TDA361 - Computer Graphics sp 2 2012

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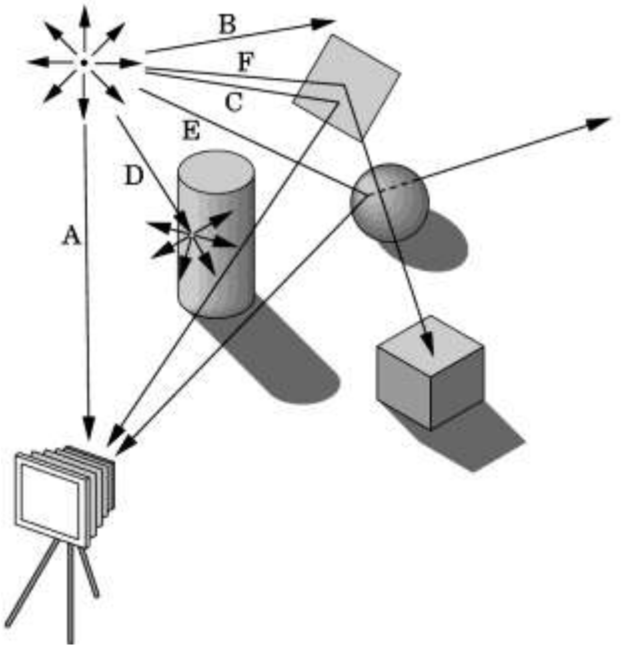
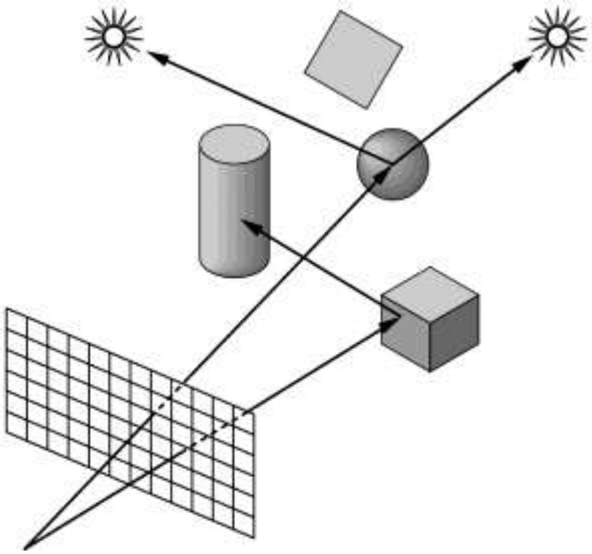
Tracing Photons



One way to form an image is to follow rays of light from a point source finding which rays enter the lens of the camera. However, each ray of light may have multiple interactions with objects before being absorbed or going to infinity.

Other Physical Approaches

- **Ray tracing**: follow rays of light from center of projection until they either are absorbed by objects or go off to infinity
  - Can handle global effects
    - Multiple reflections
    - Translucent objects
  - Faster but still slow



I’m here to help…

1. I am located in room 4115 in ”EDIT-huset”
2. Email: uffe at chalmers dot se
3. Phone: 031-772 1775 (office)
4. Course assistant:
    1. erik dot sintorn at chalmers dot se
    2. kampe at chalmers dot se (Viktor Kampe)
    3. karsch at student dot chalmers dot se (Karl Schmidt)
    4. jamot at student dot chalmers dot se (Per Jamot Johansson)

Studentrepresentanternas ansvar

- Informerar sig om sina kurskamraters synpunkter på kursen.
- Vidarebefordrar dessa samt deltar i övrigt i diskussionen vid mötena med egna synpunkter.
- Kan föreslå kursspecifika frågor i kursenkäten.
- Informerar sina kurskamrater om diskussioner och rekommendationer från mötena.

