# GDV – (mögliche) Klausuraufgaben

Die Klausur wird 10 Aufgaben haben, dabei kann jede Aufgabe aus einer Kombination mehrerer unten genannten Aufgaben bestehen.

## Inhalt

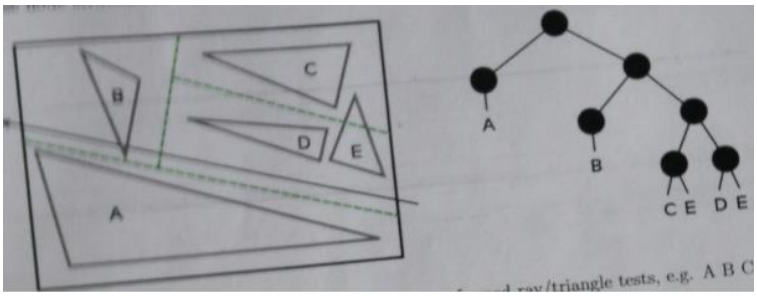
# Spatial Acceleration Structures

## Klausuraufgabe WS2017/18

***(IN AKTUELLER PROBEKLAUSUR!)***

Ray tracing an unorganized polygon soup is rather slow. Describe three different spatial acceleration structures and explain their benefits and drawbacks with regard to traversal complexity, building time and space requirements. (3-4 sentences for each).

## Klausuraufgabe WS2017/18




a) Traverse the BSP-tree! Give one possible order of perfomed ray/triangle tests, e.g. A B C D D. Do not optimize out multiple tests on the same triangle!
b) Construct a bounding volume hierachy (BVH) of your choice with at least four nodes. Don't count triangles as nodes (nodes are dots in the graph above). Draw the bounding volumes inside the picture below and draw a schematic tree for the structure you created.

## Octree / Quadtree – Klausuraufgabe WS2020/21

a) We were given a square with randomly distributed labeled nodes (a,b,...). Fill in the Quadtree structure. Subdivide if the number of remaining nodes is n > 2.
b) The Grid structure is similar to the Octree structure. Explain what their relationship is.
c) Draw the tree structure of the quadtree from a). Leaf nodes should be the contained objects. Intermediate nodes do not need to be labeled.

## Lecture Questions

Describe and compare quadtrees and grids.

Describe and compare BVHs and kD-Trees.

How do you traverse a kD-Tree? or a BSP-tree?

What is the surface area heuristic? What is it used for?

Compare lazy build and multi-level hierarchies for representing large scenes.

How can one adapt BVHs for dynamic scenes?

# Rendering Equation

## Klausuraufgabe WS2017/18

***(IN AKTUELLER PROBEKLAUSUR!)***

a) Complete the formula of Rendering Equation for surface models:

$$L(x,\omega_o) = \underbrace{L_e(x,\omega_o)}_{\text{emitted radiance}} + \int_\Omega \underbrace{f(x,\omega_o,\omega_i)}_{\text{BRDF}} \cdot \underbrace{L_i(x,\omega_i)}_{\text{incoming radiance}} \cdot \underbrace{\omega_i \cdot n}_{\text{cosine shading}} \cdot \underbrace{d\omega_i}_{\text{integral over } \Omega}$$

Explain briefly the different factors and terms in this equation.

b) How does the rendering equation account for global Illumination effects?

c) Which assumption is made for rendering equation? How can the rendering equation be simplified because of that assumption?

## Klausuraufgabe WS2019/20

Rendering Equation lückenhaft gegeben.

a) Complete the formula of Rendering Equation for surface models and explain its different parts. *(siehe oben)*

b) Give a brief reason whether the following effects can or cannot be expressed with the Rendering Equation.
   a. diffuse reflectance
   b. glossy reflectance
   c. specular reflectance
   d. subsurface scattering
   e. polarization
   f. refraction
   g. double refraction
   h. reflect to incoming direction

## Klausuraufgabe WS2020/21

Write down the rendering equation and briefly describe its terms.

## Lecture Questions

What is described by the rendering equation?

Which terms does it consist of?

How does it describe global light transport?

# BRDF – Bidirectional Reflectance Distribution Function

## Klausuraufgabe WS2017/18

***(IN AKTUELLER PROBEKLAUSUR!)***

Which of these properties does a BRDF need to fulfill to be physically valid?

| |
|---|
| conservation of energy |
| wavelength limited |
| Helmholtz reciprocity |
| can be negative |
| the unit is $\frac{1}{m^2}$ |
| the unit is $\frac{1}{sr}$ |
| the diffuse BRDF is constant |
| $\int_\Omega f_r(\omega_i, x, \omega) \cos\theta_i \, d\omega_i \leq 1$ |

## BRDF Modelle - Klausuraufgabe WS2019/20

Name three simple BRDF's which were discussed in the lecture and draw them.

## Lecture Question

What does "BRDF" stand for? What is represented by a BRDF?

Explain the differences between diffuse, glossy and mirror reflections.

How can you control the specular lobe in the Blinn reflection model?

What is a BRDF? How is it defined?

What are the properties described by it?

Which phenomena are not covered?

How can a BRDF be represented?

