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## Part-1 : Estimate the albedo and surface normals
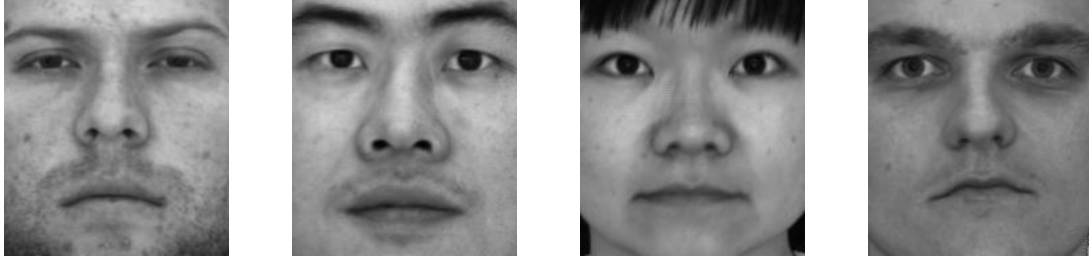
1) Insert the albedo image of your test image here:



*Figure 1 Albedo Image (a) YaleB01 (b) YaleB02 (c) YaleB05 (d) YaleB07*

2) What implementation choices did you make? How did it affect the quality and speed of your solution?

- **Data Preprocess**: Subtract all the images by the ambient image, and set the entries less then zero to be zero, and normalized the images by its maximum value to make the entry values range from 0 to 1

- **Photometric stereo**: Estimate the albedo and surface normal by setting a linear system to solve a least square problem to get $g$. First reshape the images array to be number of images by number of pixels, then solve the linear system to get $g$ to be 3 by number of pixels. And then calculate the norm of each g vector to ge the albedo. This approach speeds up the solution by only having to solve on linear system instead of having a loop over all the pixel in all the images and solve multiple linear systems.

3) What are some artifacts and/or limitations of your implementation, and what are possible reasons for them?

- The albedo image should be a fairly constant color, however in the nose area we can clearly see almost 3D structure for the nose, which is an artifact.

- In the mouth area, the artifact results the wiggle shape of lips, which is an artifact. In the 3D construction ,these artifacts are even more obvisous.

  The reason for these artifacts is that:

- The Lambert's object assumption doesn't hold for facial photo, because it deosn't have a uniform surface reflectance. And there exists specular reflection in the facial photo.

- A local shading model which assumes each point on a surface receives light only from source visible at that point, which is not accurate enough for a facial photo.

