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

Examination for

Course IN4151 - 3D Computer Graphics and Virtual Reality

Wednesday, 26 January 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. Describe the different steps in the viewing pipeline. Which coordinate systems are used?
   b. Describe the depth(z)-buffer algorithm.
   c. Which anti-aliasing techniques can be used in combination with the depth buffer?

2. a. What is the gamut of a monitor? What determines the gamut?
   b. Explain the differences between an additive and a subtractive color system. Give examples.
   c. What is the difference between intensity (in Watt) and luminance (in Lumen)?

3. a. What kind of light paths are possible in a scene? What is covered by standard ray tracing?
   b. How can ray tracing be extended to include also the other paths?
   c. Give two versions of a two-pass (ray tracing - radiosity) algorithm?

4. a. Explain the terms in the following equation: $L_{,,} = \frac{\rho}{\pi} \int_{\Omega} L(\omega_i) \cos\theta_i \, d\omega_i$
   b. Give two methods to calculate the form factor in radiosity.
   c. What are the advantages and drawbacks of discontinuity meshing in radiosity?

5. a. Give three applications/uses of texture mapping that differ in the type of surface property defined in the texture.
   b. What is surface-texture parametrisation and what difficulties may occur?
   c. Give two applications of environment mapping.

6. a. Describe how parallel rewrite systems (grammars) can be used to model plants and trees. Why are these rewrite systems called parallel?
   b. 3D computer animation techniques can be split into low level techniques and high level techniques. What are the main characteristics / differences of both?
   c. Give a short description of three techniques that can be used for the definition and calculation of rigid body animations.

end of examination

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Answers for Examination IN4151

Wednesday, 26 January 2005

1. a. *Describe the different steps in the viewing pipeline. Which coordinate systems are used? (4)*
The object is defined in the object coordinate space and transformed to world coordinate space. Objects are then transformed to viewing coordinate space. After projection the objects are mapped to a viewport in screen coordinates.
b. *Describe the depth(z)-buffer algorithm. (4)*
The depth buffer works with a screen-size intensity buffer for the (r,g,b,a) values of the pixels. In addition a screen-size depth buffer is used for the z-values. The intensity buffer is initialised to the background color and the depth buffer to an arbitrary large depth. The polygons are then scan-converted and for each pixel a depth test is done on the value in the depth buffer. If the new value is larger (behind) the existing value in the depth buffer then it is ignored. If it is smaller than the value then it is written in that location of the depth buffer and the color is written in the corresponding position in the intensity buffer ovenvriting the earlier intensity value for that pixel.
c. *Which anti-aliasing techniques can be used in combination with the depth buffer? (2)*
Supersampling and alpha-compositing.

2. a. *What is the gamut of a monitor? What determines the gamut of a monitor? (2)*
The garnut is the color range that a monitor can display. The gamut is determined by the choice of phosphors. The three phosphors span a triangle in color space which is the gamut.
b. *Explain the dzfferences beween an additive and a subtractive color system. Give examples. (4)*
A color composed by two or more light sources (such as the phosphors of a monitor) can be described by an additive color system. A tyical example is the R,G,B color system. Color as a result of mixing several printing inks that absorb certain spectra of light can be described by a subtractive color system, such as CMY(K).
c. *What is the difference between intensity (in Watt) and luminance (in Lumen)? (4)*
Intensity is the power as measured by a physical instrument (light sensor). Luminance is the intensity scaled by the lurninance efficiency curve that describes the sensitivity of the human eye for light of different wavelengths. Thus a lamp in the yellow-green range has a higher lumen than a lamp in the red or blue range with a similar power emittance.

3. a. *What kind of light paths are possible in a scene? What is covered by standard ray tracing? (3)*
Direct light reaches an object directly from a light source (if not blocked) and is partly reflected into the direction of the eye. The indirect light is light from the light source that first hits another object (or multiple objects in a row) and then hits the object to be shaded. Further there can be reflected and refracted light paths (of indirect light). The ray tracing does

cover the direct and the specular and refracted light in the direction of the eye. It does not cover the indirect reflected light paths. They are approximated by an ambient term.

b. *How can ray tracing be extended to include also the other paths? (3)*

By recursively sampling the light coming from all directions, for instance with a Monte-Carlo algorithm. *Photon map extension may also give a point.*

c. *Give two versions of a two-pass (ray tracing - radiosity) algorithm? (4)*

The standard two-pass algorithm uses the radiosity diffuse reflection for the direct light (first pass) and traces the reflection and refraction rays for the specular and transmittant components (second pass).

Another version takes the precalculated radiosity value for the indirect diffuse reflection but re-samples the direct light by shadow tracing to get more accurate shadow boundaries (so-called "final gathering"). An even more accurate two-pass algorithm uses a MC ray tracing algorithm for the first bounce and uses the pre-calculated radiosity values for the second bounce to avoid expensive recursive sampling.

There may have been some confusion in the question about what is the first pass (ray tracing or radiosity); it is always first the radiosity and then the ray tracing..

