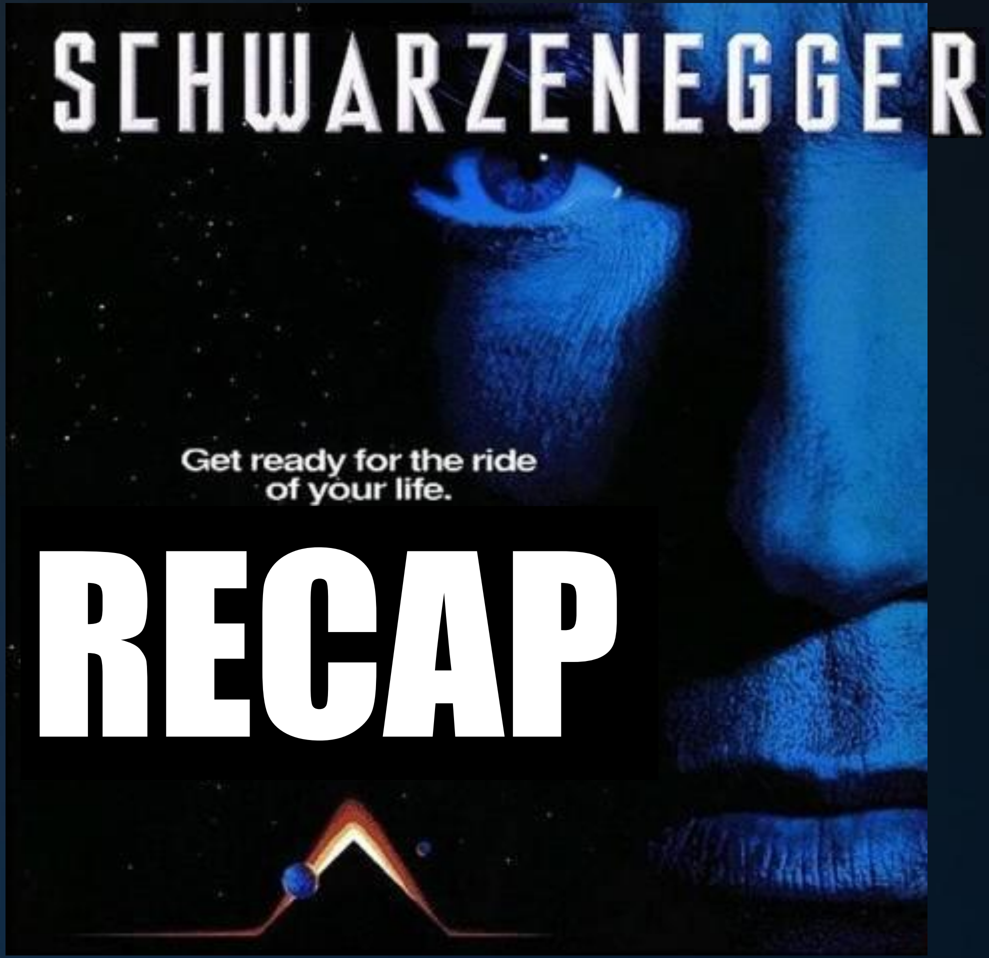
TOTAL RECAP



INFOGR – Computer Graphics

Jacco Bikker - April-July 2016 - Lecture 14: “Grand Recap”

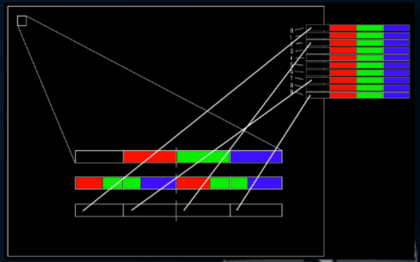
Welcome!

RECAP

Lecture 2: Rasters, Vectors, Colors

Math:
Vectors: magnitude, Pythagoras, linear (in)dependency, normalization, positions versus vectors, scalars, bases, Cartesian coordinate system, orthonormal, dot product (and its relation to the cosine), cross product.

Concepts:
Raster, discretization, rasterization, frame rate, vertical retrace, ‘frame-less’, RGB colors, 16-bit, palletized, HDR.



Questions?

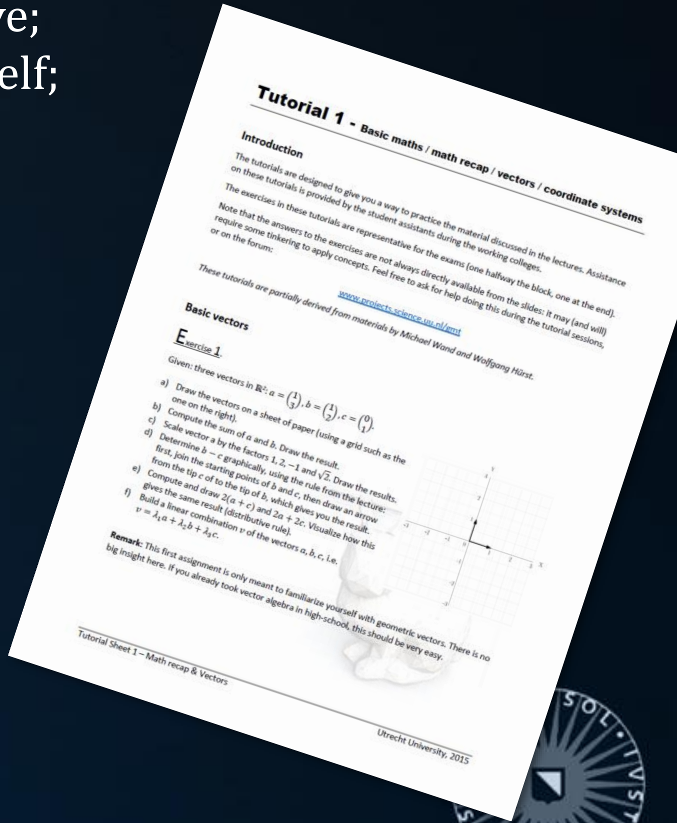
RECAP

Tutorial 1

Make sure you are able to:

- Show that the scalar product of vectors is commutative and associative;
- Show the relation between magnitude and the dot of a vector with itself;
- Interprete the meaning of $\vec{a} \cdot \vec{b} = 0 \,/\, 1 \,/ < 0 \,/ \dots$;
- Show that for two random vectors $\vec{a}$ and $\vec{b}$, $\vec{a} \times \vec{b} = -(\vec{b} \times \vec{a})$;
- Turn 2D coordinates into screen coordinates and vice versa;
- Reconstruct a unit vector based on two of its elements;
- Calculate a unit (normalized) vector for an arbitrary vector.