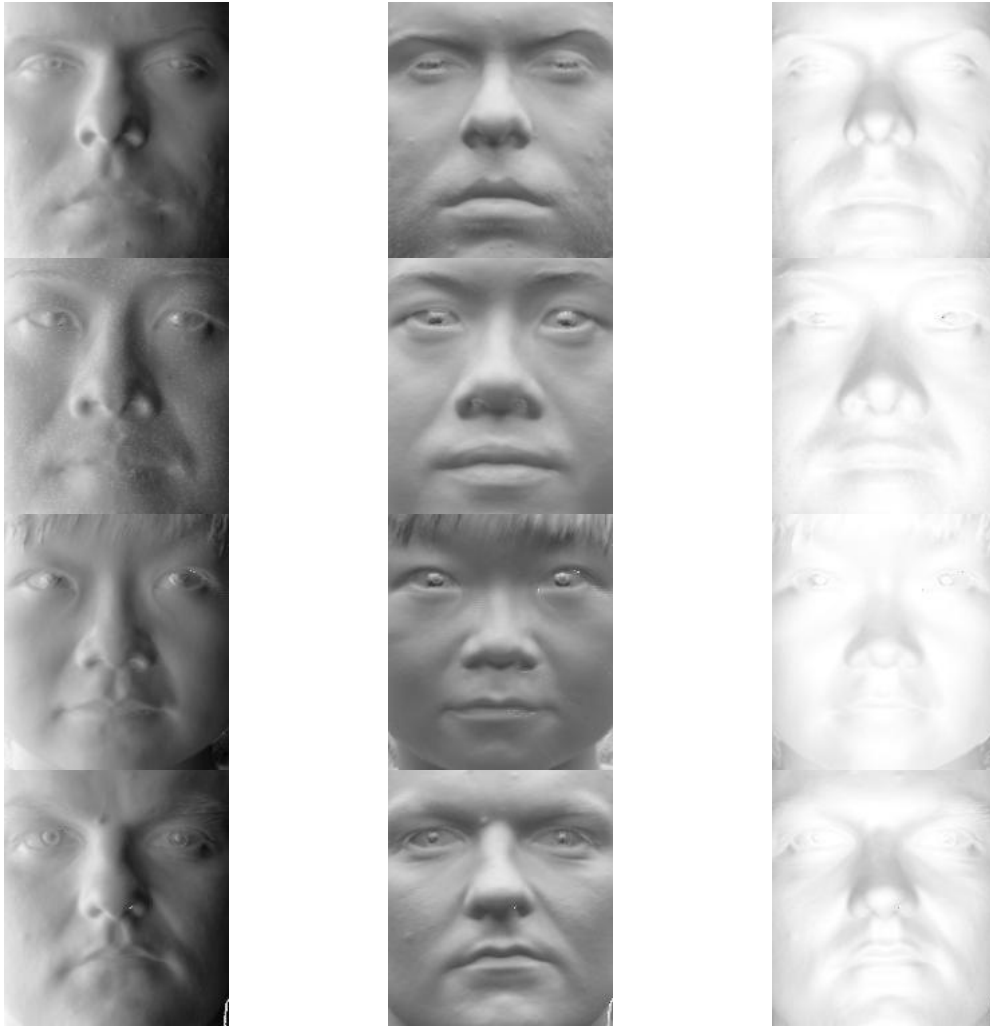4) Display the surface normal estimation images below:

*Figure 2  Row 1: YaleB01 (a) X normal (b) Y normal (c) Z normal*
*Row 2: YaleB02 (a) X normal (b) Y normal (c) Z normal*
*Row 3: YaleB05 (a) X normal (b) Y normal (c) Z normal*
*Row 4: YaleB07 (a) X normal (b) Y normal (c) Z normal*

## Part-2 : Compute Height Map

5) For every subject, display the surface height map by integration and display. Select one subject, list height map images computed using different integration method and from different views; for other subjects, only from different views, using the method that you think performs best. When inserting results images into your report, you should resize/compress them appropriately to keep the file size manageable -- but make sure that the correctness and quality of your output can be clearly and easily judged.

- Select one subject, list height map images computed using different integration method and from different views
  Here select YaleB02 using different integration scheme:

**Row Integration:**

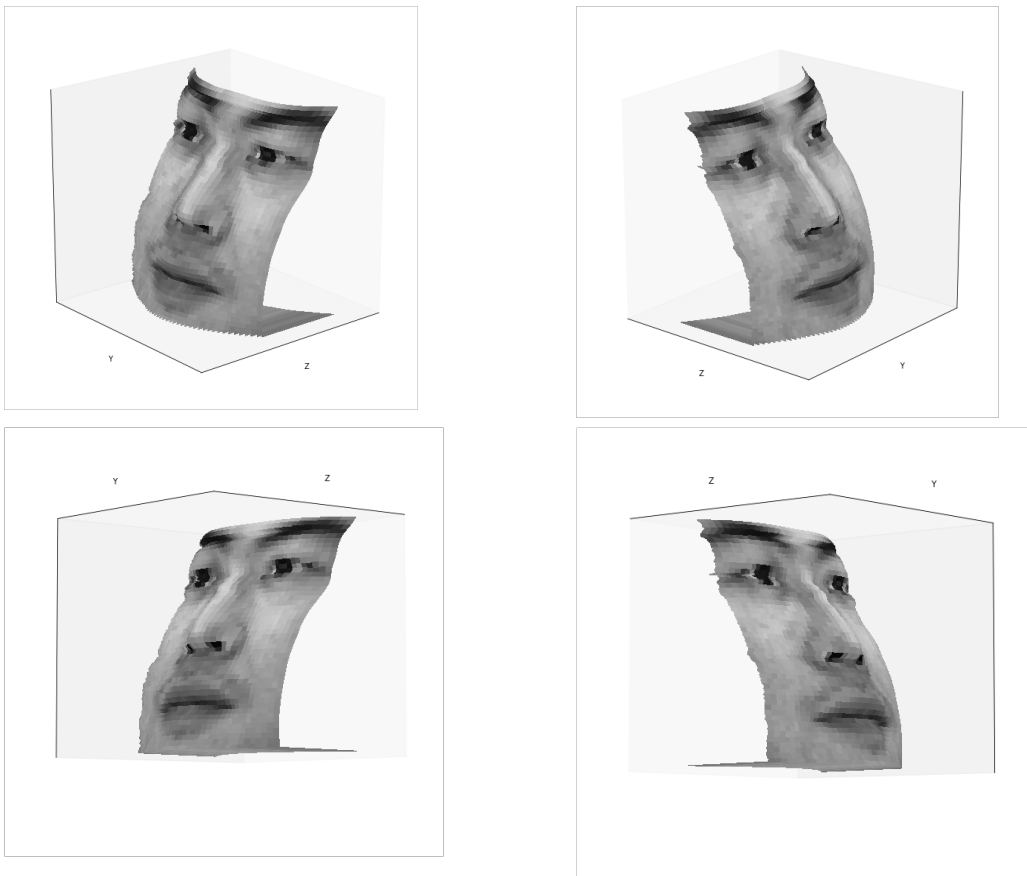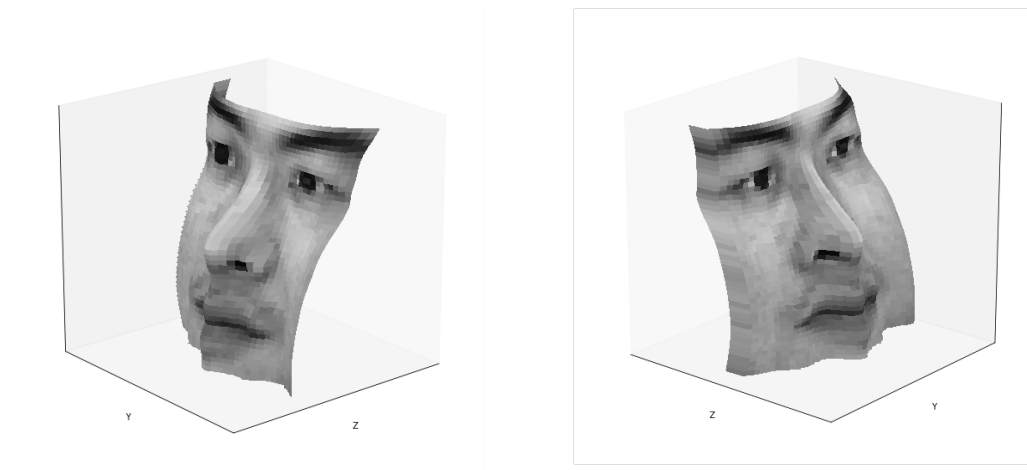Integrate first along the columns, then rows. More weights are given to the x derivative



