Hierarchical Transformation

EDAF80: Computer Graphics

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AGENDA

1. Hierarchical Transformation and Scene Graphs
2. C++/OpenGL Framework
3. Visual Studio
4. Assignment 1

Hierarchical Transformation and Scene Graphs

FROM LECTURE

$$T = \begin{bmatrix} 1 & 0 & 0 & t_x \\ 0 & 1 & 0 & t_y \\ 0 & 0 & 1 & t_z \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$R_x(\theta) = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & \cos\theta & -\sin\theta & 0 \\ 0 & \sin\theta & \cos\theta & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$S = \begin{bmatrix} s_x & 0 & 0 & 0 \\ 0 & s_y & 0 & 0 \\ 0 & 0 & s_z & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

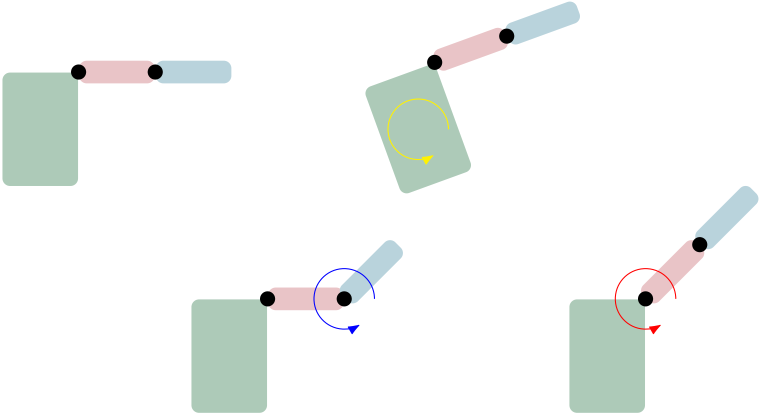
Seminar Exercise 1-1: Vertex Transformations

1. Move the triangle to the bottom left corner using the M matrix.
2. Move the triangle again, this time to the top right corner.
3. Center the triangle and scale it to fill the viewport.
4. Remove the M matrix from the transformation and replace it with the rotation matrix R_z.
5. Rotate the triangle 90 degrees clockwise.
6. Animate the triangle by letting the angle a depend on the uniform variable $time$.

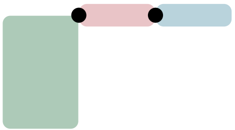
FOLLOW-UP QUESTIONS

1. What value of ***a*** rotates the triangle 90 degrees counter-clockwise?
2. Try animating something else with ***time***!
   - Cap ***time*** to $[0, 1]$ by using some trigonometric functions: `sin()`, `cos()`