Not sure? Ask about this in the tutorial session after this lecture!



Tutorial 1 - Basic maths / math recap / vectors / coordinate systems

Introduction

The tutorials are designed to give you a way to practice the material discussed in the lectures. Assistance on these tutorials is provided by the student assistants during the working colleges.

The exercises in these tutorials are representative for the exams (one halfway the block, one at the end).

Note that the answers to the exercises are not always directly available from the slides: it may (and will) require some tinkering to apply concepts. Feel free to ask for help doing this during the tutorial sessions, or on the forum:

www.projects.science.uu.nl/gmt

These tutorials are partially derived from materials by Michael Wand and Wolfgang Hürst.

Basic vectors

Exercise 1.

Given: three vectors in $\mathbb{R}^2$: $a = \binom{1}{3}, b = \binom{1}{2}, c = \binom{0}{1}$.

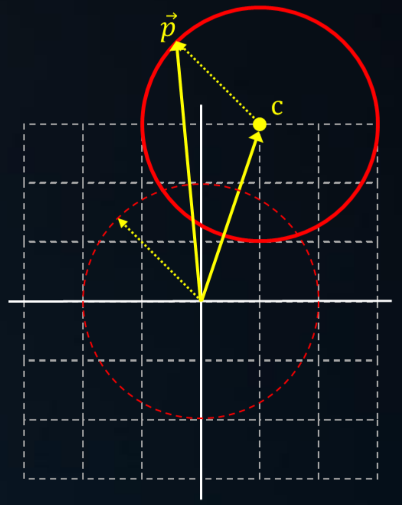
a) Draw the vectors on a sheet of paper (using a grid such as the one on the right).
b) Compute the sum of a and b. Draw the result.
c) Scale vector a by the factors 1, 2, −1 and $\sqrt{2}$. Draw the results.
d) Determine $b - c$ graphically, using the rule from the lecture: first, join the starting points of b and c, then draw an arrow from the tip c of to the tip of b, which gives you the result.
e) Compute and draw $2(a + c)$ and $2a + 2c$. Visualize how this gives the same result (distributive rule).
f) Build a linear combination v of the vectors a, b, c, i.e. $v = \lambda_1 a + \lambda_2 b + \lambda_3 c$.

Remark: This first assignment is only meant to familiarize yourself with geometric vectors. There is no big insight here. If you already took vector algebra in high-school, this should be very easy.

Tutorial Sheet 1 – Math recap & Vectors

Utrecht University, 2015

RECAP

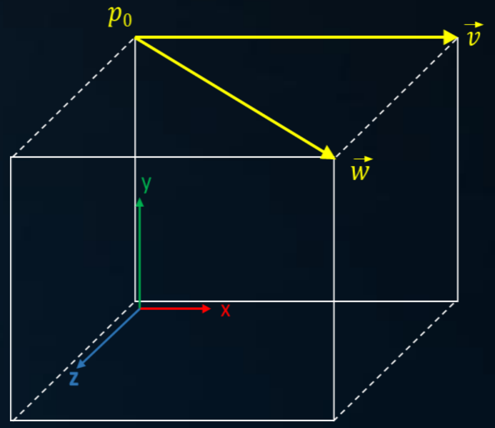


Lecture 3 – part 1: Geometry

Math:
Slope-intersect, implicit curves, functions, mappings, general implicit line form (and its relation to the normal), half spaces, parametric curves, SOHCAHTOA, implicit circles, implicit planes, parametric circles / spheres / planes.

Make sure you can:

- Extract the normal from an implicit plane equation;
- Calculate the distance of a point to a line or plane;
- Convert between various line and plane representations.



Questions?

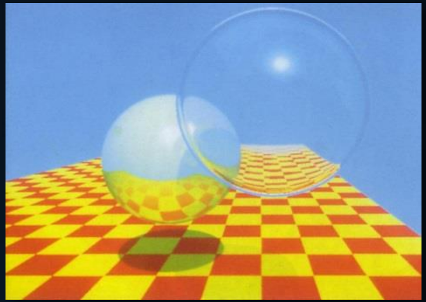
RECAP

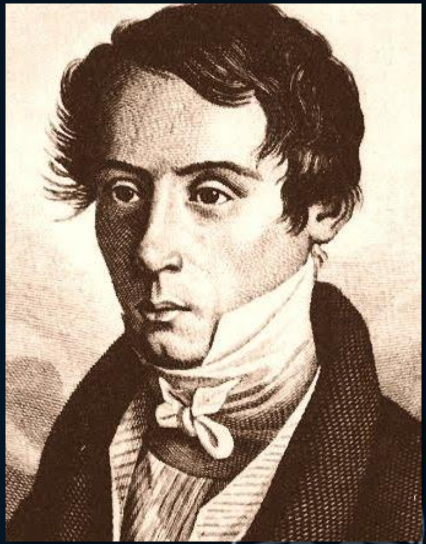
Lecture 3 – part 2: Ray Tracing Intro

Math:
Rendering equation, ray equation, setting up a world space screen plane, ray setup, ray/plane and ray/sphere intersection, distance attenuation, N dot L.

Concepts:
The “God Algorithm”: light transport in nature, light transport in a ray tracer, ray tracing versus rasterization, convex / concave, reflection and shadows in a rasterizer, global data, ray optics, Fresnel, Snell, Whitted-style (recursive) ray tracing.

Questions?



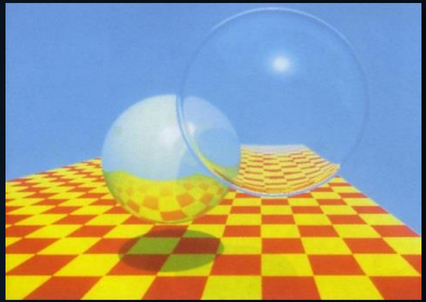


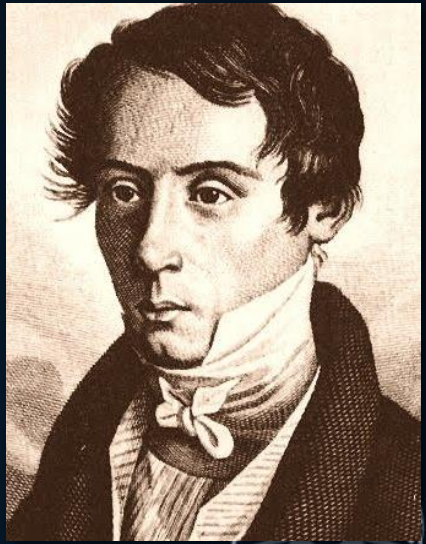
RECAP

Lecture 3 – part 2: Ray Tracing Intro

Make sure you can:

- Explain why the efficient ray/sphere intersection code on slide 30 will not work for glass spheres;
- Setup a proper ray given a view direction, FOV and up vector;
- Explain why you need an up vector.