*Figure 3 Surface height with Row integration approach*

**Column Integration:**

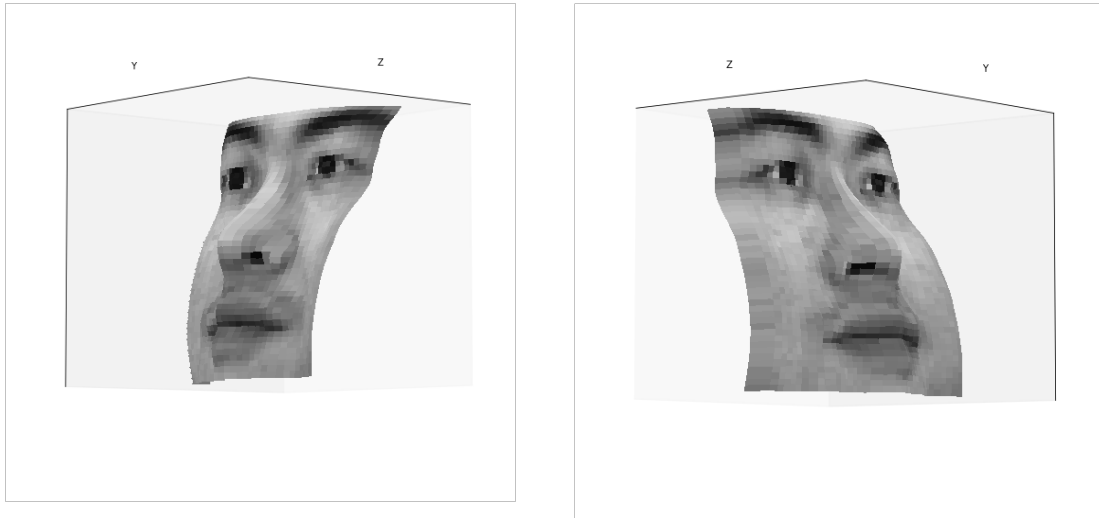Integrate first the rows and then columns, more weights being given to the y gradient component
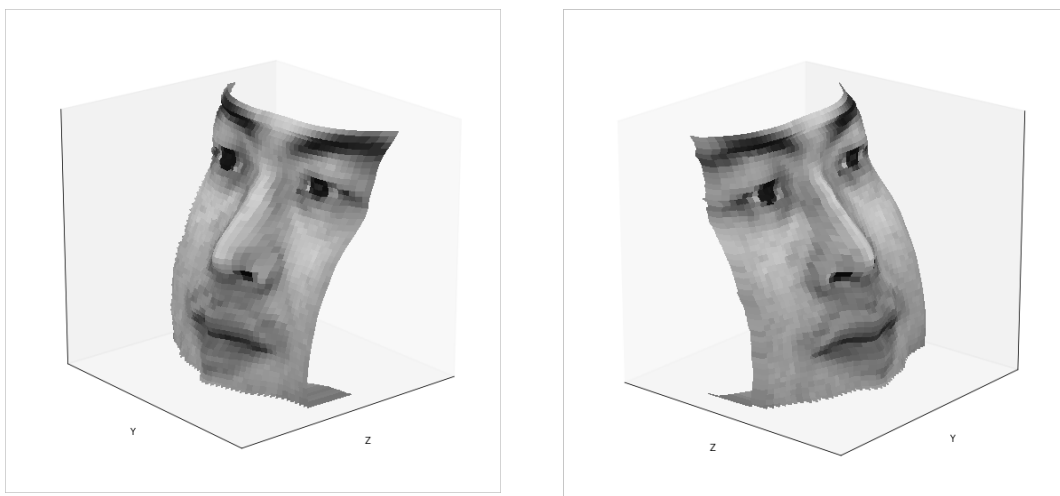
*Figure 4 Surface height with Column Integration approach*

## Average Integration:

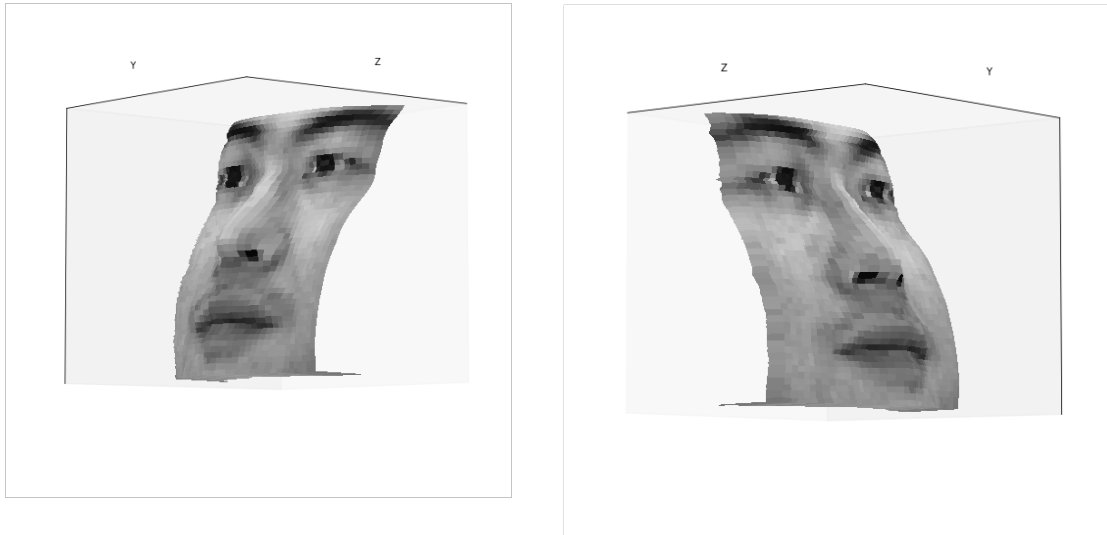Average the row and column integration approach