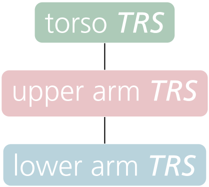
RIGID BODY



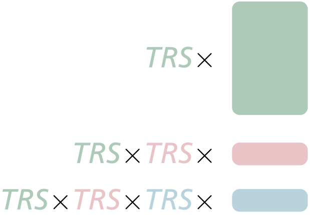
RIGID BODY



Geometry

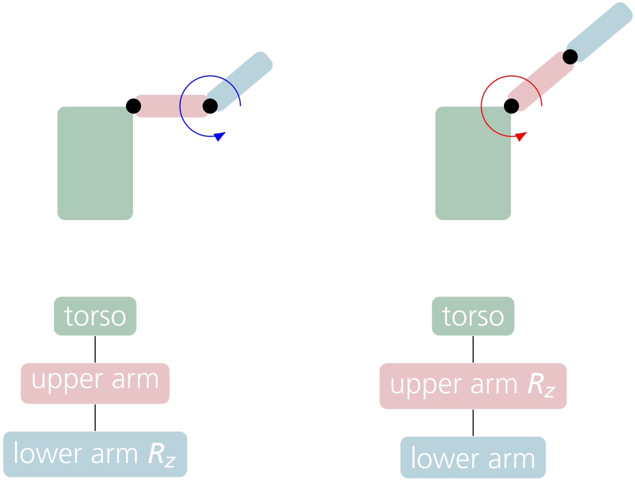


Scene graph representation

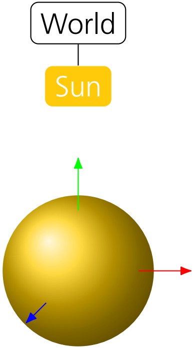


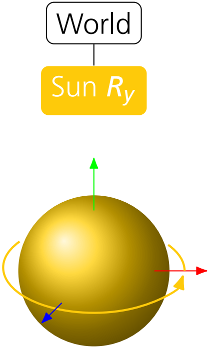
Transformations applied during rendering