RECAP

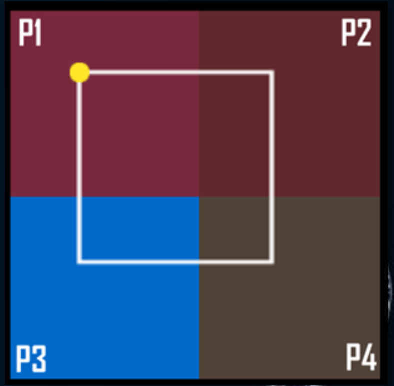
Lecture 3 – part 1: Textures

Concepts:
Procedural textures, texture mapping, clamping and tiling, oversampling, undersampling, bilinear interpolation, MIP-mapping, trilinear interpolation.

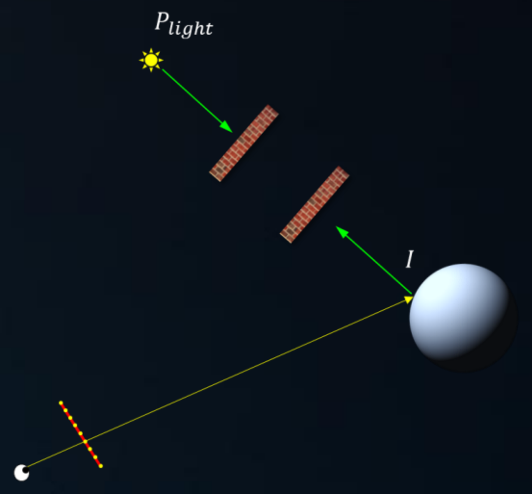
Make sure you can:

- Explain under-sampling and over-sampling;
- Describe the consequences of under-sampling and over-sampling;
- Explain bilinear interpolation;
- Calculate the space required for MIP-maps.

Questions?

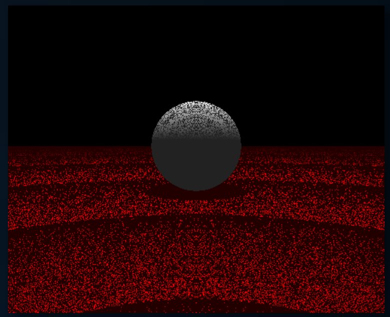


RECAP



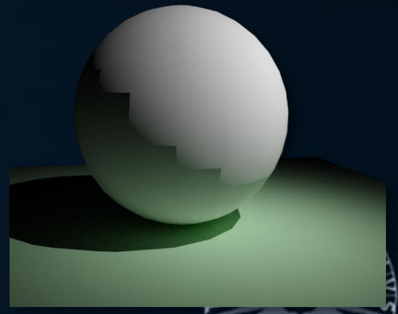
Lecture 4 – Ray Tracing (2)

Concepts:
Primary ray, primary intersection point, shadow ray, occluder, ray query, shadow acne, epsilon, ray query cost, Watt, Joule, distance attenuation, absorption, energy preservation, radiance, irradiance, calculating normals, vertex normal, normal interpolation, view frustum, fisheye lens.



Make sure you can:

- Explain why irradiance = radiance * $\cos\theta$;
- Fix shadow acne;
- List and explain factors that influence light transport;
- Calculate the normal for a sphere, plane and triangle.



Questions?

RECAP

Lecture 5 – Ray Tracing (3)

Concepts:
Reflection, pure specular, partial reflectivity, HDR, dielectrics, transmission, medium, medium boundary, Snell, Fresnel, Schlick, recursion, ray tree, diffuse / Lambert, glossy, Phong, limitations of Whitted-style ray tracing.

Make sure you can:

- Construct a vector reflected in a plane;
- Explain why a bathroom mirror is (close to) white;
- Explain why we need a cap on recursion;
- Explain why rays transport little energy in a deep ray tree;
- Explain why N dot L lighting has a constant BRDF.

Questions?

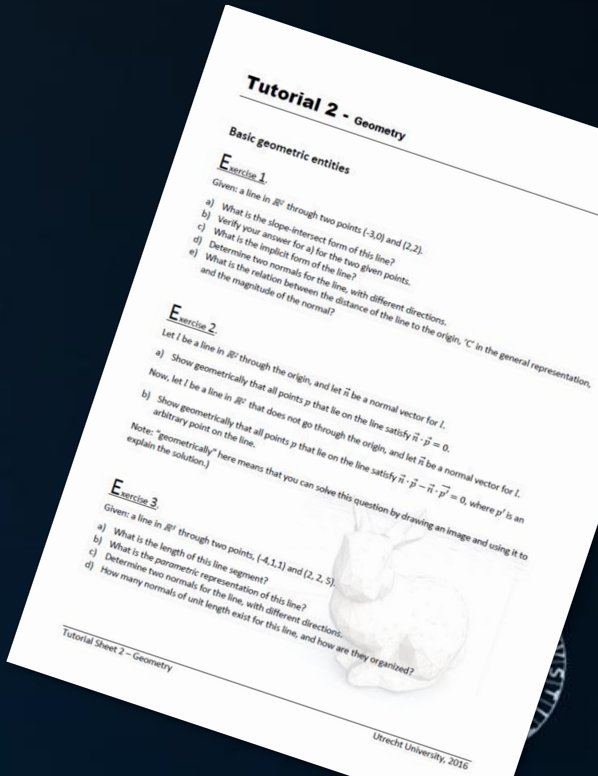
RECAP

Tutorial 2

Make sure you are able to:

- Turn a slope-intersect representation into parametric / implicit and vice versa;
- Calculate the normal for a pair of (linear independent) vectors;
- Calculate the distance of a point to a sphere;
- Determine implicit and parametric equations for spheres and elipsoids.

Not sure? Ask about this in the tutorial session after this lecture!


Tutorial 2 - Geometry

Basic geometric entities

Exercise 1

Given: a line in $\mathbb{R}^2$ through two points (-3,0) and (2,2).

a) What is the slope-intersect form of this line?
b) Verify your answer for a) for the two given points.
c) What is the implicit form of the line?
d) Determine two normals for the line, with different directions.
e) What is the relation between the distance of the line to the origin, 'C' in the general representation, and the magnitude of the normal?

