The exercises will take place in room G40 in Mühlenpförtstrasse 23. Your y-account is sufficient to login and access all tools. Ctrl+Alt+T gives you a terminal and g++ is your GNU C++ compiler.

Throughout the course you will implement your own minimal raytracer. In each exercise you will extend your raytracer a little further. To make the task easier, you are provided with a basic raytracing framework so that you just have to fill in the missing core parts. You may use your own computer to solve the exercises.

Each week you must complete the assignments and hand in your commented source code for the practical tasks, as well as your solutions to the theoretical tasks (with drawings/formulas). Please use different colors in your drawings and also make sure that formulas are recognizable in your source code. Your group must present the completed assignments on each Friday, 9:45.

To keep presentation time short, keep (a copy of) the original scene to generate the result shown below.

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### 2.1 Ray-Surface Intersection Part II (5 Points)

Some of you have already noticed the mistake in the last exercise: It was not required to implement Box::intersect, even though the scene contained a box object. Implement Box::intersect in primitive/box.cpp using what you have learned in the lecture (if you have already done so, this task should be very easy).

### 2.2 Primitive Normals (10 Points)

The normal vector, often simply called the “normal” to a surface is a vector which is perpendicular to the surface at a given point. Implement the missing part in primitive/infiniteplane.cpp, primitive/sphere.cpp, primitive/box.cpp and primitive/triangle.cpp. You will need this for all of the following shaders.

### 2.3 Refraction (25 Points)

Derive the new direction $\vec{t}$ of a ray $\vec{r}$ that hits the surface with normal $\vec{n}$ between the two media with index $\eta_1$ and $\eta_2$ according to Snells Law. The angles $\theta$ and $\phi$ have to be calculated. Take the total internal reflection into account. When does it occur?

Derive the formula and use this to implement RefractionShader::shade in shader/refractionshader.cpp. Write your derived formula as a comment in the source code. A shader can send out a secondary ray using: this->parentScene()->traceRay(ray);
2.4 Mirror Shader (20 Points)

Given a ray \( r(t) = \vec{o} + t \cdot \vec{d} \) which hits a reflective surface at \( t = t_{hit} \), the surface has the normal \( \vec{n} \) at the hit point. Derive the formula for the reflection ray and use this to implement `MirrorShader::shade` in `shader/mirrorshader.cpp`. Write your derived formula as a comment in the source code.

2.5 Shadow Ray and Point Lights (40 Points)

If a ray hits an object, we want to know if that point on the object is in a shadow. A secondary ray, called a “shadow ray”, is sent from the object to each light source. If this shadow ray intersects another object before it hits the light source, then the point is in the shadow.

Have a look at `SimpleShadowShader::shade(Ray * ray)` in `shader/simpleshadowshader.cpp` and `PointLight::illuminate(Ray *ray)` in `light/pointlight.cpp`. Implement the missing parts. A point light in our implementation should be a light source, which radiates light in all directions with quadratic intensity falloff. In other words, let \( d_p \) be the distance of an unoccluded point \( p \) to the point light, \( i \) the intensity of the point light and \( c \) the color of the point light, then the intensity (or “color”) \( c_p \) reaching \( p \) is \( c_p = \frac{i}{d_p^2} c. \)
2.6 Useful Stuff

Have a look at the following links. They may help you solving the single Tasks.

- CMake https://cmake.org/
- Realistic Ray Tracing, Peter Shirley.