How do you measure a BRDF?

# Path Tracing

## Klausuraufgabe WS2017/18

For some of the following scenes, a path tracer will definitely produce black images. Which ones?

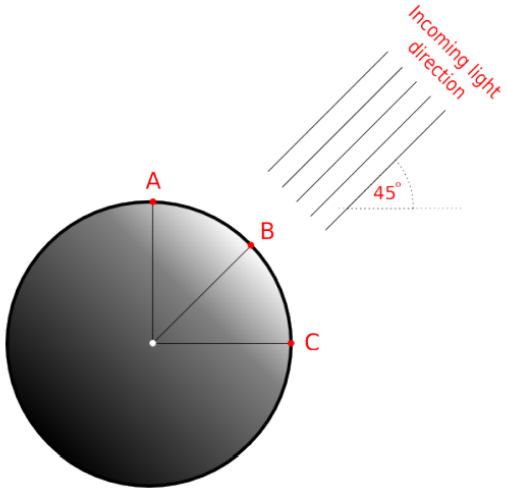
| |
|---|
| A pinhole camera model is used |
| All light sources are point lights |
| All light sources are directional lights |
| All light sources are area lights |
| All light sources are area lights behind glass |
| All surfaces which are not light sources are mirrors |
| All surfaces which are not light sources are white |
| All surfaces which are not light sources are black |

# Shading

## Directional Light Source – Klausuraufgabe WS2017/18

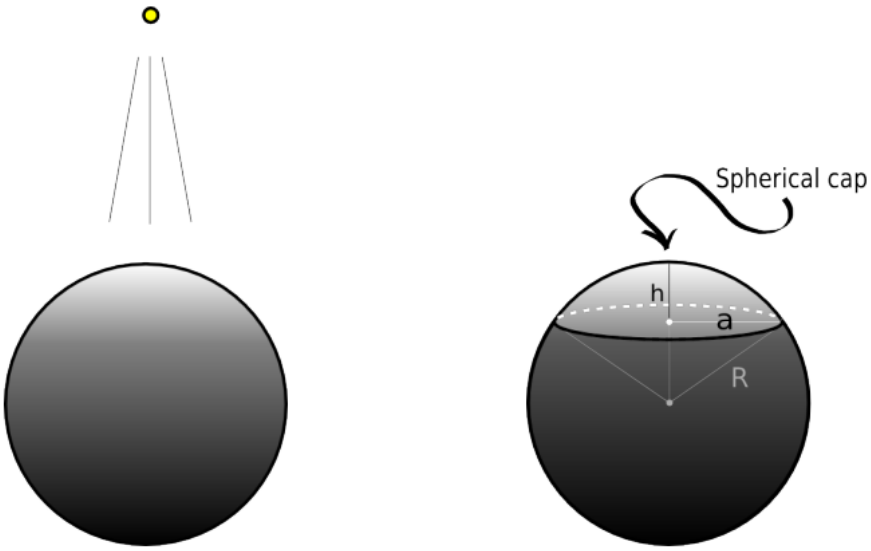
***(IN AKTUELLER PROBEKLAUSUR!)***

Compute the irradiance of a directional light source on a sphere for three points $A, B$ and $C$, with the incoming radiosity (from a surface perpendicular to the light direction) being $L_s$.




## Point Light Source – Klausuraufgabe WS2017/18

***(IN AKTUELLER PROBEKLAUSUR!)***




A point light source illuminates a sphere with radius $r$, as illustrated in the picture. The distance of the light source to the center of the sphere is $d$. Given the light source power $\phi_s$ compute the total radiant power incident on the sphere Note:

- Do not compute any integral.
- Pythagoras says: $a^2 + b^2 = c^2$ for a rectangular triangle.
- The height $h$ of a rectangular triangle can then be computed by $h \cdot c = a \cdot b$.
- The area of a spherical cap is given by $S = \pi(a^2 + h^2)$.

## Phong Illumination – Hauptklausur WS2020/21

The Phong illumination model is used to model glossy reflection. Of which three terms does it consist?

## Lecture Question

How do you evaluate the shading for a diffuse surface?

# Sampling

## Bayer Pattern – Klausuraufgabe WS2017/18

***(IN AKTUELLER PROBEKLAUSUR!)***

Most affordable color cameras use a color filter array in front of the image sensor so that each sensor pixel captures only one of the three primary colors. The most popular pattern is the tiling by Bayer (1975), which is depicted below.

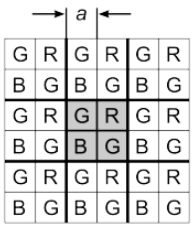



Figure 1: Bayer pattern. We assume square pixels of length $a$.

Using a sensor with pixel size a and Bayer color filter, what is the highest spatial frequency for each color channel individually that can be captured without aliasing (in every direction)?

## Klausuraufgabe WS2017/18

a) Why is a Gauss filter not optimal for prefiltering before sampling to avoid aliasing? Which filter would be better?
b) Name four supersampling sample placement strategies. Explain the sample placement for each. (Abstastmöglichkeiten für Sampling)
c) How well do the sample placement strategies from b) perform considering noise and aliasing?