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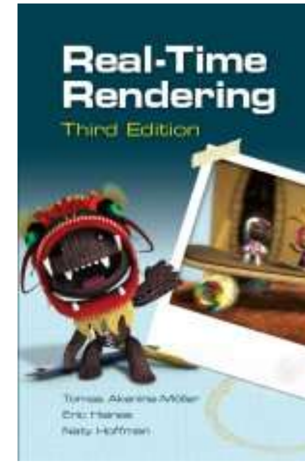
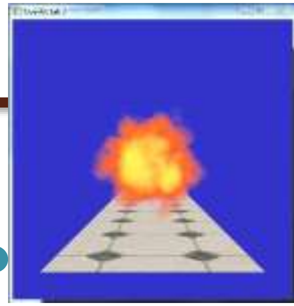
Course Info

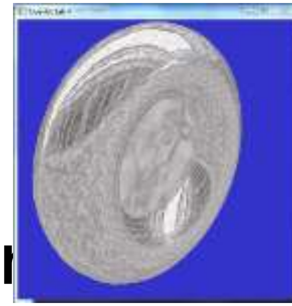
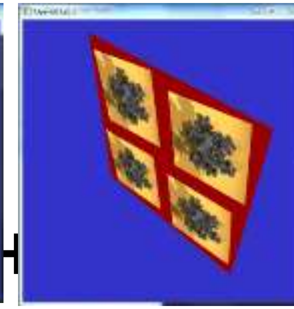
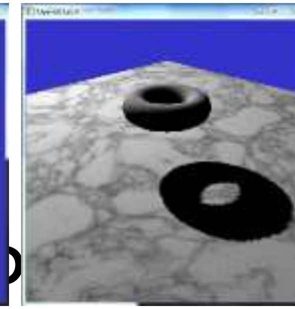
- Study Period 2 (lp2)
- Real Time Rendering, 3rd edition
  - Available on Cremona
- Schedule:
  - Wed 08-10 HC3+ Fri 9-12 HB4
    - 14 lectures in total, ~2 / week
  - Labs: 17-21 everyday,
13-17 Thursday and Friday
- Homepage:
  - Google "TDA361" or
  - "Computer Graphics Chalmers"



Tutorials

- Rooms 4211,4213,4215
  - Or your favorite place/home
- 4th floor EDIT-building
- EntranceCards (inpasseringskort)
  - Automatically activated for all of you that are course registered and have a CTH/GU-entrance card (inpasseringskort)
- Recommended to do the tutorials in groups (Labgrupper) of 2 and 2

3D World Tutorial - SOLUTION

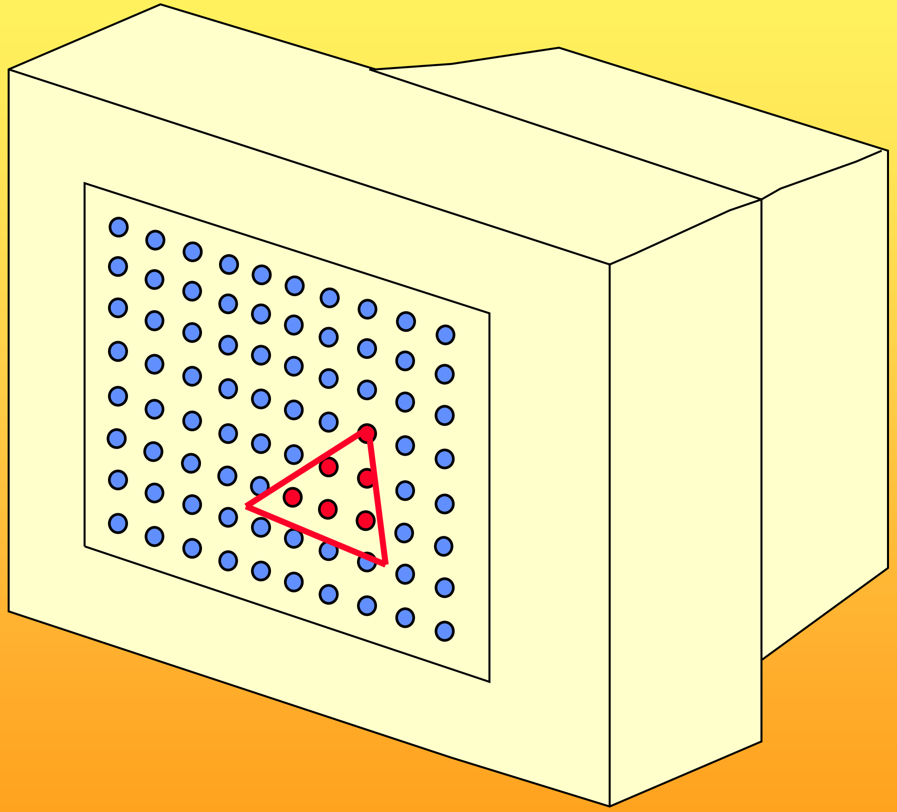
Overview of the Graphics Rendering Pipeline and OpenGL

