Delft University of Technology
Faculty Electrical Engineering, Mathematics,
and Computer Science
Mekelweg 4, Delft

TUDelft

Examination for

Course IN4151 - 3D Computer Graphics and Virtual Reality

Monday, 27 June 2005, 14:00 – 17:00 h.

Please use a separate sheet for each question.

Write on each sheet: your name + initials, study number, course code (IN4151), date, and the question number. This is important because each question is graded separately.

Criteria for receiving the maximum grade per question are correctness and brevity of the answers.

Make sure your writing is legible and drawings are clear!

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1. a. Explain the principles of ray tracing.
   b. Give two algorithms for the ray-sphere interesection: the algebraic and the geometric version.
   c. Describe a spatial subdivision method for speeding up the ray tracing.

2. a. The Phong reflection model is given by $I = I_a.k_a + I_i(k_d(\mathbf{L.N}) + k_s(\mathbf{R.V})^n)$. Describe the three components of the model and the physical meaning of the parameters $\boldsymbol{k}$, k_d, $\boldsymbol{k}$, and $\boldsymbol{n}$.
   b. Are I, and I_i related? If so, in what way? Could you imagine a scene where I, is very small?
   c. How is the colour of the object and the light source represented in the Phong reflection model? How do these colours interact? Is this different for the three components of the model?

3. a. Ray tracing may lead to aliasing effects. Describe these effects and explain why they occur.
   b. Filtering as an averaging of discrete samples is a method to reduce aliasing. Describe different filter techniques/shapes.
   c. There are many strategies how to sample the domain under the filter shape. Give and explain some sampling strategies.

4. a. Within the radiosity method, the form factor F_{ij} describes which part of the energy emitted/reflected by patch A_i is received by patch $\boldsymbol{Aj}$. Give the form factor equation and explain the geometric terms.
   b. Describe two methods to calculate the form factor.
   c. How is color taken into account within the radiosity calculation? Why is the radiosity method able to calculate "colour bleeding" between patches and a local method (e.g. Phong) not?

5. a. Explain why low latency rendering is important in virtual reality.
   b. Describe two image-based rendering techniques to accelerate the rendering.
   c. Explain the principles of light field rendering. How is the light field stored and how can it be retrieved for display?

6. a. What is 2D morphing? How can it be used in 3D computer animation?
   b. What user input is required to define a 2D morph?
   c. Which three steps are executed by the computer to calculate a 2D morph? Give a clear description of each of these three steps.

end of examination

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Answers for Examination IN4151

Monday, 27 June 2005

1. a. *Explain the principles of ray tracing (3 pt)*
From the eye point rays are cast through the pixels into the scene and intersection is sought with the objects in the scene. The nearest intersection is the visible object. From this point shadow rays are cast to the light sources to determine the incoming light. Additional secondary rays are shot to account for mirronng reflection or refraction. The contributions of the secondary rays are summed to find the reflected light in the direction of the eye point. This value is assigned to the corresponding pixel.

   b. *Give two algorithms for the ray-sphere interesection: the algebraic and the geometric version (4)*
The vector equation of the ray is r = e + t.f , where e is the eye point, and f the direction of the ray. Substitute r,. r_y and r, in the quadratic equation of a sphere (x-c,)' + $(y-c_y)^2 + (z-c_z)^2 = r^2$ where c is the centre of the sphere and solve for t. This gives a quadratic equation with two roots (two intersections), a double root (touching the sphere) or zero roots (no intersection).
The geometric version calculates the distance from the eye to the point on the ray of closest approach with the sphere as t„ = **(c-e).f** (i.e. the projection of f on the vector c-e. The distance from the centre of the sphere to the ray is: d = sqrt ($|(\mathbf{c}-\mathbf{e})|^2$ - $|(\mathbf{c}-\mathbf{e}).\mathbf{f}|^2$). If t_{hc} = sqrt(R^2 -d^2) < 0 than no intersection, else t, = t„-t_{hc} and t, = t_{ca}+ t„

   c. *Describe a spatial subdivision method for speeding up the ray tracing (3).*
The most simple spatial subdivision is the grid that subdivides the space into a regular pattern of cells. In a preprocessing all objects are classified with respect to the gnd cells and stored in the cells that they intersect. Dunng ray tracing the ray traverses the cell structure and for each cell, it is tested whether there is an object and whether the ray intersects the object. If one or multiple intersection points are found in a cell then the nearest to the eye is taken as the visible intersection and the gnd traversal can be stopped. The ray-cell traversal is made efficient with an incremental parameter step in either x, y or z direction, whatever gives the nearest pointalong the ray.