## Klausuraufgabe WS2019/20

Es ist das Sampling einer Funktion gegeben.

a) Warum ist dieses Sampling schlecht? (Hoch freq. Signal, niedrig freq. Comb.)
b) Wie kann man dieses Sampling verbessern?
c) Reconstruction: Lineare interpolation. Warum ist das nicht optimal? Wie wäre es besser und warum?

## Klausuraufgabe WS2019/20

a) The plot on the left shows samples which were taken from the function from the plot on the right. Explain why the chosen sampling pattern is not suitable to represent the function.
b) What can be done to improve the sampling?
c) (Neue Plots!) On the left, there is a sine with a frequency of 2 Hz which has been sampled 10 times per cycle. On the right there is the piecewise linear reconstruction of the sample points. That reconstruction is not optimal. Describe why the reconstruction is not good and explain how and why the original sine could be obtained with a different strategy.

## Lecture Questions

Why do we hardly see aliasing in digital photo cameras?

10x zoom (3x optical) – what does this mean?

# Affine Transformations

## Klausuraufgabe WS2017/18

***(IN AKTUELLER PROBEKLAUSUR!)***

a) Affine Invariance: Explain what affine invariance means and give a simple example.
b) Perspective Transformation: Is the perspective projection an affine transformation?

# Splines - Bezier

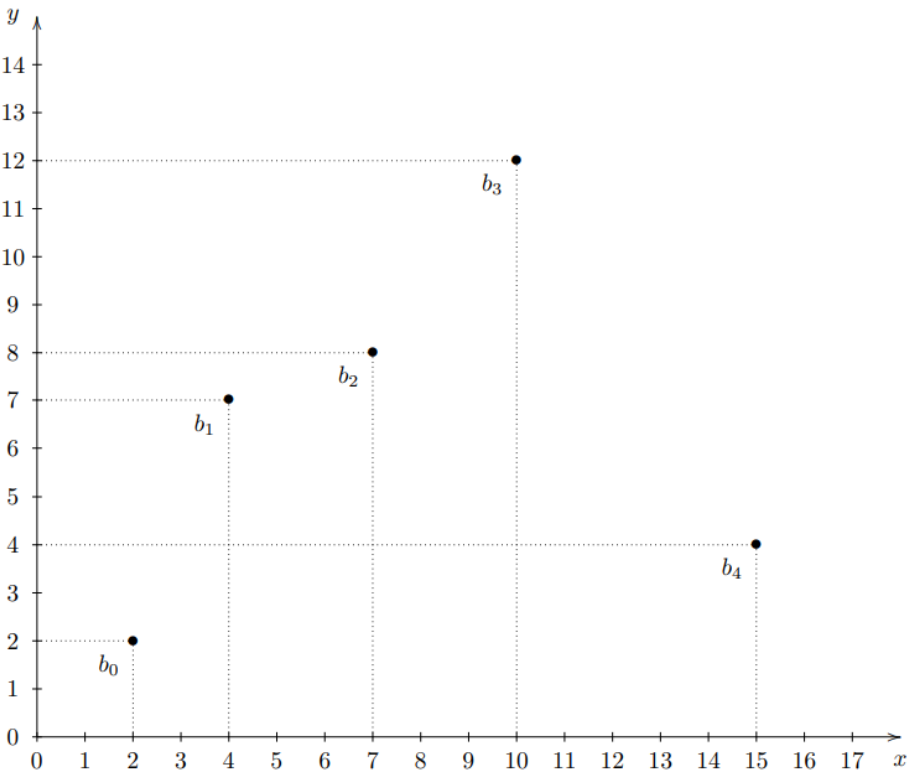
## Splines - Klausuraufgabe WS2017/18

***(IN AKTUELLER PROBEKLAUSUR!)***

a) How many times can a spline of degree n be differentiated? Assume spline segments to be polinomials of degree n and the joints between the segments to be as smooth as possible. Explain!

b)

Given five control points $b_0, \dots b_4$ of a Bezier curve $P(t)$ with degree 4, $t \in [0, 1]$, as depicted below. Apply the *deCasteljau* algorithm graphically and numerically to compute the point $P_{0.5} = P(t = 0.5)$ on the curve.



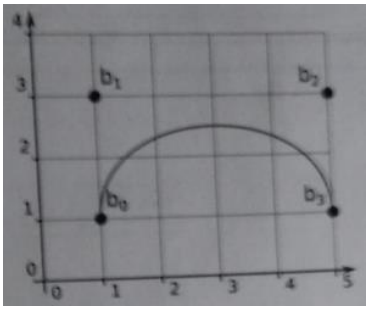

- $b_0(2,2)$ , $b_1(4,7)$ , $b_2(7,8)$ , $b_3(10,12)$ , $b_4(15,4)$

## Catmull-Rom Splines – Klausuraufgabe WS2017/18

a) Draw and calculate the Catmull-Rom Spline tangent vectors of the points p1,…,p4. P0(0,2); P1(1,1); P2(2,3); P3(3,2); P4(5,4); P5(8,2)

b) Which continuity does a Catmull-Rom Spline (including transitions between spline segments) have?

