CS_217 (2012-2013)

COMPUTER GRAPHICS 1: IMAGE PROCESSING AND SYNTHESIS

(*Attempt 2 questions out of 3*)

Question 1

(a) **Ray Tracing**

(i) How are rays cast in orthographic projection and perspective projection for ray tracing? Contrast with a diagram. **[2 marks]**

(ii) Generally, describe the process of ray-object intersections. Specifically, derive the ray-sphere intersection equation. **[4 marks]**

(iii) Describe (with diagrams) how ray tracing manages reflection, refraction and shadows. **[3 marks]**

(iv) Calculate the number of intersections that are required for ray tracing a scene of your own choice. **[2 marks]**

(v) How can bounding volumes lead to better computational times? **[2 marks]**

(vi) Discuss how a hierarchy of bounding volumes constructed manually can reduce computation times. **[2 marks]**

(vii) How does an automatic hierarchical acceleration structure such as a kd-tree or an octree operate? How does it accelerate ray-tracing? **[4 marks]**

Ray Tracing

(i) Diagram showing rays originating from pixels in parallel or diverging from centre of projections. ***[2 marks]***

(ii) 3D ray equation solved with equation of primitive in question. ***[2 marks]*** *Derive the ray-sphere intersection algorithm.* ***[2 marks]***

(iii) Show the diagram for each one in question - particularly labelling surface normal, secondary rays and any angles. ***[3 marks]***

(iv) Give an example - e.g. chessboard with 3200 triangles, and 1000x1000 image = 3.2 Billion intersections. ***[2 marks]***

(v) Describe placing a bounding volume around objects and thus a single test against bounding volume can remove the need for tests against all embedded objects if it does not hit the bounding volume. ***[2 marks]***

(vi) Describe nested bounding volumes. ***[2 marks]***

(vii) Describe the algorithm for building an octree or kdtree and then the algorithm for intersecting a ray against the model. ***[4 marks]***

*Part **a** subtotal=**[19 marks]***

(b) **Sampling**

Describe each of the following approaches to sampling with a diagram and textual description. Also highlight their advantages and/or disadvantages:

(i) Jittered sampling. **[2 marks]**

(ii) Random/stochastic sampling. **[2 marks]**

(iii) Poisson disk sampling. **[2 marks]**

Sampling

(i) Show grid with randomly offset samples. ***[2 marks]***

(ii) Show single pixel with multiple randomly placed samples. ***[2 marks]***

(iii) Show samples with minimum distance. ***[2 marks]***

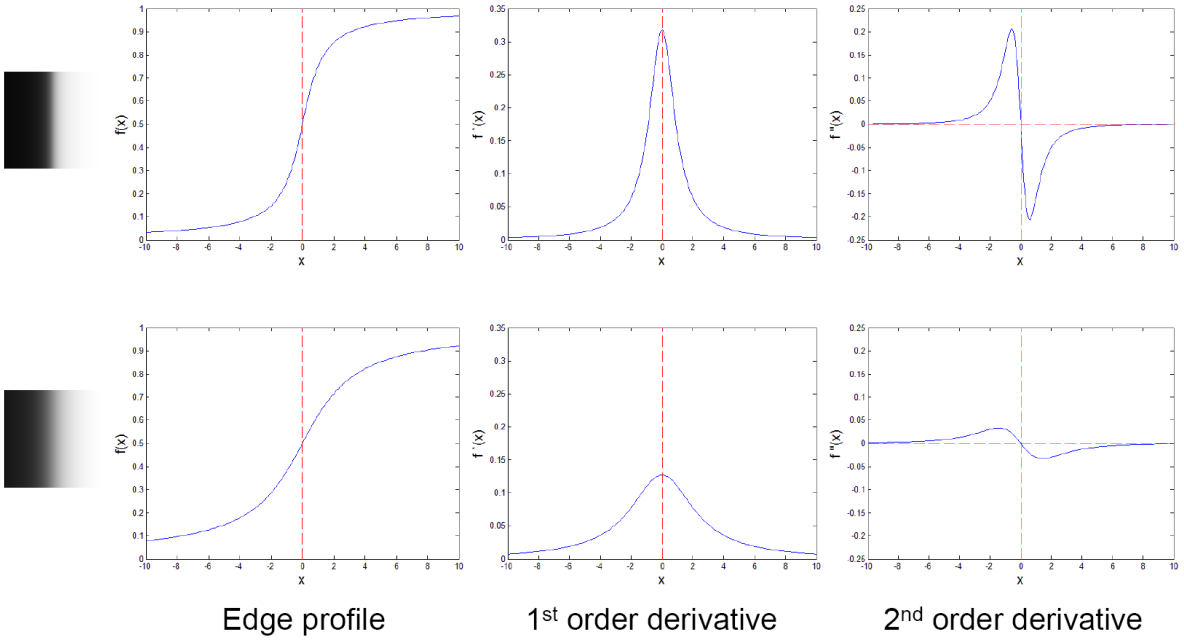
*Part **b** subtotal=**[6 marks]***

Question **1** total=**[25 marks]**

Threshold: 10 marks for (a), 4 marks for (b), Total=14 marks

Question 2

(a) Edges in images can be found by considering the first or second derivatives of the intensity gradient in the image. Referring to the following figure, how are edges obtained using the first and second derivatives? Which method generally produces more accurate results in localising edges and why?



[6 marks]

[Bookwork, understanding of advanced topic]

First derivative: Threshold the image to find maxima (i.e. all values above a certain value will be considered edges).

Second derivative: The edge is at the point where the graph crosses the x axis, therefore determine in the image where the pixel values cross the zero value.

The second derivative produces the more accurate edges because the exact crossing point can be interpolated, whereas for low sampled images the maxima could be over several pixels, and therefore determining just one for the edge is more difficult. ***[6 marks]***

Part ***a*** *subtotal=****[6 marks]***

(b) **Digital Images**

Define the terms *sampling* and *quantization* in the context of digital images. How are digital images stored in memory? Give some figures for storage sizes for various sized example images.

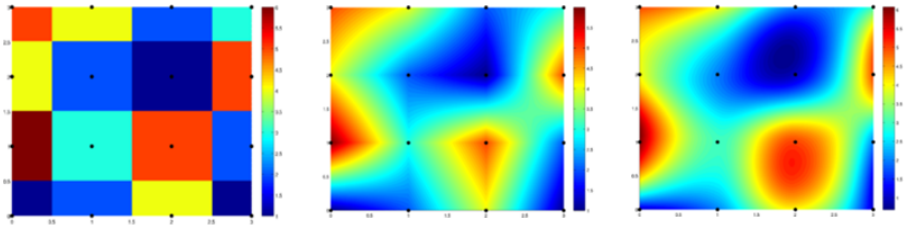
[6 marks]

Continuous images are sampled at a given resolution to create 2D arrays of pixel intensities (and colours). ***[2 marks]*** *The resulting values may have to be quantized to fit the chosen data type (usually 8 bits per*

colour channel). ***[2 marks]*** *Typical storage formats are 8 bits (3R3G2B), 8 bit colour tables, 15/16 bits (5R5G5B), true colour (8R8G8B), or floating point (for HDR).* ***[1 marks]****. Pixels are stored in a 2D array within memory. e.g. true colour will be a 2D array of 24 bit values, a 1Mega pixel image would require 3MBytes uncompressed to store.* ***[1 marks]***

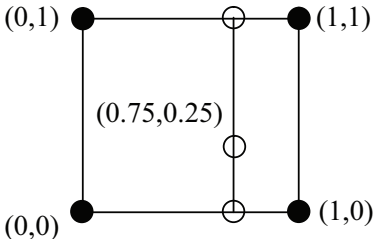
Part ***b*** *subtotal=****[6 marks]***

(c) **Interpolation**



Source: wikipedia

(i) Identify and briefly describe the interpolation scheme used in each of the images above. Assume the black dots are the positions of the known colours, and all other points are interpolated from those known colours and positions. **[4 marks]**



Point	Intensity
(0, 0)	50
(1,0)	150
(0,1)	75
(1,1)	200

(ii) Give the equations and process for linear and bilinear interpolation and demonstrate their use to calculate the intensity at positions (0.75, 0) and (0.75, 0.25) in the above square.

