin 36°

x coordinate of vertex 2 = x + width

x coordinate of vertex 2 = x + (length * sin 54°)

y coordinate of vertex 2 = y – height

y coordinate of vertex 2 = y – (length * sin 36°)

z coordinate of vertex 2 = z

Figure 7: Method of working out the coordinates of pentagon vertex 2 and 5

The equations of the lines are needed in order to perform intersection tests on the radials.

The intersections of particular radials correspond to ideal points on the face. For example, the ideal nose tip point is the intersection of Pentagon 1,Vertex 2, Radial 9 and Pentagon 1, Vertex 3, Radial 10, Figure 9.

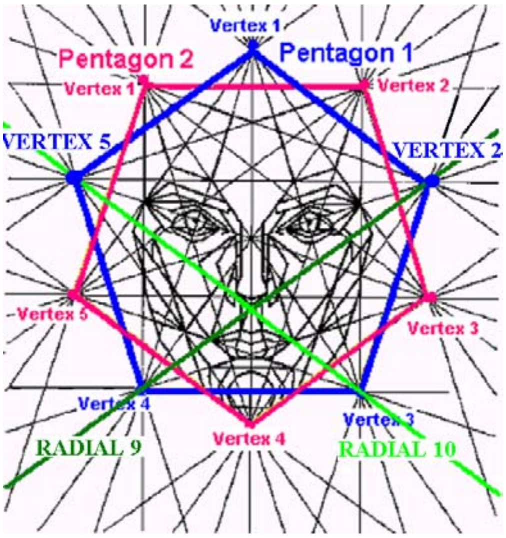


Figure 9: Ideal nose position: Pentagon 1,Vertex 2, Radial 9 Intersection Pentagon 1, Vertex 3, Radial 10

The intersections are found using the equations of both lines. By replacing the value of x and y in one equation, by the value of x and y in the other equation, the resulting point of intersection is found.

Once the ideal points of the face are computed, they are compared to the corresponding points on the face mesh. For example, the user clicks on a vertex on the mesh that corresponds to the tip of the nose. The result of ideal point 9 (as of Figure 8) is then compared with the meshes nose tip and the deviation from actual to ideal is noted, Figure 10.

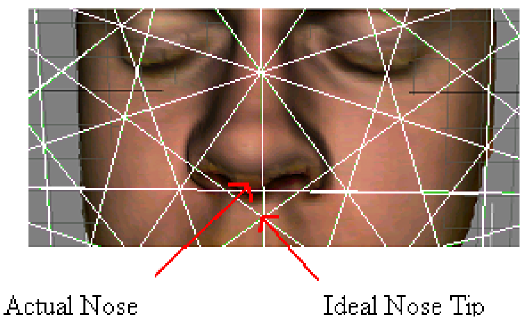


Figure 10: Deviation from actual nose tip to ideal nose tip

5. MORPHING FACE MESHES

Once the deviation from actual to ideal is known, the features are morphed to conform to the ideal. Softselection is a 3DS Max 4 tool, which allows the smooth moving of vertices, without tearing the mesh (making a hole in it), Figure 11. The Softselection controls allow a selection of vertices to behave as if surrounded by a "magnetic field", i.e. when the selected vertices are moved, surrounding vertices are also moved, but to a lesser extent. The extent to which they are moved depends on their weight.

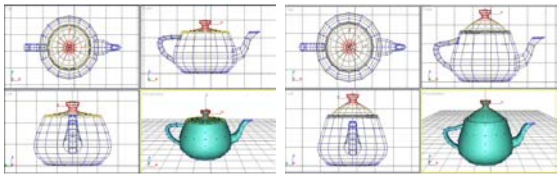


Figure 11: Top, front, left and perspective views of a teapot (left). Red vertices indicate selected vertices and blue are unselected vertices. The Soft Selection controls make a selection of vertices behave as if surrounded by a "magnetic field". The red, yellow and orange vertices indicate this magnetic field. Unselected vertices within the field (yellow and orange vertices) are drawn along smoothly while the selected vertices are being transformed, the effect diminishing with distance. Top, front left and perspective views of the teapot after a transformation has been applied (right).