## Splines – Klausuraufgabe WS2017/18




a) What is the coefficient matrix A for the monomial representation of the Bézier spline shown above? The basis Matrix M for Bézier splines is:

```
(-1   3   -3   1)
(3   -6    3   0)
(-3   3    0   0)
(1    0    0   0)
```

b) Calculate the position of the point P(0,5) with t=0,5 on the spline.
c) Calculate the tangent vector P'(0,5) with t=0,5 on the spline.

## NURBS – Klausuraufgabe WS2019/20, WS2020/21

What does NURBS stand for? What is their purpose?

## Klausuraufgabe WS2019/20

Drei Felder mit Splines waren gegeben: Einmal ein Spline, der aus zwei Teilsplines zusammengesetzt war, dann ein Feld für die eigene Lösung und dann ein Feld für den Catmul-Rom-Spline

a) Describe what you have to do to make the spline on the left (the composite spline) as smooth as possible by changing as little as possible. Draw your solution in the empty plot in the middle (control points and curve).
b) Interpolate the given control points in the plot on the right with a Catmul-Rom spline. Describe how you construct the curve.

## Catmull-Rom Splines – Klausuraufgabe WS2020/21

There was a figure given with six points p0 to p5 where p1 to p4 were connected by a Catmull-Rom spline.

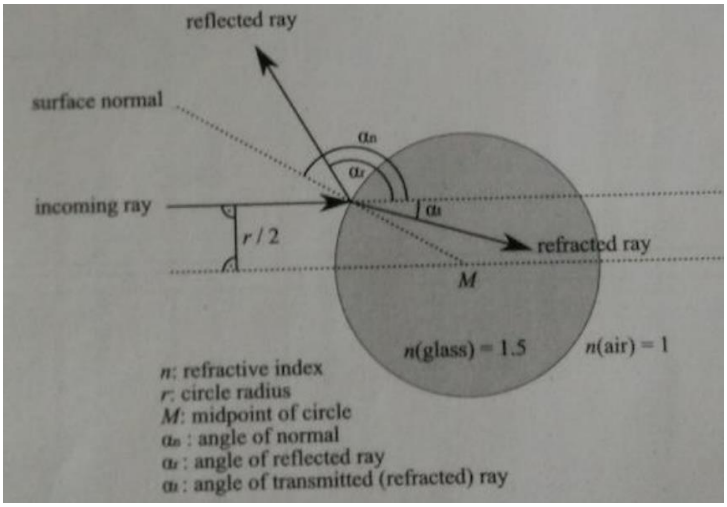
a) Calculate the tangents of p1 to p4 and draw them into the figure.
b) What continuity does a Catmull-Rom spline have?

# Geometry

## Klausuraufgabe WS2017/18

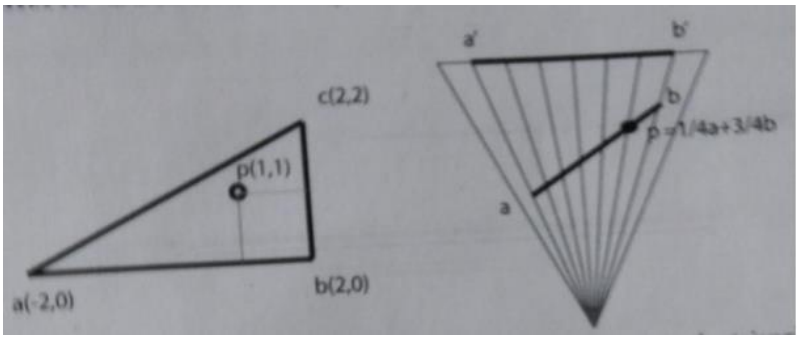
Given is a 2D sphere (circle) that is being hit by a light ray as depicted in the figure below. Calculate the following angles exactly with respect to the initial ray direction:

- Give the result in symbolic form using arcsin(…) etc.
- The distance of the ray from the sphere diameter (eccentricity) equals to half the sphere radius.
- For the refracted ray, use Snell's law and the given refractive indices of the materials.
- sin(30°) = ½




a) The angle of the surface normal ray, $\alpha_n$
b) The angle of the reflected ray, $d_r$
c) The angle of the refracted ray, $\alpha_t$

## Barycentric Coordinates – Klausuraufgabe WS2017/18




a) Compute the barycentric coordinates $\lambda A$, $\lambda B$, $\lambda C$ of the point p(1,1) in the triangle shown in the left figure.
b) Explain why barycentric coordinates need to be calculated before applying a perspective projection as seen in the right figure. Compare this to the case where one computes the barycentric coordinates on the projected triangle. (No numbers required).

## Intersection - Klausuraufgabe WS2019/20

The image shows a section of an axis-aligned unit-cylinder centered on and parallel to the z-axis with infinite height. Further, a ray of direction d is starting at point O.

Calculate the closest intersection point of ray and cylinder. The following values are given:

$$Cylinder: \mathrm{x}^2 + \mathrm{y}^2 = 1$$

$Ray: r(t) = O + td$ with O = (2, -1,3) and d = (-3,1,-2)

## Intersection – Klausuraufgabe WS2020/21

A figure of a ray intersecting a sphere was given. Calculate the first intersection of the ray with the sphere. The ray is given by

$$r(t) = o + td$$

The sphere is given by

$$1 = x^2 + y^2 + z^2$$

Furthermore you can use the Mitternachtsformel.