[6 marks]

(i) Nearest neighbour, bilinear and bicubic interpoatlon. Could show equations for bilinear to get full marks, or could describe bicubic at a high level for full marks. Or any combination. ***[4 marks]***

(ii) Equations for linear interpolation and, bilinear interpolation and application ***[3 marks]****. (0.75,0)=125, (0.75,1)=168.75, (0.75,0.25)=135.9375* ***[3 marks]***

Part ***c*** *subtotal=****[10 marks]***

(d) **Colour Models** Draw and describe the HSV and RGB colour models. Indicate the parameters controlled by each axis in each model, and the effect of altering each of the parameters.

[3 marks]

[Bookwork and understanding]

Draw RGB cube and HSV cone, describe altering the HSV or RGB parameters ***[3 marks]****.*

Part ***d*** *subtotal=****[3 marks]***

Question **2** total=**[25 marks]**

Threshold: 2 marks for (a), they should at least be able to say something about the methods. 4 marks for (b), this is from the first few lectures - they should know this stuff. 6 marks - They should be able to carry out the interpolation and identify the types. 3 marks - Colour models are relatively simple. Total = 15 marks.

Question 3

(a) **Descriptions** Write detailed descriptions (about $\frac{3}{4}$ of a page) about three of the following six topics. Some topics have suggested keywords in brackets:

- Diffuse / Lambertian reflection (surface normals, dot product, lighting as a function of θ);
- Maximum intensity projection (volume data and sources, sampling, the algorithm);
- Gamma correction and the eye;
- Adaptive supersampling;
- Median filtering algorithm;
- Correlation.

[12 marks]

Descriptions

Draw a digram with surface normal, theta and light source. Discuss cos theta.
Maximum intensity projection: Rays are sent through volume data to detect the maximum value. This value is mapped onto the grey scale display. Produces x-ray like images.
Gamma correction: Raise pixel to the power of gamma. Allows non-linear variation of image brightness. Adapts to log sensitivity of eye.
Describe taking more samples in a cross shape when it is determined that one of the samples is greater than some threshold away from the others. Recurse on each sub pixel. Gather all samples together for the final pixel colour.
Median filtering: To remove dust, noise and scratches from images. For a block of nxn pixels, sort the pixels and take the middle value to replace the current value.
Cross-correlation algorithm for multiplying a filter with the underlying image and then normalising. May mention high and low pass filters.

[12 marks]

*Part **a** subtotal=**[12 marks]***

(b) **Dithering** What are the two main approaches for dithering studied in this course (and name the two methods of each approach we examined)? Briefly, how does each approach operate, and what are the main advantages and disadvantages of each approach?

[7 marks]

Dithering

Error diffusion: Passes error from current pixel to neighbouring pixel (where it is added before deciding whether it is represented as a black or white pixel). Error passed down to next row at the end of the row (thus zig-zag through image). ***[2 marks]***

Floyd-Steinberg passes error to 4 undrawn pixels: (7,1,5,3) sixteenths of error passed. ***[1 marks]***

Half-toning (pattern and ordered dither): Calculate average intensity of an area and use pattern matrix to replace the region with a pattern. Ordered dither differs in that each pixel is compared rather than the region. ***[2 marks]***

The main disadvantage of half-toning is that they introduce patterns into the image. (Other advantages+disadvantages can be discussed, but this is the main one sought). ***[2 marks]***

*Part **b** subtotal=**[7 marks]***

(c) **Histograms**

(i) What is a histogram of an image? What would the histograms of a dark image and a light image look like? **[2 marks]**

(ii) Give the bit of code you would use to compute the histogram. You can assume the array `image[j][i][c]` gives the intensity of colour channel `c` at pixel `(i,j)`. **[2 marks]**

(iii) What does the process of histogram equalisation achieve, and what benefits does it confer? **[2 marks]**

Histograms

(i) Count of the number of pixels at each intensity level. Demonstrate a diagram. ***[2 marks]***

(ii)
```
int[][] h;
h=new int[256][3];
for (j=0; j<height; j++)
   for (i=0; i<width; i++)
      for (c=0; c<3; c++)
         h[image[j][i][c]][c]++;
```
[2 marks]

(iii) Increases the contrast by trying to create a level histogram (using the cumulative distribution function to create a new mapping). ***[2 marks]***

Question **3** total=**[25 marks]**

Threshold: 8 marks for (a), they should be able to pick and choose something they've revised. 3 marks for (b). They should be able to remember at least one of the dithering methods. 3 marks for (c). Total=14 marks.