Exercise 2

Let l be a line in $\mathbb{R}^2$ through the origin, and let $\vec{n}$ be a normal vector for l.

a) Show geometrically that all points p that lie on the line satisfy $\vec{n} \cdot \vec{p} = 0$.

Now, let l be a line in $\mathbb{R}^2$ that does not go through the origin, and let $\vec{n}$ be a normal vector for l.

b) Show geometrically that all points p that lie on the line satisfy $\vec{n} \cdot \vec{p} - \vec{n} \cdot \vec{p}' = 0$, where p' is an arbitrary point on the line.

Note: "geometrically" here means that you can solve this question by drawing an image and using it to explain the solution.)

Exercise 3

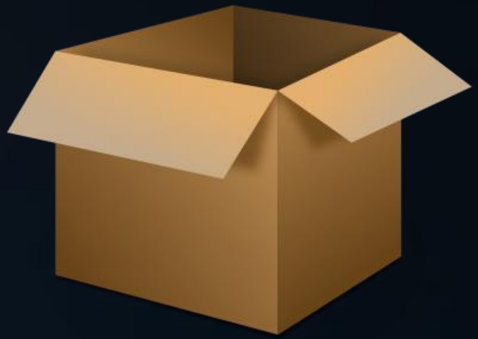
Given: a line in $\mathbb{R}^3$ through two points, (-4,1,1) and (2, 2, 5).

a) What is the length of this line segment?
b) What is the parametric representation of this line?
c) Determine two normals for the line, with different directions.
d) How many normals of unit length exist for this line, and how are they organized?

Tutorial Sheet 2 – Geometry

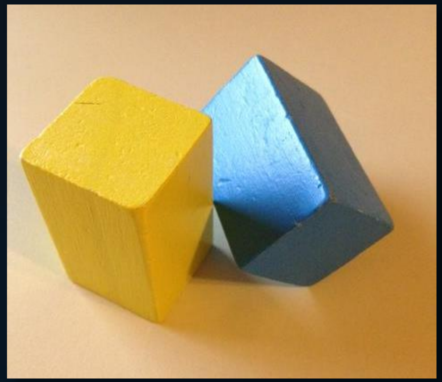
Utrecht University, 2016

RECAP



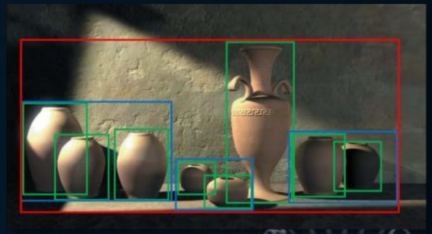
Lecture 6 – Boxes

Concepts:
AABB, culling, conservative tests, false negatives, early out, precalculate, loop hoisting, incremental rendering, rasterization, z-buffer, global data.



Make sure you can:

- Construct an AABB for a triangle, sphere, mesh, … ;
- Intersect a ray and a triangle;
- Intersect a ray and an AABB using the slab test;
- Cull a sphere and an AABB against a frustum;
- Explain situations where the basic test fails.



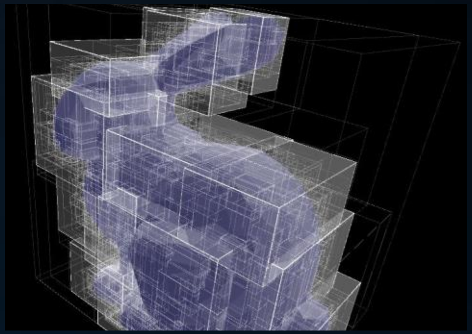
Questions?

RECAP

Lecture 7: Accelerate

Concepts:
Required ray tracing performance, grids / nested grids / octrees / kD-trees (and their (dis)advantages), the bounding volume hierarchy, BVH construction, BVH traversal, BVH size bounds, BVH depth, good BVHs: SAH, construction termination, ~~packet traversal~~.

Questions?



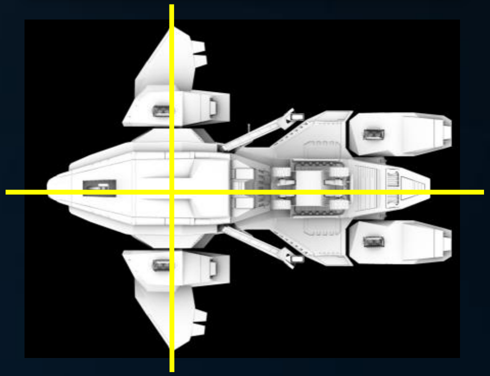
RECAP

Lecture 8: Engine Fundamentals

Math:
Matrices: coefficients, diagonal matrices, the identity and zero matrix; matrix addition, matrix/scalar, matrix/vector and matrix/matrix multiplication, distributive, associative, commutative, transpose, inverse, determinant, Laplace, Sarrus, cofactors, adjoint, (uniform) scaling, shearing, projection, reflection, rotation, linear transforms, transforming normals.

Concepts:
Rendering pipeline, scenegraph, object space, camera space, screen space, connectivity data, fragments.

Questions?