## Lecture Question

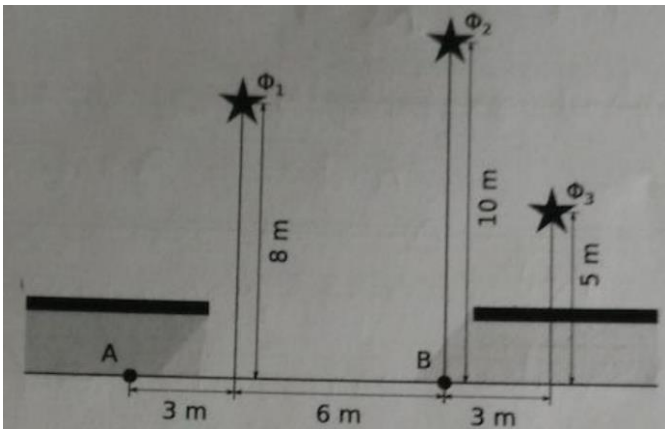
How do you compute the ray intersections with:

- Plane
- Box
- Triangle
- Sphere
- Cylinder

# Light Transport

## Klausuraufgabe WS2017/18

Given is a 3D scene as sketched below from the side. The scene contains three light sources with their radiant powers $\phi 1$ , $\phi 2$ and $\phi 3$ , a ground plane as well as some occluders. Calculate the irradiances at the points A and B. Do not take indirect lightning into account.



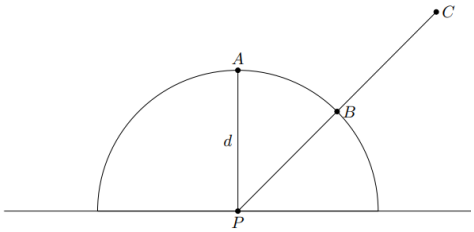

## Radiometric Quantities - Klausuraufgabe WS2017/18

List all radiometric Quantities.

## Klausuraufgabe WS2020/21

a) Describe these three terms (Irradiance, Radiosity, Radiance).

b)




A point light source is at location A with power 60W. Calculte the Irradiance E1 at P, where the distance to A is 10m. Furthermore calculate the irradiances E2, E3, if the light source is at B, C (distance 2d), respectively.

## Lecture Questions

Why is radiance so important for ray tracing?

# Mip-Mapping

## Klausuraufgabe WS2017/18

a) Compute the mip-map of the following 4x4 image.

| | | | |
|---|---|---|---|
| 7 | 11 | 0 | 0 |
| 9 | 5 | 0 | 12 |
| 7 | 2 | 5 | 4 |
| 1 | 10 | 4 | 3 |

b) Compute the memory consumption for a 4096x4096 mip-map with 8 bits per pixel and one color channel. Note:
   - A mip-map includes the original texture.
   - Give a compact formula rather than the final number.

c) What are the benefits from using mip-maps?

## Klausuraufgabe WS2019/20

a) Complete two mip-map levels for the 4x4 image which is given below.

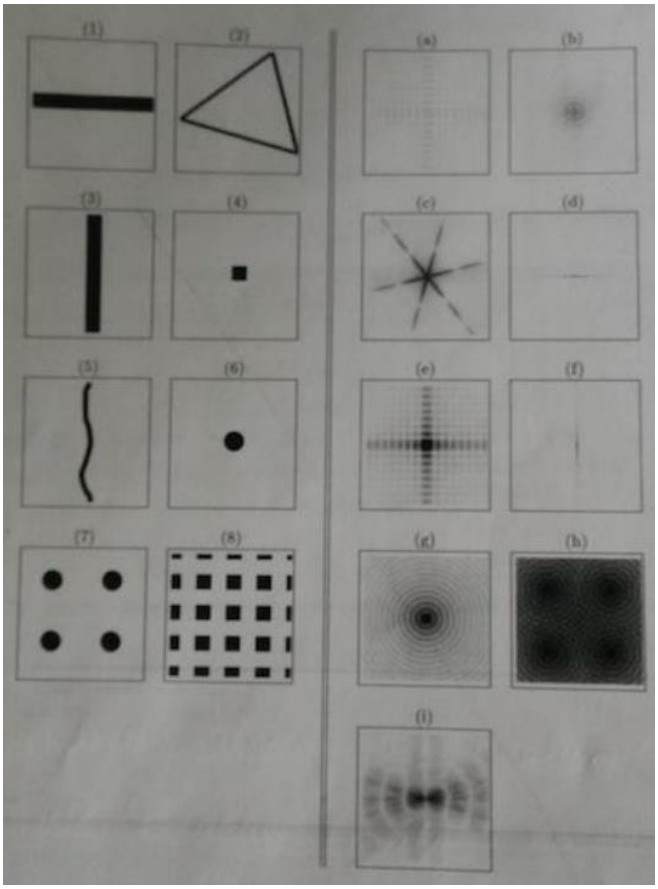
b) Derive the formula to compute the memory consumption for the mip-map of an image of size $2^n \times 2^n$ with one color channel and 8 bits per pixel.

c) Describe the benefits of using mip-maps.