4. a. *Explain the terms in the following equation:* $L_s = \frac{\rho}{\pi}\int_{\Omega} L(\omega_i)\cos\theta_i d\omega_i$ *(4)*

The equation is the radiance at point *s*. The term under the integral sign is the incoming radiance scaled by the cos of the angle of incident (angle with normal at point *s*). The integral is over the hemisphere Ω and ***dw*** is the solid angle. The sum of all received intensity over the hemisphere is the irradiance for point *s*. The radiosity is the total incoming irradiance scaled/multiplied by the reflection coefficient **p.** For diffuse reflection the outgoing radiance L for point *s* is equal to the radiosity divided by π.

L, *is nor the specular reflection! The index s is indicating the point s, and dw is not the distance.*

b. *Give two methods to calculate the form factor in radiosity. (4)*

The hemi-cube method uses a depth-buffer type approach where the surrounding surface/patches are projected on the faces of a hemi-cube and the number of "pixels" covered by the projection is a measure for the form factor. An alternative method is to use ray tracing. If the rays are spread equally over the hemi-sphere than the amount of rays hitting a surface is a measure for the form factor with that surface. If the rays are directed to the vertices of the patches (only visibility checking) than an additional form factor calculation has to be done taking into account the distance and the orientation of the patches.

c. *What are the advantages and drawbacks of discontinuity meshing in radiosity? (2)*

The mesh edges are chosen along shadow boundaries. This avoids fuzzy (too much blended) shadows and shadow-leaking. It also contributes to a quicker convergence in case of progressive radiosity. Drawbacks are the complex geometric preprocessing that has to be done for a given light source configuration. This is even more complex for scenes with curved surfaces.

5. a. *Give three applicationslusesof texture mapping that differ in the type of surface property defined in the texture. (2)*

Colour pattern mapping, bump mapping, displacement mapping, reflection mapping, environment mapping

b. *What is surface-texture parametrisation and what difficulties may occur? (4)*

The parametrisation defines how the texture is mapped to the surface, i.e. how the texture parameters in (u,v) are associated with the surface parameters (s,t). If for (s,t) a linear scan-line interpolation is chosen then this will give distortions in the mapping. Only a (2D) perspective interpolation will give a correct stretching of the texture on the surface. If the polygon is not rectangular than this stretching may give distortion problems. For curved surfaces the texture parametrisation can be associated with the parametric representation of the surface but also then foreshortening or stretching will occur. Associating a texture with a mesh of polygons is also problematic. Some of these problems may be solved by two-part texture mapping, where the texture is first mapped on a simple intermediate surface before it is projected on the more complex surface.

c. *Give two applications of environment mapping. (4)*

An environment map can be used as an "imposter" for the background for instance in virtual reality to simplify the rendering, and it can be used for adding mirroring reflections in a projective display algorithm (as a ray tracing short-cut).

6. a. *Describe how parallel rewrite systems (grammars)can be used to model plants and trees. Why are these rewrite systems called parallel? (3)*

Parallel rewrite systems define strings of characters. The characters can be interpreted as drawing instructions. In this way strings defined by the grammar have graphic counterparts. The rewrite systems are called parallel because the substitution rules are applied to all non-terminal symbols (characters) in a string in parallel in order to get the next generation of the string (and therefore the corresponding tree object).

b. *3D computer animation techniques can be split into low level techniques and high level techniques. What are the main characteristics / differences of both? (4)*

Low level techniques are techniques that aid the animator in precisely specifying motion. These kinds of techniques are used when the animator has a fairly specific idea of the exact motion that he wants. It takes a lot of effort from the animator to specify the animation. High level techniques are typically algorithms or models to generate a motion using a set of rules or constraints. The animator sets up the rules of the model, or chooses an appropriate algorithm, and selects initial values or boundary values. The system is then "set into motion", and the motion of the objects is controlled by the algorithm or model. The model-based / algorithmic approaches often rely on fairly sophisticated computation, such as physically based motion control. It does not take much effort from the animator to specify the animation.

In practice, these categories are the extremes which characterize a continuum of approaches. Any technique requires a certain arnount of effort from the animator and a certain amount of effort from the computer. At a very low level of abstraction, the animator can color in every pixel individually in every frame. At the other extreme, at a very high level of abstraction, the animator could tell the computer to make a movie about a dog, for instance.

c. *Give a short description of three techniques that can be used for the dejìnition and calculation of rigid body animations. (3)*

Key frame animation: The animator specifies the position and orientation of objects at the key frames. The system calculates the positions and orientations for the frames between the key frames (in-betweening).

Animation languages: The animator programs the animation. The programming language may contain programming constructs from 'normal' programming languages, like loop-constructs and conditional statements. Furthermore, the language may contain special constructs for animation specification.

Procedural / model based animation: The model rules the animation. The animator specifies the start conditions, time interval and parameter values for the animation. The computer calculates the whole animation from these parameter values. Example: Falling object in a gravitational field, govemed by the laws of Newton.