2. a. *The Phong reflection model is given by $I = I_a k_a + I_i(k_d(L.N) + k_s(R.V)^n)$. Describe the three components of the model and the physical meaning of the parameters k, k_d, k, and n (4).*
The three terms are the ambient reflection, the diffuse reflection and the specular reflection. The parameters *k*, k_d, k_s are the material-dependent reflection coefficients which describe the portion of light that is reflected for the ambient, diffuse and specular reflection. The parameter *n* is also a surface property and defines the spread of the specular reflection (higher values give a smaller but bnghter highlight).

   b. *Are I_a and I_i related? If so, in what way? Could you imagine a scene where I_a is very small (3)?*
The ambient light is due to indirect reflection from the light sources. To simplify the model, the ambient light is taken as constant for the whole scene (and is thus an average of the indirect reflection). It is low for a scene with only one spotlight, and for outdoor scenes with a clear atmosphere, i.e. no light scattering by clouds (this also applies to outer space).

   c. *How is the colour of the object and the light source represented in the Phong reflection model? How do these colours interact? Is this different for the three components of the model (3)?*
The *I*,, ***I;*** are vectors representing the colour bands (eg. R, ***G***, B) and ***k***, k_d, k_s are the reflection coefficients of the surfaces (for these wavebands) and they determine the colour of the object (which frequencies are mostly reflected and which ones are mostly absorbed). By multiplying

the I_λ with k, we get the reflection for waveband h (if we apply this to the three components). There is a difference between the ambient/diffuse and the specular reflection in that the ambient and diffuse reflection more strongly change the colour of the reflection towards the colour of the object, while the specular reflection maintains the colour of the light source, i.e. the k, coefficients for the specular reflection (for the different wavebands) are more equal to each other and represent the object colour less than the k, and k, coefficients.

3. a. *Ray tracing may lead to aliasing effects. Describe these effects and explain why they occur (3).*
Ray tracing is a point sampling algorithm and the ray density (resolution) determines the minimum frequencies that can be represented faithfully from the individual discrete samples. If there are frequencies higher than the Nyquist limit (half the sampling rate) then the information can not be represented correctly which shows up as staircasing, moiré patterns and disappearing details.

   b. *Filtering as an averaging of discrete samples is a method to reduce aliasing. Describe different filter techniques/shapes (3).*
Averaging is the same as filtering with a box filter. A better filter is the cone filter that applies a weighted averaging, i.e. samples nearer to the reconstruction point (i.e. the pixel centre) have a stronger impact. Ideally, the best reconstruction is obtained with a sinx/x filter, but this filter has an infinite extent which makes it very costly. A good compromise is often a gaussian-shaped filter.

   c. *There are many strategies how to sample the domain under the filter shape. Give and explain some sampling strategies (4).*
With regular sampling ray tracing is done in a regular pattern, i.e. at the (sub)pixel centres. Stochastic sampling adds randomness to the sampling positions. In this way we introduce small local errors, but the stochastic sampling is less sensitive for interference with regular structures in the sampling domain. The net effect is that aliasing is turned into noise, which is less disturbing for the human eye. Adaptive sampling adds new samples to areas of the domain where an improved estimate may be expected, eg. near edges and other regions with strong constrast and high frequencies, such as textures. Stratified sampling is a strategy where a domain with a high variance is recwsively subdivided with the intention to localize the high variance to a small subpart of the domain. The total variance as the sum of the variances of the subdivided regions is generally smaller than the variance of the undivided domain.