RIGID BODY

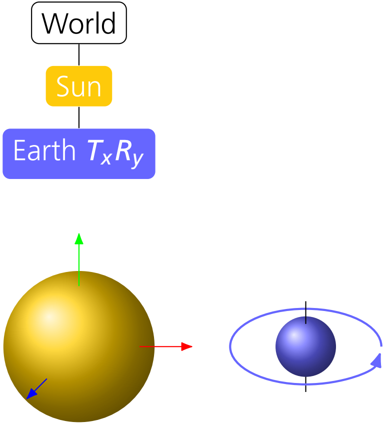


SPIN

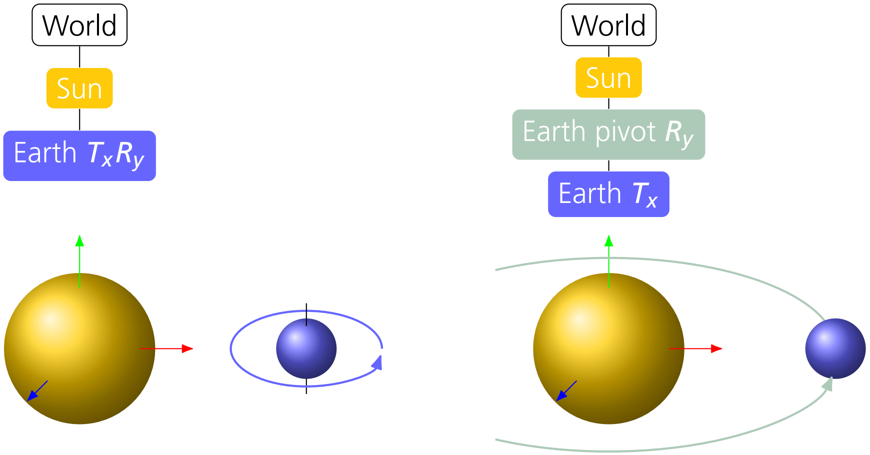




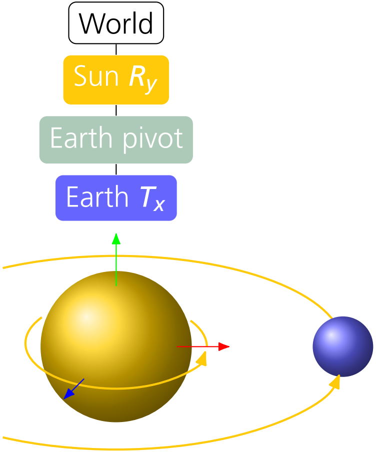
SPIN

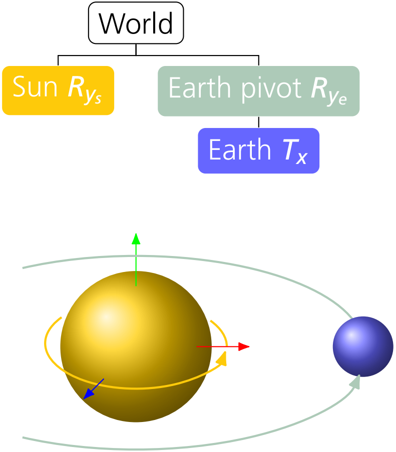


ORBIT

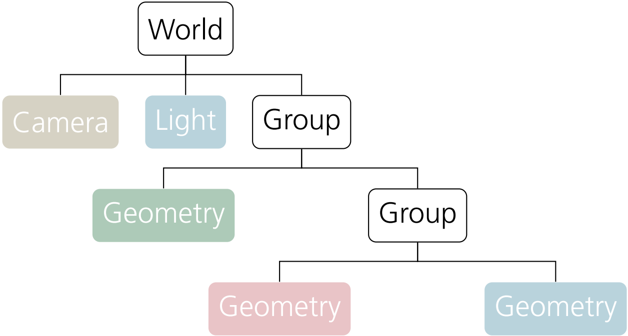


UNCOUPLING SPIN AND ORBIT





SCENE GRAPHS



Seminar Exercise 1-2: Hierachiacal Transformations

The vertices in this program define a cube with different colors on each side. Currently, the vertices are transformed only by the view and projection matrices.

1. Get the cube to spin by replacing the unit matrix in $\boldsymbol{M}$ with the rotation matrix $\boldsymbol{R_s}$.
2. Now, add the translation $\boldsymbol{T_o}$, so that the cube is spinning offset from the center. The cube should not orbit!
3. The last rotation, $\boldsymbol{R_o}$, will make the cube orbit as well. Add it to the correct position in the chain of transformations.

FOLLOW-UP QUESTIONS

1. What was the correct order of transformations?
2. We have seen how to use uniforms variables to move vertices around. How would you move the camera?

C++/OpenGL Framework

C++/OPENGL FRAMEWORK: LIBRARIES

- C++/OpenGL framework: **Bonobo**
- User interface: **GLFW**, **imgui**
  - Window, GL context, mouse, key, log window, GUI
  - Using OpenGL 4.1
- Resource loading
  - Model/geometry loading: **assimp**
  - Image/texture loading: **stb**
- Vector algebra library: **GLM**
  - Based on OpenGL Shading Language (GLSL) specification
- Don't need to look at this code, just use them as tools

C++/OPENGL FRAMEWORK: FUNCTIONS

- Mesh structure (`bonobo::mesh_data`)
- Node class
  - Child pointers to build a simple scene graph
  - `render(proj, trans)`
    - Member function to draw node
    - Takes two matrices: projection and transformation
- OpenGL texture setup function (`loadTexture2D()`)
- Shader setup: loading, compiling, linking (`createProgram()`)
- `while` loop to render scene graph
  - Add per frame node operations here (for example: `sun.rotate_y(0.01f)`)
  - Pushes `root_node` onto stack, then process all child nodes

CREATING A NODE

- `sphere` and `shader` are set up and can be used as is

```
Node sun = Node();
sun.set_geometry(sphere);
sun.set_program(shader);

GLuint sun_texture = loadTexture2D("sunmap.png");
sun.add_texture("diffuse_texture", sun_texture, GL_TEXTURE_2D);
```

ADDING MORE NODES

- Add more nodes and start building the scene graph

```
Node world = Node();

world.add_child(&sun);
...
sun.add_child(/* Add planets */);
```

MOVING NODES

- Use translation, rotation and scaling functions
- Use a time variable to animate

```
/* Absolute transformations */
sun.get_transform().SetScale(2.0f);
earth.get_transform().SetTranslate(glm::vec3(3.0f, 0.0f, 0.0f));
earth.get_transform().SetTranslate(glm::vec3(time, 0.0f, 0.0f));

/* Relative transformations */
earth.get_transform().Scale(0.9f);
sun.get_transform().RotateY(0.7f);

/* Useful rotation transformations */
earth.get_transform().LookTowards(...); /* Look in a given direction */
earth.get_transform().LookAt(...);      /* Look at a fixed point */
```

INTERACTION

- FPS camera
  - Keyboard: "WASD" to move camera forward/left/backward/right
  - Keyboard: "QE" to move up/down
  - `shift` and `ctrl` to modify speed of movement
  - Mouse: Click and drag left mouse button