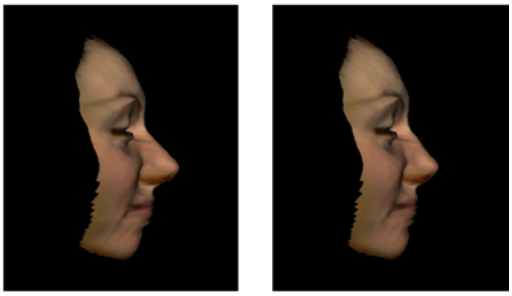
Softselection is implemented by first retrieving the weights of the unselected vertices. The selected vertices have a weight of 1. The unselected vertices in the field are weighted by a value between 0 and 1, depending on their distance from the nearest selected vertex. Unselected vertices that are not in the field have a weight of 0. All of the weights of the vertices of the mesh are collected into a *weightArray*. The *weightArray* is then searched, and for all the vertices with weight values greater that 0, the coordinates of these vertices are incremented by the move vector. This move vector is the value of the deviation of the face feature from actual to ideal. This method allowed the smooth movement of the features to fit the ratio.

Please see avi for a full demonstration of the program in action. Avi can be downloaded from *In The Eye of The Beholder* website, [McN03].

6. RESULTS

In this section the results of two facial scans are described, in both cases subtle changes to the facial mesh were applied.

Example A



Example B

In example A, the left image, or "before picture" did not fit the mask. A number of alterations were needed before it would fit the ideal mask. For instance, the nose was moved to the left, the mouth to the right. The chin and forehead were elongated. The sides of the face were stretched outwards and finally, the eyebrows were lifted.

The image on the right shows the face after the alterations were performed. This is obviously a useful tool for the visualization of "before and after" plastic surgery images.

In example B, in order for the left image to fit the lateral (side view) mask the chin was brought forward, the nose moved slightly back and the forehead surface was smoothened. The image on the right shows the results of these transformations.

An interactive survey was set up online [McD03]. Images of 6 faces were presented in the before and after states. Participants were asked to compare the 2 versions of each of the faces, without knowledge of which was which. They then had to make a decision about which ones they found more attractive. It was discovered that a significant portion of the viewers preferred the after pictures of each of the face meshes, which implies the success of the process.

The original premise for this work was to develop a visualization tool for plastic surgeons. This tool is effectively a 3D simulation of the proposed result of plastic or reconstructive surgery, with a 3D model of a face, as it would look after surgery. Due to the fact that underlying mesh has been accurately acquired through the scanning process, and realistically manipulated, this provides the patient with a reasonable preview of the effect of the surgery on *their* face, not a generic model of a face. It also allows multiple views of the face as opposed to a simple photograph. Furthermore, it gives the plastic surgeon an indication of the most effective procedures to perform (e.g. if the program finds that the nose and eyebrows of the patient deviate from the ideal, then the surgeon could suggest the correction of those features), Figure 12 and 13 show the tool as it could be used by a plastic surgeon.