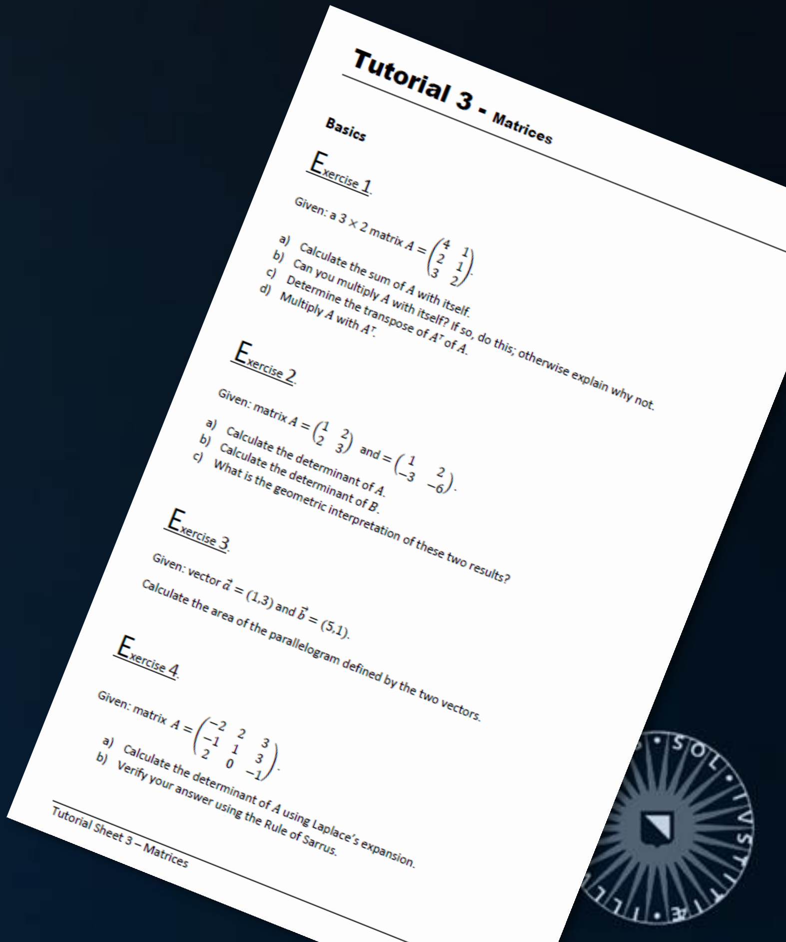
RECAP

Tutorial 3

Make sure you are able to:

- Multiply two matrices;
- Determine the transpose of a matrix;
- Calculate the determinant of a matrix;
- Construct a scaling matrix;
- Transform a normal;
- Construct a matrix with translation;
- Invert a matrix;
- Explain the geometrical interpretation of matrices and matrix determinants.

Not sure? Ask about this in the tutorial session after this lecture!



Tutorial 3 - Matrices

Basics

Exercise 1

Given: a 3×2 matrix $A = \begin{pmatrix} 4 & 1 \\ 2 & 1 \\ 3 & 2 \end{pmatrix}$.

a) Calculate the sum of A with itself.
b) Can you multiply A with itself? If so, do this; otherwise explain why not.
c) Determine the transpose A^T of A.
d) Multiply A with A^T.

Exercise 2

Given: matrix $A = \begin{pmatrix} 1 & 2 \\ 2 & 3 \end{pmatrix}$ and $= \begin{pmatrix} 1 & 2 \\ -3 & -6 \end{pmatrix}$.

a) Calculate the determinant of A.
b) Calculate the determinant of B.
c) What is the geometric interpretation of these two results?

Exercise 3

Given: vector $\vec{a} = (1,3)$ and $\vec{b} = (5,1)$.

Calculate the area of the parallelogram defined by the two vectors.

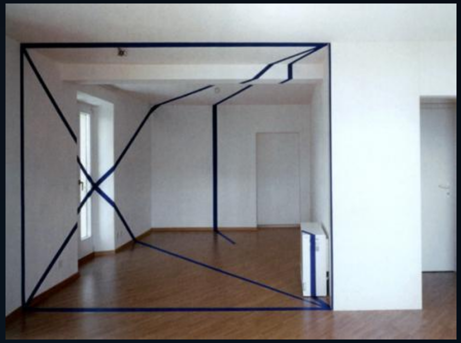
Exercise 4

Given: matrix $A = \begin{pmatrix} -2 & 2 & 3 \\ -1 & 1 & 3 \\ 2 & 0 & -1 \end{pmatrix}$.

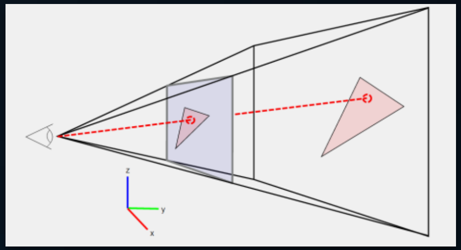
a) Calculate the determinant of A using Laplace's expansion.
b) Verify your answer using the Rule of Sarrus.

Tutorial Sheet 3 – Matrices

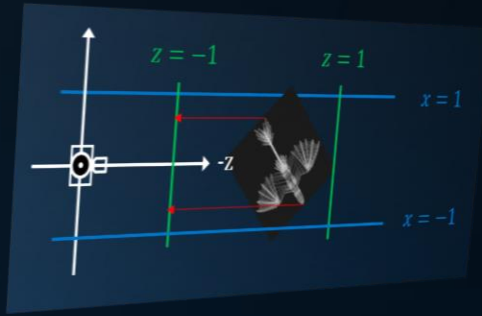
RECAP



Lecture 9: Projection & Rasterization

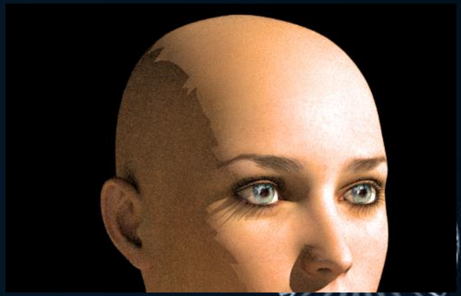


Math:
View frustum, camera space, orthographic view volume, canonical view volume, perspective projection, homogeneous coordinates, homogenization.



Concepts:
Linear perspective, fish eye lens, parallel projection, perspective projection, rasterization, connectivity data, triangle strips, normal interpolation, per-vertex shading, per-pixel shading, light reflection, barycentric coordinates.

Questions?



RECAP

Tutorial 4

Make sure you are able to:

- Construct a ‘look-at’ matrix using E, $\vec{V}$ and $\overrightarrow{up}$;
- Construct the matrix to convert from camera space to orthographic space;
- Construct the matrix to convert from orthographic view to canonical view;
- Explain and apply the concept of storing 3D translations in a 4x4 matrix;
- Transform a 3D vector using a 4×4 matrix (including homogenization).

Not sure? Ask about this in the tutorial session after this lecture!

Tutorial 4 - Perspective

Basics

In the following, we want to look into the steps of the graphics pipeline dealing with perspective projection, i.e. the matrix multiplications that transform our 3D models and vectors into the 2D representations that are shown on the computer screen. Chapter 7 of the book and the slides from the lecture describe the individual steps involved in this process. It will be handy if you have those around while doing the following exercises. Let’s start by taking a closer look into some of the individual steps involved.

Exercise 1

Our 3D models and scenes are usually expressed in world coordinates: that is, with respect to a general coordinate system (usually a Cartesian coordinate system). In these world coordinates, the location and orientation of our camera can be described by the eye position E specifying the camera’s location and the view vector $\vec{V}$ specifying the direction in which our camera is looking. To project the 3D scene towards our camera, it would be much easier if the origin was placed at the position of the eye and the z-axis was pointing in the viewing direction (or negative viewing direction). We can do that by moving from world coordinates to camera coordinates where our 3D models and vectors are expressed with respect to a coordinate system centered at the eye vector, and the axes are aligned with the viewing window and view vector.