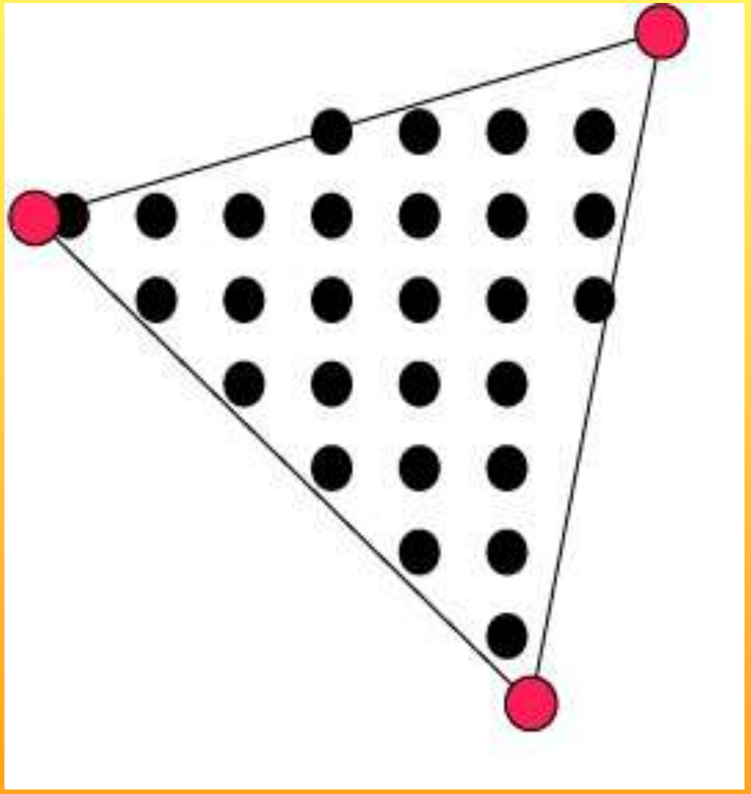
CHALMERS

3D Graphics

Ulf Assarsson

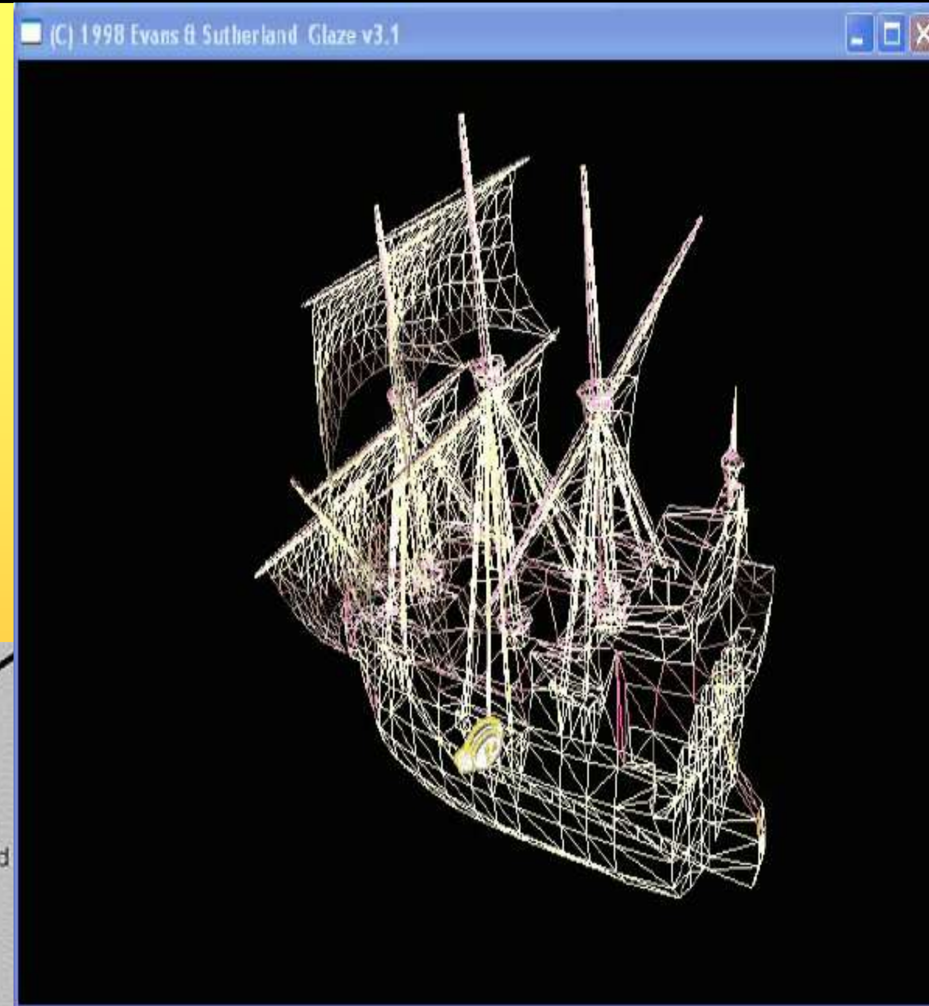
The screen consists of many pixels

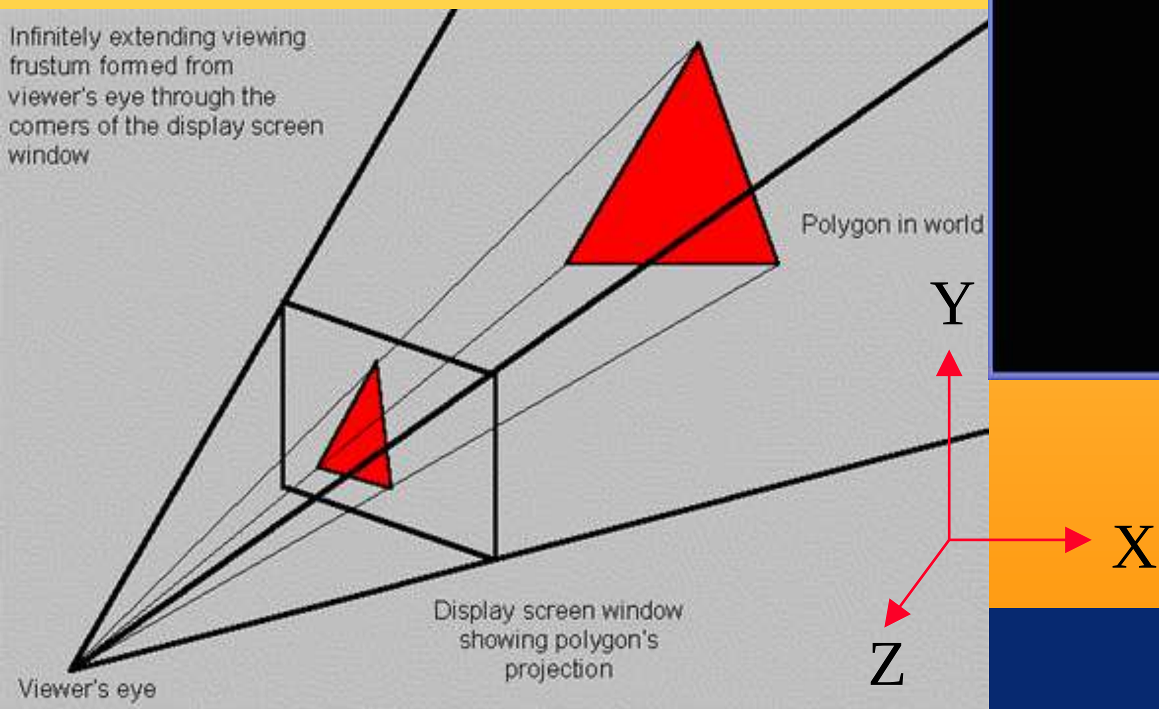




3D-Rendering