*Figure 5 Surface height with Average integration approach*

**Random Integration:**

Average of multiple random path. This is the best approach for which it gives equal weights to the x and y gradients.
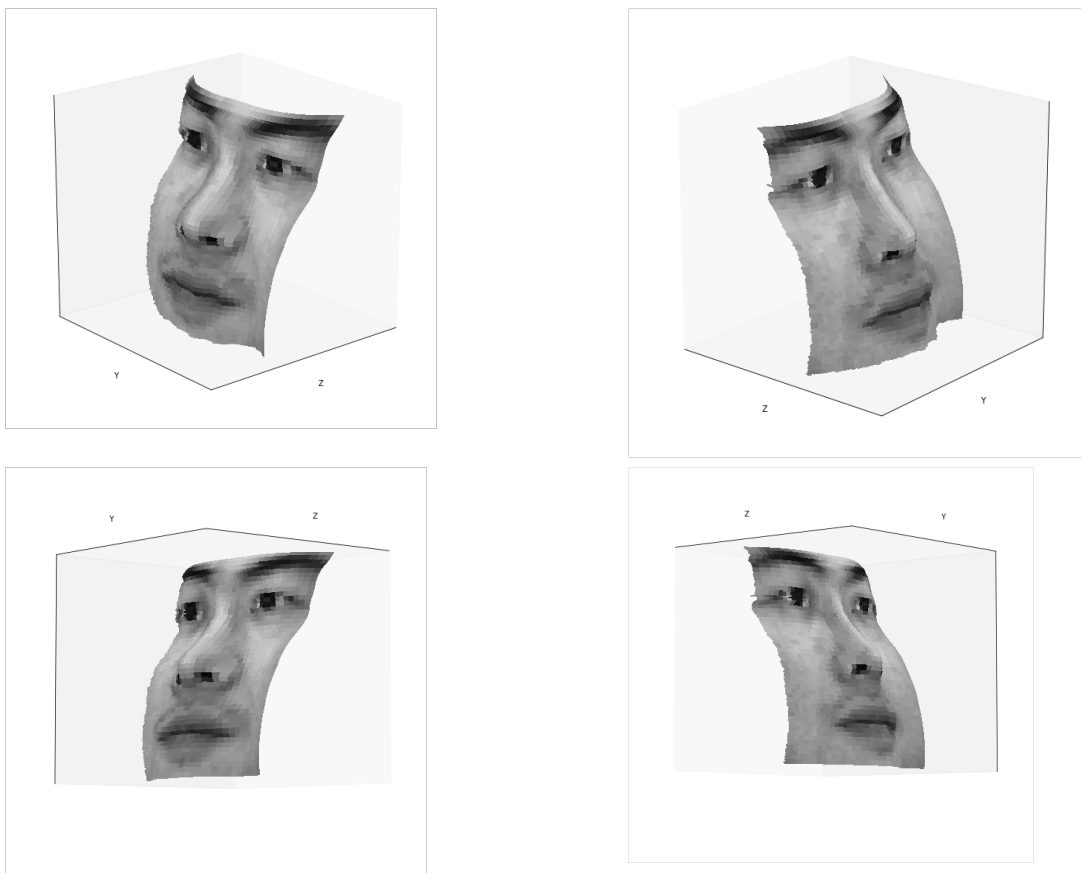


*Figure 6 Surface height with Random Integration approach*

- For other subjects, only from different views, using the method that you think performs best