Let’s look at a simple example in 2D to understand the difference between “expressed in world coordinates” versus “expressed in camera coordinates”. Assume a 2D world coordinate system with base vectors $\vec{b}_1 = (1,0)$ and $\vec{b}_2 = (0,1)$, and a camera placed at position $E = (2,1)$, looking in direction $\vec{V} = (\frac{1}{2}\sqrt{2}, \frac{1}{2}\sqrt{2})$. Notice that the view vector is already a unit vector, so $\vec{u} = \vec{V}$ and $\vec{v} = (-\frac{1}{2}\sqrt{2}, \frac{1}{2}\sqrt{2})$ gives us a camera coordinate system.

a) Draw an image of this scene including a point $P = (3,1)$ expressed in world coordinates.

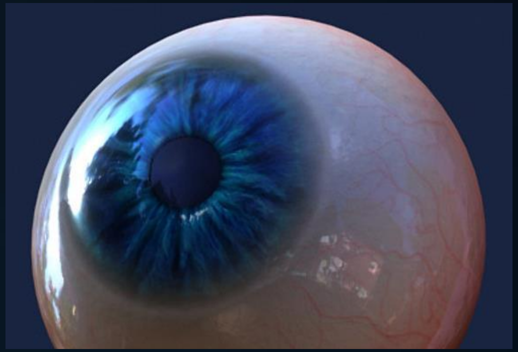
b) If a point P is expressed with respect to a particular coordinate system, e.g. the world coordinates given by $\vec{b}_1, \vec{b}_2$, we often denote this by P_{xy}. Likewise, if this point is expressed in camera coordinates, we denote it P_{uv}.
Write down the general form of a point P_{xy} in world coordinates (i.e., write down P_{xy} as a linear combination of the base vectors $\vec{b}_1$ and $\vec{b}_2$).
Write down the general form of a point P_{uv} in camera coordinates (i.e., write down P_{uv} as a linear combination of the base vectors $\vec{u}$ and $\vec{v}$).
Note: you don’t have to fill in and calculate the actual numbers yet.

c) We can transform between these two coordinate systems using matrix multiplication. The procedure is the same as in the case of rotation around an arbitrary vector that we discussed in the lecture about transformations.

Tutorial Sheet 4 – Perspective

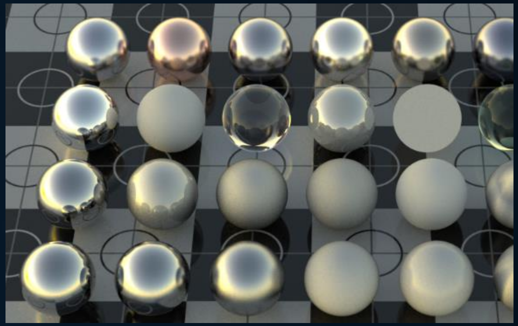
RECAP

Lecture 10: Shading Models



Math:
Clamped cosine, irradiance: integrating over hemisphere, steradians.

Concepts:
Light transport: emitters, surfaces and materials, sensors; IES lights, absorption, scattering, directional lights, irradiance, material properties, optical discontinuities, exitance, radiance, pinhole camera, aperture, shading, BRDF, Phong, ‘ambient’, physically based rendering.



Questions?

RECAP

Lecture 11: Visibility

Concepts:
Painter's, overdraw, BSP traversal (back-to-front, front-to-back), z-buffer, values in the z-buffer, z-fighting, Sutherland-Hodgeman clipping, n-gons, guard bands, back-face culling, frustum culling, hierarchical bounding volume culling, culling using a grid, portals: visibility, mirrors, 'portals'.

Questions?

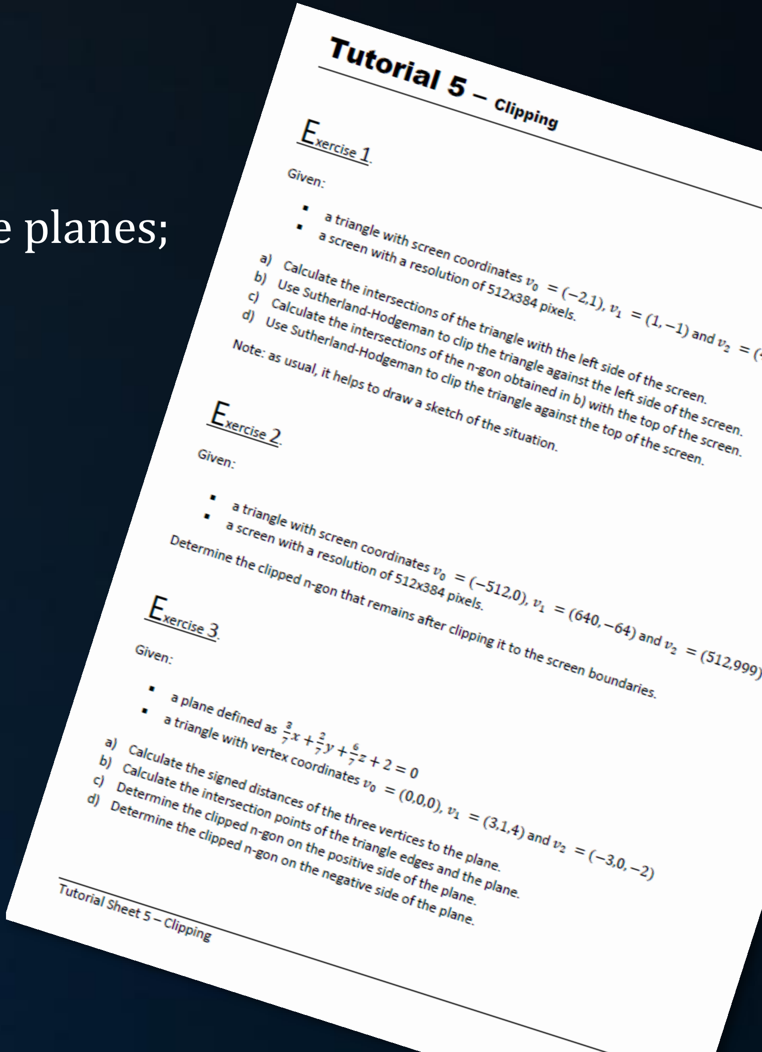
RECAP

Tutorial 5

Make sure you are able to:

- Calculate the intersection between a line segment and a plane;
- Apply Sutherland-Hodgeman for a single plane as well as multiple planes;
- Explain how data is accurately stored in a z-buffer.