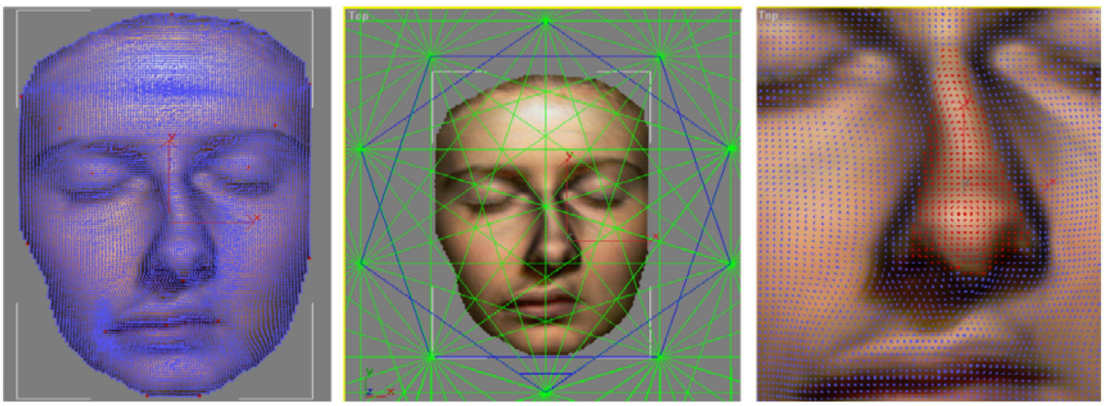


Figure 12: Program in operation. User selects the vertices on the mesh that correspond to the actual features (left). The program calculates the pentagon complex and draws it to the screen (middle). User selects the vertices that correspond to the features of the face (right).

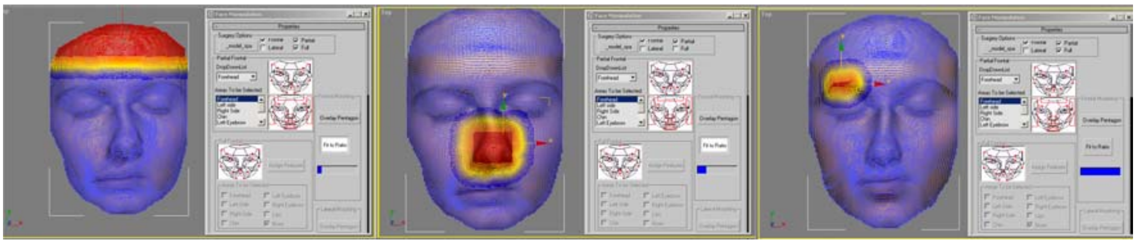


Figure 13: Program in operation. Program moves the forehead to the ideal position (left). Program moves the nose to the ideal position (middle). Program moves eyebrow to ideal position (right).

Figure 14: Example of using the tool for modelling. The model on the left gets progressively more beautiful the closer her features are morphed to fit the Golden Ratio.

7. CONCLUSIONS & FUTURE WORK

We have applied the Golden Mask, developed by Marquardt [Mar02; Mar94], to 3D scanned meshes of the human face. The meshes are morphed to obey the rules of the Golden Ratio. The obvious application is a visualization tool to generate "before and after" pictures for plastic or corrective surgery, as described in Section 5.

This work could also be used in character modeling to generate beautiful characters, whose features conform to the ratios, or conversely to create "ugly" characters whose characteristics deviate significantly from the Golden Mask, as shown in Figure 14.

Extending this idea further, the Golden Mask could be used to aid application of make-up, to real or synthetic actors and characters. By calculating the ideal distances between features we can accentuate or minimize features using cosmetics to create highlights and contours in an effort to replicate a beautiful face.

We conclude with a quote from one of the leading experts regarding the use of the Golden Mask in the quest for beauty.

"Every time I performed facial reconstructive surgery and changed a face to make it look closer to the Mask it did indeed become more attractive. This concept has been invaluable to me in facial surgery." – Dr Marquardt PhD, UCLA.

8. REFERENCES

[Pla03] U.S. plastic surgery homepage, www.plasticsurgery.org

[Koch02] R. M. Koch, S. H. M. Roth, M. H. Gross, A. P. Zimmermann, H.F. Sailer: *A Framework for Facial Surgery Simulation.* Proceedings of ACM SCCG 2002.

[Bic01] Bicalho, A. and Feltman, S. *MAXScript and the SDK for 3ds max 4®*

[Mar02a] Marquardt, S., beauty analysis home page, www.beautyanalysis.com

[Mar02b] Marquardt, S., examples of Golden Mask fitting attractive faces, http://www.beautyanalysis.com/index2_mba.htm

[Mar94] Marquardt, S., Dr.Marquardt's beauty mask patent, U.S. Patent Number 5,659,625

[Min02] Minolta 3d scanner homepage,

http://www.minoltausa.com/vivid/default.asp

[McN03] McNamara, A. *In The Eye of The Beholder* webpage,

http://www.cs.tcd.ie/people/Ann.McNamara/proj5.html

[McD03] McDonnell, R., Survey webpage, http://www.cs.tcd.ie/Rachel.McDonnell/survey