# Fourier Transform

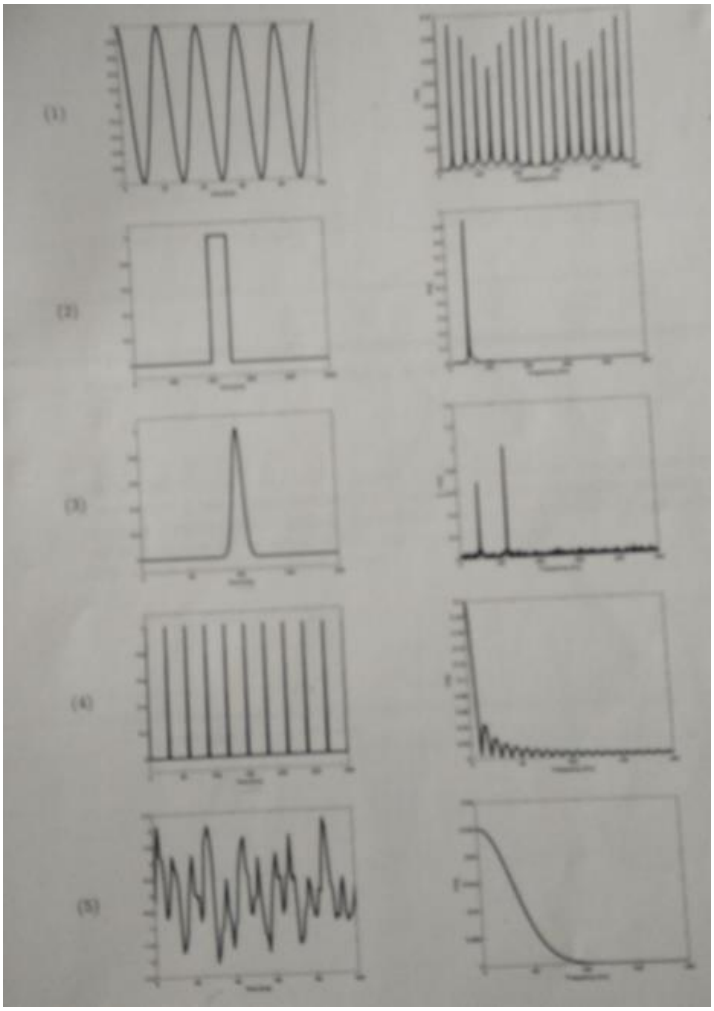
## Klausuraufgabe WS2017/18

Pair each of the images 1-8 with the corresponding Fourier spectra a-i. (Ones does not correspond).



## Klausuraufgabe WS2017/18

Pair each picture on the right to the corresponding image on the left.



## Klausuraufgabe WS2020/21

There were five function diagrams drawn on the left side and five discrete fourier transforms drawn in function diagrams on the right side On the left there are five functions drawn. On the right the discrete fourier transform of each of those functions is drawn. Mark for each DFT to which function it belongs.

## Lecture Questions

What does the Fourier transform do?

How does the power spectrum looks like for a horizontal/ vertical bar, set of dots, circles of varying sizes?

How to perform a convolution?

What is a low-pass, high-pass, band-pass filter?

# Lightfields

## Klausuraufgabe WS2017/18

a) Describe the information about the scene that is contained in a Lightfield and two possible parametrizations to store this data. What is dimensionality of the Lightfield?
b) Given a Lightfield, what novel renderings of the captured scene can be produced?
c) Name 3 disadvantages of Lightfields

## Reflectance Fields – Klausuraufgabe WS2019/20

a) Given a 4D reflectance field (which is drawn above), explain the following statements:
    a. It is not possible to render the scene from an arbitrary viewpoint.
    b. The scene can be relighted as illuminated by an environment map.
    c. Reproduction of fluorescent materials that change the color of incoming light upon reflection, e. g. from green to red, is not possible.
b) Which changes / extensions to the setup, recording process, and data structure would be required to allow for the points above that were not possible so far? Give explanations.
c) Explain at least two kinds of artifacts that can occur if the space of incoming light direction is sampled too sparsely.

## Lecture Questions

What is the information that is represented in a light field?

How is this different from a reflectance field / BRDF?