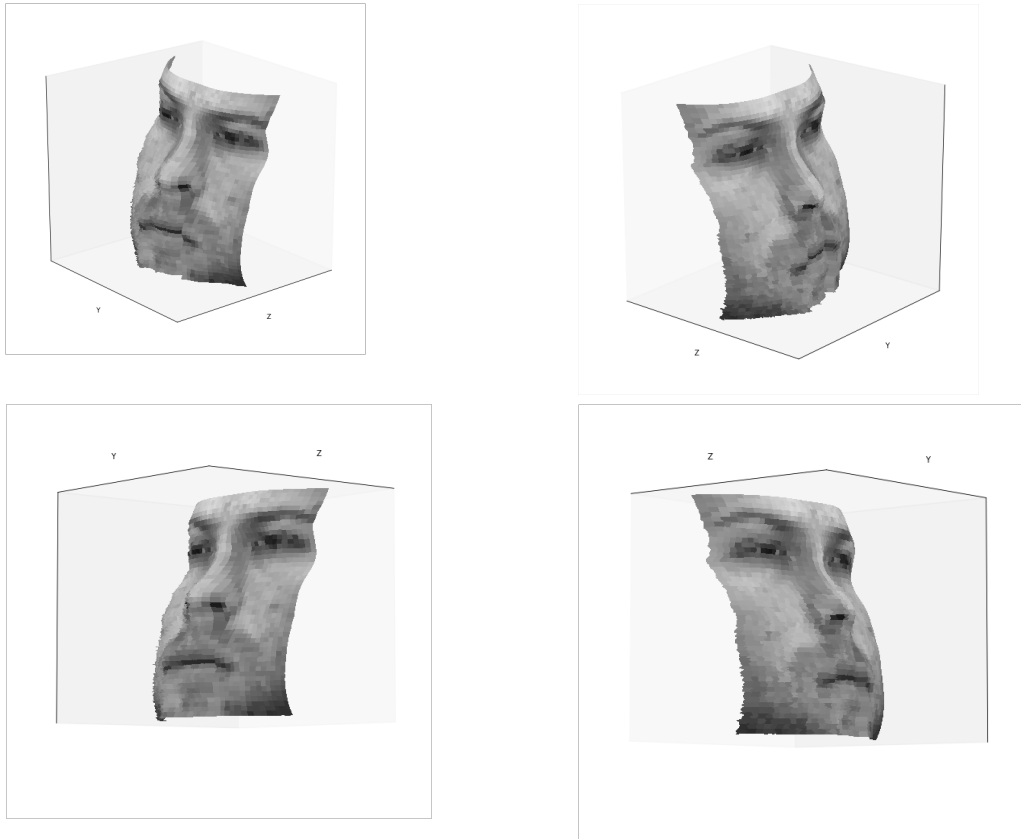The best method is the random integration approach.