4. a. *Within the radiosity method, the form factor F_{ij} describes which part of the energy emitted/reflected by patch A; is received by patch Aj. Give the form factor equation and explain the geometric terms (3).*
For the equation see the sheets. The form factor between points dAi to dAj is a function of the orientation (cos with respect to the line between the two points), the inverse of the squared distance, and the visibility along the connecting line. The form factor for the total patches is the double integral over the two patch surfaces, scaled by the inverse of the area of the emitting patch.

   b. *Describe two methods to calculate the form factor (4).*
With the hemicube method the form factor is approximated by using the Nusselt analog which states that the projection of a patch through an intermediate hemisphere onto the plane of an other patch is equal to the form factor between these two patches. Instead of an hemisphere the hemicube uses the approximation of a half cube to allow a straightforward depth buffer approach to calculate the size of the projection including the solving of the visibility.

   c. *How is colour taken into account within the radiosity calculation? Why is the radiosity method able to calculate "colour bleeding" between patches and a local method (e.g. Phong) not (3)?*
The radiosity method calculates the exchange of spectra1 energy between patches. The radiant exitance is specified for a number of wavebands (eg. R, G, B). The distribution of a strong radiance from a for instance red patch to its neighboring white patches will create a "reddish" reflection at the neighboring patches.

5. a. *Explain why low latency rendering is important in virtual reality (2).*
Within *VR* the virtual eye point (i.e. the origin of the viewing coordinate system) is linked to the eye point in the real world and if the virtual eye point lags too much behind, then this destroys the illusion of immersiveness. In particular for head-mounted displays low latency tracking and rendenng is essential because head rotations may introduce large changes in view direction which have to be anticipated directly. For projective systems the requirements are less severe because head rotations do not change the viewing and projection parameters.

b. *Describe two image-based rendering techniques to accelerate the rendering (4).*
Environment mapping and imposters both use images to represent objects at a distance that would require many polygons for an exact representation. With imposters, the 3D geometry is just replaced by a "bill board". For environment mapping the environment is captured with a spherical or cubical panorarnic image and for a given viewing direction the segment that falls within the viewing pyrarnid is used as background.

c. *Explain the principles of lightjìeld rendering. How is the light field stored and how can it be retrieved for display (4)?*
We can store the outgoing light field from an object or scene by storing radiance values for a dense collection of directions starting at this object or scene. As light intensity is constant along a ray we only have to store one radiance value for each direction. A simple way to specify ray directions is to use two parallel planes and connect a discrete rectilinear sampling in the one plane (u,v positions) with a discrete rectilinear sampling (s,t) on the other. We capture the light from an object or scene by taking multiple photographs and store the measured radiance values at corresponding light field directions. A new picture can be made from any given view point by casting for each pixel of the image plane a ray into the light field and to do a look-up to find the nearest ray to provide an estimate for its radiance. If necessary we can do an interpolation between several nearest rays.

6. a. *What is 2D morphing? How can it be used in 3D computer animation (3)?*
2D morphing is a shape transformation from a source image to a target image resulting in a sequence of in-between images.
Although it is a 2D image processing technique, it can be used for transformations on 2D images of 3D objects. If the source image and the target image are images of 3D objects, then the in-between images will also look like images of 3D objects. Therefore 2D morphs are useful in 3D computer animation.

b. *What user input is required to dejìne a 2D morph (3)?*
- Source image (a bit map image)
- Target image (a bitmap image)
- Nodes (positions) in the source image and corresponding nodes (positions) in the target image. The correspondence of nodes leads to a correspondence of tnangles. A triangle in the source image will morph smoothly into the corresponding triangle in the target image.
- Time interval of the morph (How many seconds does the whole morph take?)

c. *Which three steps are executed by the computer to calculate a 2D morph? Give a clear description of each of these three steps (4).*
Step 1: Warp shape of object in source image to shape of corresponding object in target image. This leads to a sequence of images with colors of the source image but warped (shifted) pixels → sequence 1.
Step 2: Warp shape of object in target image to shape of corresponding object in source image. Same as step 1 but now the colors of the target image are used → sequence 2.
Step 3: Cross-dissolve. For i = 1 to number of images: Mix (interpolate) pixel colors of i-th image of sequences 1 and sequence 2.