Not sure? Ask about this in the tutorial session after this lecture!


Tutorial 5 – Clipping

Exercise 1

Given:

- a triangle with screen coordinates $v_0 = (-2,1)$, $v_1 = (1,-1)$ and $v_2 = ($
- a screen with a resolution of 512x384 pixels.

a) Calculate the intersections of the triangle with the left side of the screen.
b) Use Sutherland-Hodgeman to clip the triangle against the left side of the screen.
c) Calculate the intersections of the n-gon obtained in b) with the top of the screen.
d) Use Sutherland-Hodgeman to clip the triangle against the top of the screen.

Note: as usual, it helps to draw a sketch of the situation.

Exercise 2

Given:

- a triangle with screen coordinates $v_0 = (-512,0)$, $v_1 = (640,-64)$ and $v_2 = (512,999)$
- a screen with a resolution of 512x384 pixels.

Determine the clipped n-gon that remains after clipping it to the screen boundaries.

Exercise 3

Given:

- a plane defined as $\frac{3}{7}x + \frac{2}{7}y + \frac{6}{7}z + 2 = 0$
- a triangle with vertex coordinates $v_0 = (0,0,0)$, $v_1 = (3,1,4)$ and $v_2 = (-3,0,-2)$

a) Calculate the signed distances of the three vertices to the plane.
b) Calculate the intersection points of the triangle edges and the plane.
c) Determine the clipped n-gon on the positive side of the plane.
d) Determine the clipped n-gon on the negative side of the plane.

Tutorial Sheet 5 – Clipping

RECAP

Lecture 12: Post Processing

Concepts:
Post processing, camera / sensor behavior, lens flares, vignetting, chromatic aberration, noise / grain, HDR bloom and glare, tone mapping / exposure control, color correction / grading, gamma, gamma correction, depth of field, circle of confusion, ambient occlusion, screen space AO, bilateral filtering, screen space reflections, limitations of screen space approaches.

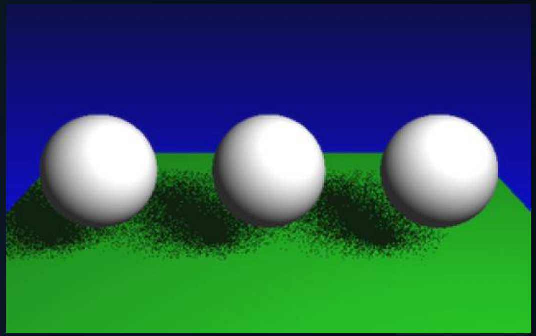
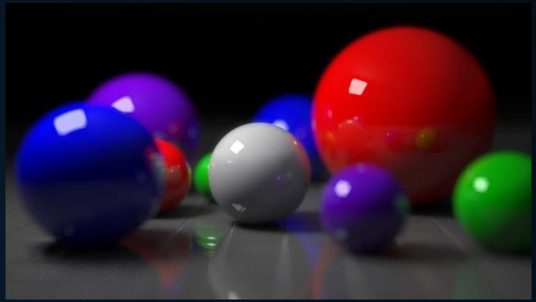
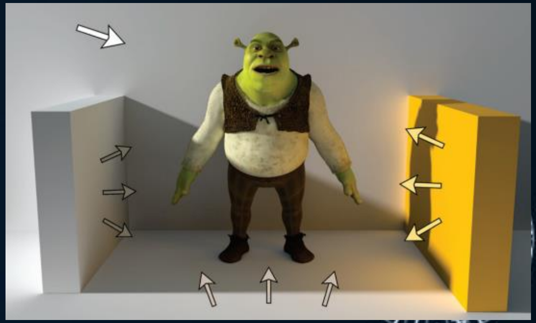
Questions?

RECAP

Lecture 13: Stochastic & Ground Truth

Concepts:
Distributed ray tracing, glossy reflections, soft shadows, umbra, penumbra, area lights, shadow maps, contact shadows, visibility integral, Monte-Carlo, stochastic soft shadows, variance / noise, stochastic reflections, stratification, depth of field, motion blur, dispersion, anti-aliasing, ray tree, indirect light, path tracing.

Questions?

RECAP

RELEVANT QUESTIONS FROM MIDTERM EXAM 2015

Given the following matrix for linear transformations in 3D, with $a, b \neq 0$:

$$A = \begin{pmatrix} 1 & b & c \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

a) What kind of transformation do we get if we apply matrix A to a vector in 3D?

b) Write down matrix A’, which is the inverse of matrix A.

RECAP

RELEVANT QUESTIONS FROM MIDTERM EXAM 2015

Write down a matrix for non-uniform scaling with respect to the point (1,1) by a factor 2 in the x-direction, and a factor 4 in the y-direction in 2D.

Solution: use three matrices; the first one shifts point (1,1) to the origin; the second one applies the specified scale; the third shifts back to (1,1). Since translation is involved, we will use 3x3 matrices and homogeneous coordinates.

So we get: $\begin{pmatrix} 1 & 0 & 1 \\ 0 & 1 & 1 \\ 0 & 0 & 1 \end{pmatrix} \cdot \begin{pmatrix} 2 & 0 & 0 \\ 0 & 4 & 0 \\ 0 & 0 & 1 \end{pmatrix} \cdot \begin{pmatrix} 1 & 0 & -1 \\ 0 & 1 & -1 \\ 0 & 0 & 1 \end{pmatrix}$ (note the ordering!)

Doing some matrix multiplications then yields: $\begin{pmatrix} 2 & 0 & -1 \\ 0 & 4 & -3 \\ 0 & 0 & 1 \end{pmatrix}$.

Verify for point (2,2): $\begin{pmatrix} 2 & 0 & -1 \\ 0 & 4 & -3 \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} 2 \\ 2 \\ 1 \end{pmatrix} = \begin{pmatrix} 3 \\ 5 \\ 1 \end{pmatrix}$, which is correct.

RECAP

RELEVANT QUESTIONS FROM FINAL EXAM 2015

Given: a matrix with the column vectors $x = (\frac{3}{5}, 0, \frac{-4}{5})$, $y = (\frac{7}{25}, \frac{24}{25}, 0)$ and $z = \left(\frac{4}{5}, 0, \frac{3}{5}\right)$. The column vectors are unit vectors, but the matrix is not orthonormal. Make this matrix orthonormal without changing the view direction (i.e., do not change the z-vector).