**YaleB01:**



*Figure 7 YaleB01 Surface height with Random integration approach*

**YaleB05:**

*Figure 8 YaleB05 Surface height with Random integration approach*
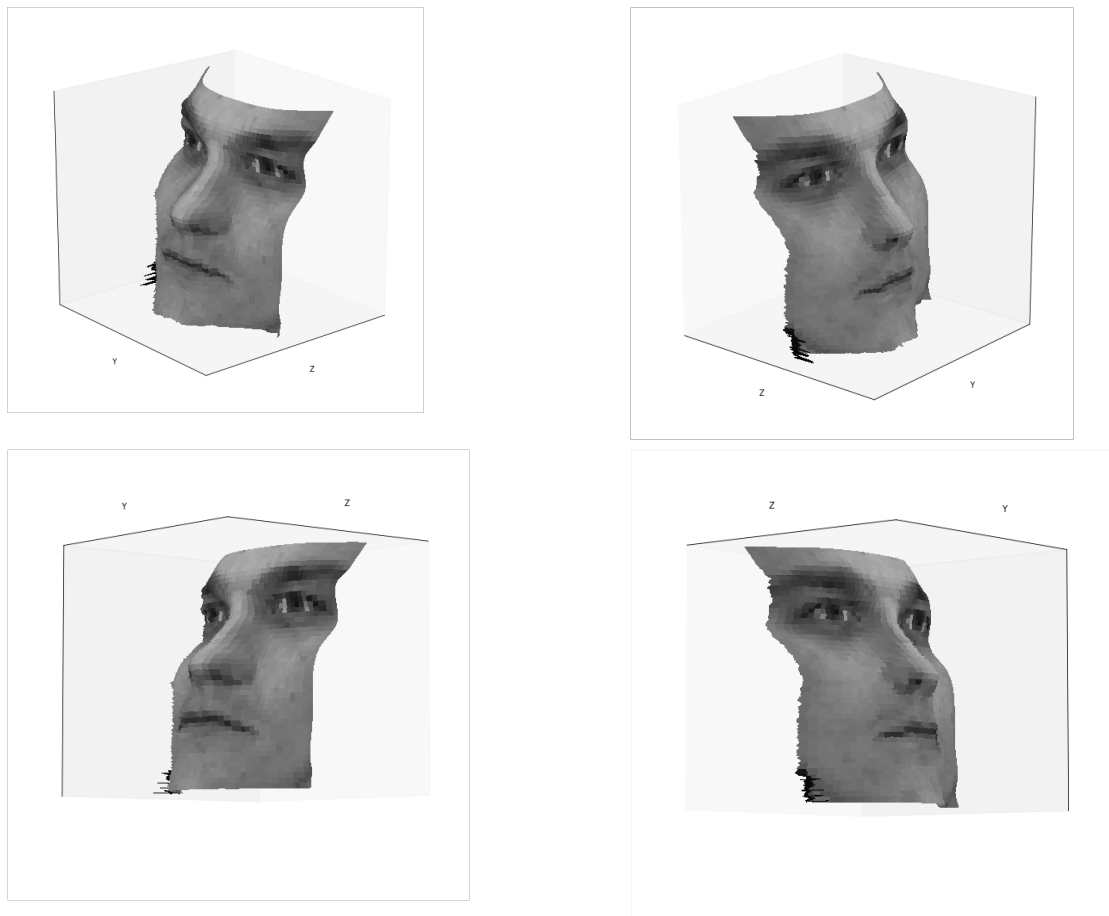
## YaleB07:



*Figure 9 YaleB07 Surface height with Random Integration approach*

6) Which integration method produces the best result and why?

The best integration method is the random integration approach. The random integration approach integration the surface height over n random integration path, and take the average of all these paths, therefore the surface height solution is less bias to the integration approach, and it is more general then the other integration approach which heavily depends on how the path is constructed.

7) Compare the average execution time (only on your selected subject, "average" here means you should repeat the execution for several times to reduce random error) with each integration method, and analyze the cause of what you've observed:

| Integration method | Execution time (s) |
|---|---|
| random | 79.20148397316437 |
| average | 0.0003823242679407651 |
| row | 0.00022611472840336236 |
| column | 0.00021838661367920312 |

The most time consuming approach is the random integration approach, the test was done using 50 random path, however the random approach minimize the integration path bias and result the best results. This is because the integration is performed more times then the other approaches, and also there is an factor that the random integration approach code is not written to its optimality, but even that the random approach should consume more time.

## Part-3 : Violation of the assumptions
8) Discuss how the Yale Face data violate the assumptions of the shape-from-shading method covered in the slides.

The assumptions of the shape-from-shading methods: (1) A Lambertian object (2) A local shading model (each point on a surface receives light only from sources visible at that point) (3) A set of known light source directions (4) A set of pictures of an object, obtained in exactly the same camera/object configuration but using different sources (5) Orthographic projection.
Face texture doesn't belong to Lambertian object, because the face doesn't have uniform surface reflectance. Also in the Yale face photos there exists specular reflection. Also the all these photo are not taking at the exact same set up but with different light source, there are some minor difference in the nose, eyes and lips area, which will result 3D reconstruction artifact. And it also not an Orthographic project.

9) Choose one subject and attempt to select a subset of all viewpoints that better match the assumptions of the method. Show your results for that subset.

*Figure 10 (Left) All viewpoints (Right) Subset of viewpoints*

10) Discuss whether you were able to get any improvement over a reconstruction computed from all the viewpoints.

The results are improve by selecting the better viewpoints photos, as shown in Figure 10, the mouth area is improve, the contour is more clear, and the wiggles on the lip is significantly reduced.