- User interface (imgui) with mouse

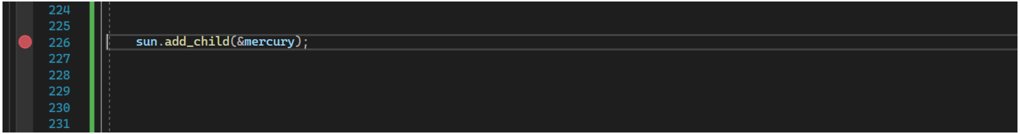
Visual Studio

VISUAL STUDIO DEBUGGING

- Breakpoints
- DataTips
- printf

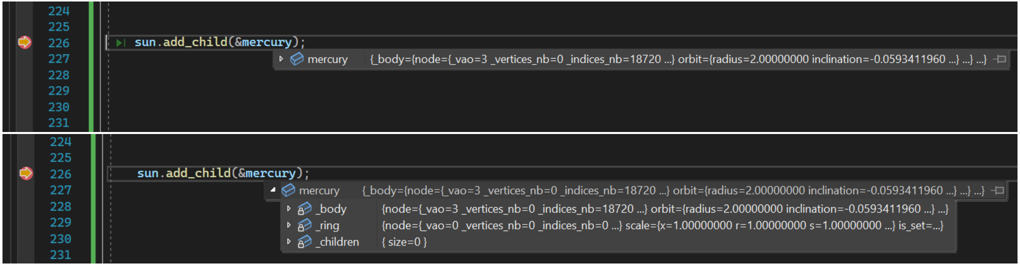
BREAKPOINTS

- A breakpoint pauses execution
- Allows for inspection of variables, stepping of lines
- Toggle breakpoint on currently line with **F9**, or click the area to the left of the line
- Right-click a breakpoint to add conditions
- Once breakpoint is hit, step (**F10**), step into (**F11**) or continue (**F5**) execution



DATATIPS

- Inspect/edit variables by hovering above them with mouse pointer
- Click to expand
- Right-click and select “Watch” to pin variable to the Watch-window



printf

- Brute force debugging
- Print whatever you need to monitor to the standard output (console window)

```
printf("Monitored value: %f\n", var);
```

- Or use `std::cout`

```
std::cout << "Monitored value: " << var << "\n";
```

- Can format the output
- Can monitor output continuously as the program executes
- Messy code ☹

Assignment 1

ASSIGNMENT 1

- **Model the solar system!**
  - Sun, planets, moons, comets, ...spaceships? It's up to you
  - Resources included in the Bonobo framework are at your disposal
  - Models, textures, shaders
  - Code for how to add shaders is included (more in assignment 3–4)
- See assignment description for details
  - Available on the course webpage
  - Source code in assignment description
- Files you have to modify
  - `src/EDAF80/assignment1.cpp`
  - `src/EDAF80/CelestialBody.cpp`

CELESTIAL BODY

```
class CelestialBody
{
public:
    CelestialBody(...);
    glm::mat4 render(...);
    void add_child(CelestialBody* child);
    ...

private:
    struct {
        Node node;
        struct { /* radius, inclination, speed, rotation_angle */ } orbit;
        struct { /* axial_tilt, speed, rotation_angle */ } spin;
    } _body;

    struct { Node node; ... } _ring;
};
```

RENDER

```
glm::mat4 CelestialBody::render(
    glm::mat4 const& view_projection,
    glm::mat4 const& parent_transform,
    ...)
{
    ...

    glm::mat4 world = parent_transform;

    /* Edit world matrix here */
    glm::mat4 scale = glm::scale(glm::mat4(1.0f), glm::vec3(0.5f));
    world = world * scale;

    /* Supply full transformation matrix! */
    _body.node.render(view_projection, world);

    return parent_transform;
}
```

DEMO

NEXT

- Download the code and get started
- Post questions on the discussion forum
- Use the reference implementation to compare your results