# OpenGL

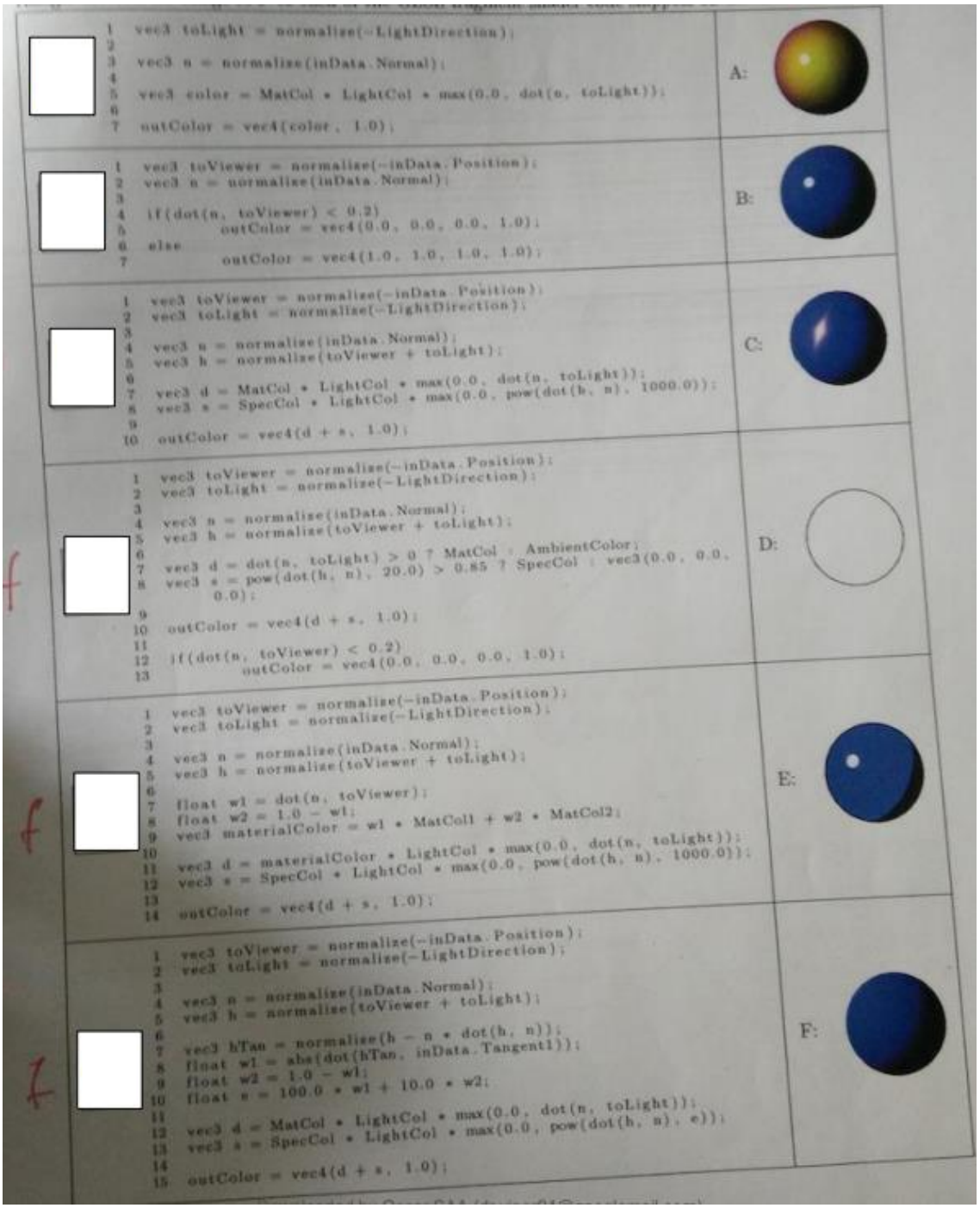
## Klausuraufgabe WS2017/18

Describe the follwing terms. Explain for each what it is or what is does, where it is located in the OpenGL rendering pipeline and give an example application.

a) Transform Feedback
b) Fragment Shader
c) Vertex Shader
d) Vertex Array Object

## Klausuraufgabe WS2017/18, WS2019/20

Which Code belongs to which BRDF?



## Klausuraufgabe WS2020/21

Why is the OpenGL implementation of raytracing so much faster than our own implementation?

# Image Processing

## Image Filtering – Klausuraufgabe WS2017/18

a) The original image was convolved with different filters: Gaussian, Bilateral and Sobel. Assign the correct filter to the images.

b) Describe in short the median filter. Is the median filter appropriate to remove salt and pepper noise?

# Transformations

## Homogeneous Transformations – Klausuraufgabe WS2017/18

Describe what affect following matrices have:

a)

| | | | |
|---|---|---|---|
| 7 | 0 | 0 | 0 |
| 0 | 7 | 0 | 0 |
| 0 | 0 | 7 | 0 |
| 0 | 0 | 0 | 7 |

b)

| | | | |
|---|---|---|---|
| 3 | 0 | 0 | 3 |
| 0 | 3 | 0 | 3 |
| 0 | 0 | 3 | 3 |
| 0 | 0 | 0 | 3 |

c)

| | | | |
|---|---|---|---|
| 3 | 0 | 0 | 0 |
| 0 | 3 | 0 | 0 |
| 0 | 0 | 3 | 1 |
| 0 | 0 | 1 | 0 |

d)

| | | | |
|---|---|---|---|
| 3 | 0 | 0 | 0 |
| 0 | 3 | 0 | 0 |
| 0 | 0 | 3 | 0 |
| 0 | 0 | 0 | 1 |

e)

| | | | |
|---|---|---|---|
| 0 | -1 | 0 | 0 |
| 1 | 0 | 0 | 0 |
| 0 | 0 | 1 | 0 |
| 0 | 0 | 0 | 1 |

f)

| | | | |
|---|---|---|---|
| 1 | 0 | 0 | 0 |
| 0 | 3 | 0 | 0 |
| 0 | 0 | 1 | 0 |
| 0 | 0 | 0 | 1 |

g)

| | | | |
|---|---|---|---|
| 2 | 0 | 0 | 0 |
| 0 | 0 | -2 | 0 |
| 0 | 2 | 0 | 0 |
| 0 | 0 | 0 | 2 |

h)

| | | | |
|---|---|---|---|
| 1 | 0 | 0 | 0 |
| 0 | 0 | -1 | 0 |
| 0 | -1 | 0 | 0 |
| 0 | 0 | 0 | 1 |

