# 2nd Exam Computer Graphics Class

Date: April 3, 2012 Time: 9:00–12:00

**Instructions, read carefully:** Fill in your **name and student number** on each of the answer sheets that you hand in. You have 3 hours to answer the questions. Please answer in English if possible, **write clearly** (parts that are unreadable will not be awarded any points). When in doubt, use a small sketch/illustration to make your point. When deriving an equation, **show all the steps you took** to get to your result **in detail**, otherwise points cannot be awarded.

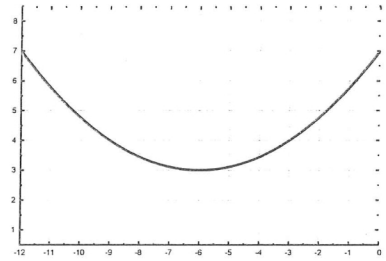
This exam has a total number of **10 questions** on **2 pages**. The total number of points (100%) is 100. As announced, the final grade for the class will be derived from both this final exam and the tutorials.

**Question 1: Bresenham Midpoint Algorithm (20 points)**

One important problem in computer graphics is to scan-convert a curve such as a straight line, a circle, a parabola, or a general function, i. e., to compute the pixels to set on a raster display that are to represent this curve. Given shall be the function of your teacher's currently favorite parabola (also shown on the right)

$$f(x) = \left(\frac{x}{3}+2\right)^2 + 3.$$

Bresenham's midpoint algorithm can be used to scan-convert this function precisely and efficiently. For this purpose, the parabola is first split in half at the symmetry axis ($x = -6$), and each of the sides again into 2 segments which meet where the slope of the curve is equal to 1 or $-1$.




Note: The grid above is NOT a pixel raster; one could, e. g., use 10 pixels per unit to scan-convert the curve.

a) Looking at the positive (i. e., right) half of the curve ($x \geq -6$), between which pixels, relative to the pixel previously set, is the decision made for each iteration step (***use the notation with N, NE, E, SE, S, SW, W, and NW for naming these directions***)? I. e., from a previously set point, in which directions can you possibly go to set the next pixel? Give the answer for each of the above mentioned two segments. (2 points)

b) Derive the decision variable $d$ and the two increments for $d$ that the Bresenham midpoint algorithm uses for the first segment ($0 <$ slope $< 1$) of the positive (right) half of the curve. Show the detailed steps! (14 points)

c) Derive the second order differences for the increments you just derived. I. e., how do the two increments of $d$ change, depending on which decision was made in the previous step? (4 points)

**Question 2: Homogeneous Coordinates (5 points)**

a) What are homogeneous coordinates and why are they necessary? (3 points)

b) Using column vectors, write the computation of a transformed vertex $P'$ from an original vertex $P$ if you want to achieve first a translation $T_1$, then a scaling $S$, then a rotation $R$, and finally another translation $T_2$ (give it in the form $P' = A \cdot B \cdot \ldots \cdot N \cdot P$). (1 point)

c) If you would visualize the regular 2D space in the homogeneous 2D space, what would this look like? (1 point)

**Question 3: Transformation Matrices (10 points)**

a) Give the transformation matrices for 2D translation and non-uniform scaling in homogeneous coordinates. (4 points)

b) Derive the transformation matrix in homogeneous coordinates for a 2D counter-clockwise rotation around the coordinate origin by an angle $\phi$. Use a sketch to support your explanations. (6 points)

You can use $cos(a+b) = cos(a)cos(b) - sin(a)sin(b)$ and $sin(a+b) = sin(a)cos(b) + cos(a)sin(b)$ for answering this question.

**Question 4: z-Buffering (10 points)**

Explain the z-buffer algorithm (what is it used for, what do you start from, what steps are taken, which data elements are affected and how, and what is the result; a brief bulleted list with the important steps/elements is sufficient).

**Question 5: Phong Illumination Model (10 points)**

Rendering a scene requires determining how light gets reflected at a location on the surface of an object.

a) Which three aspects of light reflection does the Phong illumination model capture and which phenomena of real physical reflection do these represent? (6 points)
b) Give the formula of the Phong illumination model. (3 points)
c) How do you achieve smaller but more pronounced highlights, i. e., which parameter in the equation do you have to change and how? (1 point)

**Question 6: Shading Techniques and the GPU (10 points)**

a) What is shading in computer graphics? (2 points)
b) What is Phong shading and how is it realized? (2 points)
c) Which (programmable) parts of the GPU pipeline are needed to implement Phong shading? (2 points)
d) What does the programmer specifically have to do in each of these stages to realize Phong shading? (3 points)
e) What changes when you want to implement Gouraud shading instead? (1 point)

**Question 7: Texture Mapping (5 points)**

Often during rendering, texture mapping is used.

a) Why is texture mapping necessary? (2 points)
b) For what properties other than color is texture mapping typically used? Name 3 techniques and which property they affect. (3 points)

**Question 8: Color and Color Representation (10 points)**

In computer graphics, color is usually specified using three values.

a) What is color? (1 point)
b) Why do we generally use three values to represent color (biologic & physical reasons)? (2 points)
c) Can the combination of three physical colors (such as done in RGB screens) represent all perceivable colors? Why/why not? (5 points)
d) What are metamers? (2 points)

**Question 9: General Clipping Approach (10 points)**

Describe the general process for clipping lines in 2D, i. e., which steps does a line undergo to determine whether it lies in a axis-aligned clipping rectangle to determine its visible parts. You do not need to explain each algorithm in detail, just explain the overall procedure to get from a set of line segments to a set of line segments that are all visible.

**Question 10: Raytracing (10 points)**

a) Describe the general approach of raytracing using very general pseudo-code. (5 points)
b) Which aspects of physical light behavior does raytracing capture particularly well, which does it not capture well? (2 points)
c) What are ways to speed up raytracing? Name at least three ways. (3 points)