This question is easy when you realize x and z are perpendicular: 0.6*0.8+(-0.8)*0.6=0. The y-axis must be the problem; without further calculations it can simply be set to **<u>(0,1,0)</u>** as this vector will be perpendicular to x and z.

The correct matrix is thus: $\begin{pmatrix} \frac{3}{5} & 0 & \frac{4}{5} \\ 0 & 1 & 0 \\ \frac{-4}{5} & 0 & \frac{3}{5} \end{pmatrix}$ i.e.: $\begin{pmatrix} 0.6 & 0 & 0.8 \\ 0 & 1 & 0 \\ -0.8 & 0 & 0.6 \end{pmatrix}$.

RECAP

RELEVANT QUESTIONS FROM FINAL EXAM 2015

In the context of texture mapping, ‘oversampling’ refers to:

a) Reading from several textures for a single fragment
b) Reading several pixels from the same texture for a single fragment
c) Writing to several fragments using the same texture pixel
d) None of the above

RECAP

RELEVANT QUESTIONS FROM FINAL EXAM 2015

Mark each correct option. There may be more than one correct option.
When using guard bands, the following polygons are not rasterized:

a) Polygons outside the visible screen area and the guard band
b) Polygons outside the visible screen area, but (partially) inside the guard band
c) Polygons partially inside the visible screen area, and partially in the guard band
d) Polygons completely inside the visible screen area.

RECAP

RELEVANT QUESTIONS FROM FINAL EXAM 2015

Given: an eye position $E = (-2,0,1)$, a view vector $\vec{V} = (2,1,4)$ and an up vector $\overrightarrow{up} = (0,1,0)$. Construct the orthonormal view (‘look-at’) matrix.

In our matrix, z will be the normalized version of $\vec{V}$, and x will be the vector perpendicular to $\vec{V}$ and $\overrightarrow{up}$. Finally, y is the vector perpendicular to x and z. Normalization can be postponed until you have the three vectors, to avoid having to work with unpleasant numbers. This process yields:

$z = \vec{V}$; $x = \overrightarrow{up} \times \vec{V} = (4,0,-2)$; $y = z \times x = (-2,20,-4)$.

Normalizing these vectors: divide x by $\sqrt{20}$, y by $\sqrt{220}$ and z by $\sqrt{21}$.
Construct the final matrix as a 4x4 matrix using x, y and z. The translation is $(x \cdot -E, y \cdot -E, z \cdot -E)$.
This process is described in Tutorial 4 q. 6, and in the book.

Correct answer:

$\begin{pmatrix} 4 & -2 & 2 \\ 0 & 20 & 1 \\ -2 & -4 & 4 \end{pmatrix}$, with x divided by $\sqrt{20}$, y divided by $\sqrt{220}$ and z divided by $\sqrt{21}$.

RECAP


SCHWARZENEGGER
Get ready for the ride of your life.
TOTAL RECAP

What’s Next?

Upcoming Attractions:

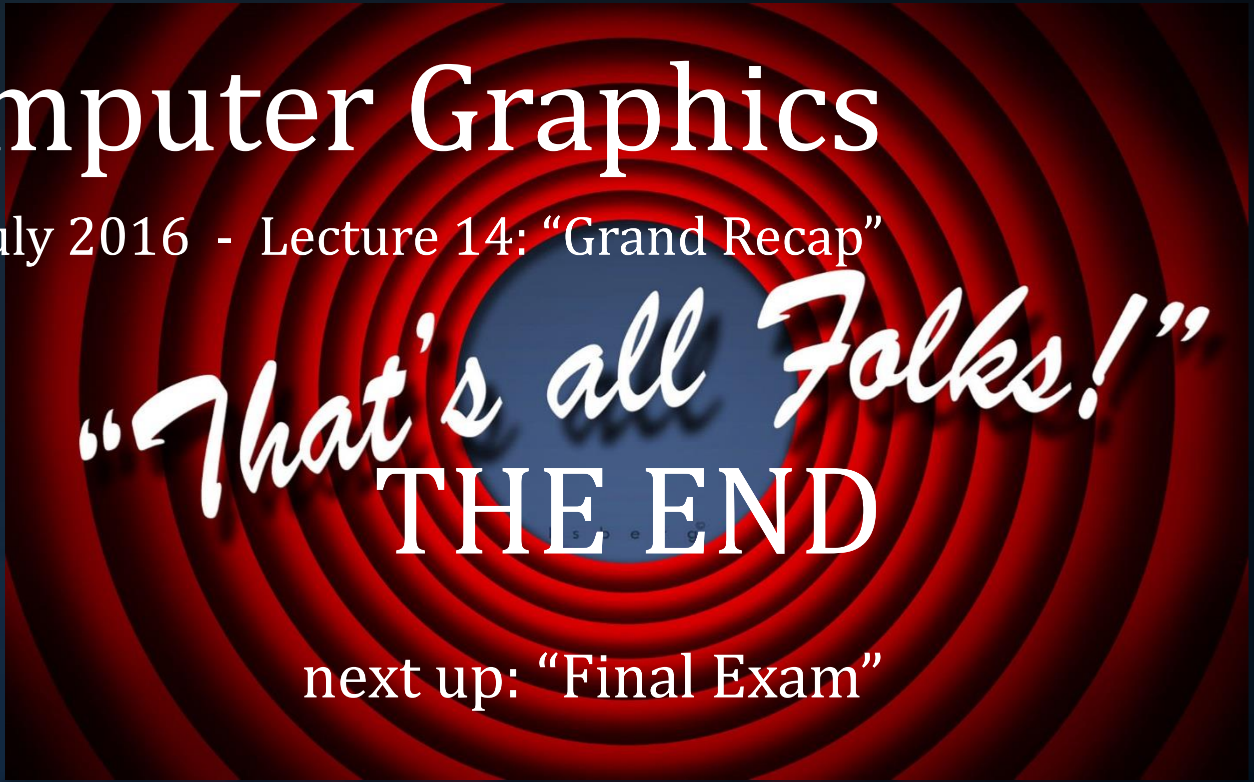
- Two more tutorials: *one right after this lecture.*
- Final Exam: Thursday June 30, 17:00
- P3 deadline: Tuesday June 28, 23:59
- Retake Exam: Thursday July 14, 13:30

Master:

- Optimization & Vectorization
- Advanced Graphics

INFOGR – Computer Graphics

Jacco Bikker - April-July 2016 - Lecture 14: “Grand Recap”



THE END

next up: “Final Exam”

CARACAL

INFOGR