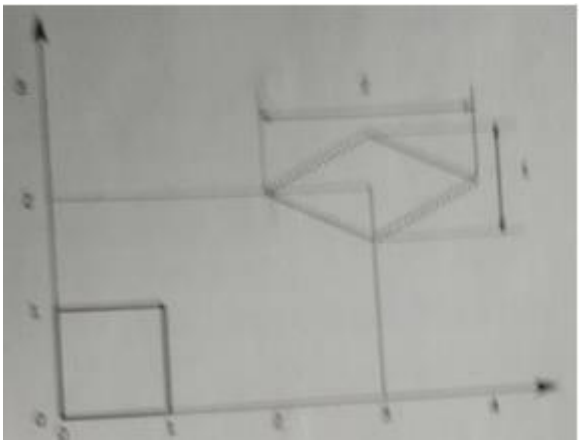
## Klausuraufgabe WS2019/20

Write down the matrices for the following transformations:

a) identity
b) rotation
c) x-axis rotation
d) z-axis rotation
e) mirror on y-axis
f) uniform scaling
g) non uniform scaling
h) projection
i) rotation and mirroring

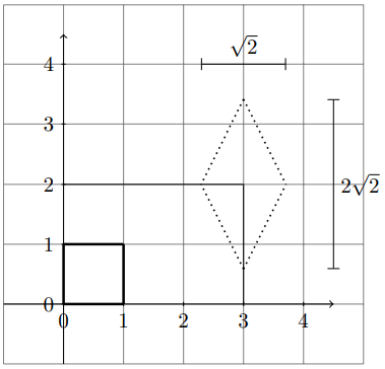
## Transformations – Klausuraufgabe WS2017/18

Calculate the transformation. Final matrix has not to be computed.



## Transformations – Klausuraufgabe WS2020/21

Write down the individual transforms needed, to transform the square to the dotted position. Then write down the full combination of transforms, that would make up the complete transform.



# Camera Model

## Klausuraufgabe WS2019/20

Kamera Model: Es ist ein Kameramodel gegeben als Bild mit 8x8 Image Plane

a) Construct and draw a ray which goes through the pixel (6,1).
b) Derive the general equation for a ray which goes through an arbitrary pixel (x,y)

## Klausuraufgabe WS2020/21

a) A camera model is described with:
    - Camera origin o
    - Viewing direction d
    - Up vector u (with $u \cdot d = 0$)
    - Focal length f which is the distance to the image plane
    - Image width and height a.

    Derive the equation for a camera ray through pixel (x,y).

b) The point camera is our perfect model for the perspective transformation. Real cameras use lenses. Name and describe two types of artifacts that come from real lenses, that we can simulate to make computer generated images look more realistic.

# Color Spaces

## Klausuraufgabe WS2019/20

Which are the three main colors within camera chips? Which is the most dominant one in the human visual system?

# Ray Tracing

## Klausuraufgabe WS2020/21

a) Write down a function for raytracing with lambert shading in pseudo code. You can use the different given functions. Use N samples per pixel. Do at most 3 ray bounces. Hint: Start by using two for-loops to iterate over x and y.

   Given functions:

   - GenerateCameraRay(pixelX, pixelY) // returns a camera ray through pixelX, pixelY
   - Ray(origin, direction) // returns a ray
   - intersect(ray) // returns the first hitpoint
   - SampleRandomCosine(hitpoint) // sample a new cosine distributed direction
   - brdf(hitpoint) // return the brdf of the hitpoint location.
   - emit(hitpoint) // returns the energy emitted at hitpoint, if any
   - accumulate(color, pixelX, pixelY) // accumulates the color at pixelX, pixelY

b) Order the three materials paper, glass, miror, milk as to how many calcualtions they require in a raytracer (less operations < more operations). Give a short reasoning.

## Lecture Question

Write down and explain the principle steps of a recursive ray tracer.

# Texture

## Klausurfrage Ws2020/21

Bump mapping and Displacement mapping both can be applied to surfaces. What is the difference between those two?

## Lecture Questions

What spaces are involved in texture mapping?

What is forward and inverse mapping?

Why do we need filtering in texture mapping?

How is a mip map organized?

What are bump mapping and reflection mapping?

# Corner Cutting

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Given: A figure with 6 points connected by lines

a) Draw the new points after one iteration of corner cutting with ratio 1:3 and label them
b) Calculate the positions of the new points next to p0 and p1. Refer to them with their respective labels from a).