- Objects are often made of triangles
- x,y,z- coordinate for each vertex

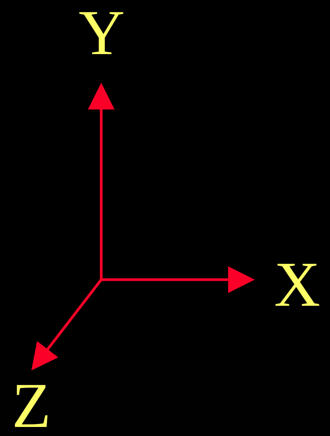




4D Matrix Multiplication

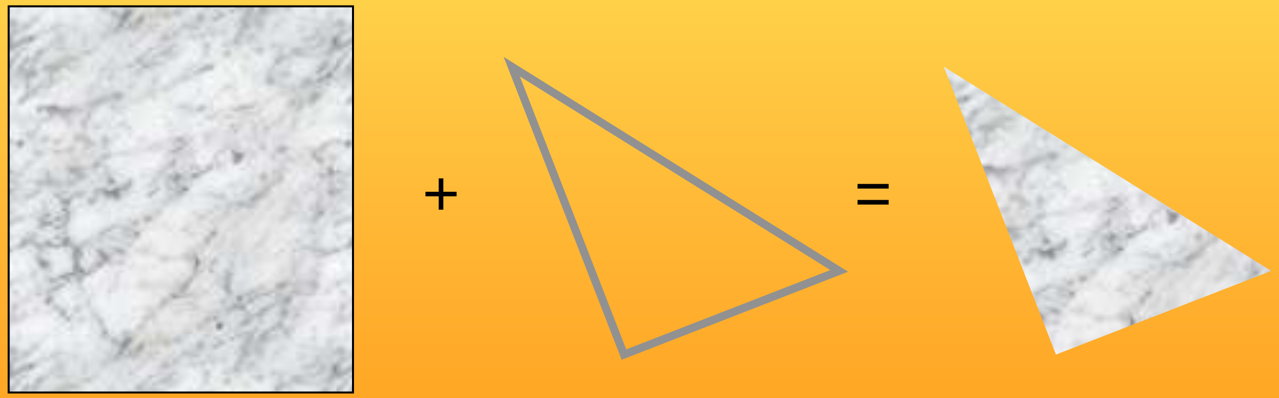
$$\begin{bmatrix} s_x & \bullet & \bullet & t_x \\ \bullet & s_y & \bullet & t_y \\ \bullet & \bullet & s_z & t_z \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x \\ y \\ z \\ w \end{bmatrix}$$

Real-Time Rendering


Y
X
Z

Textures

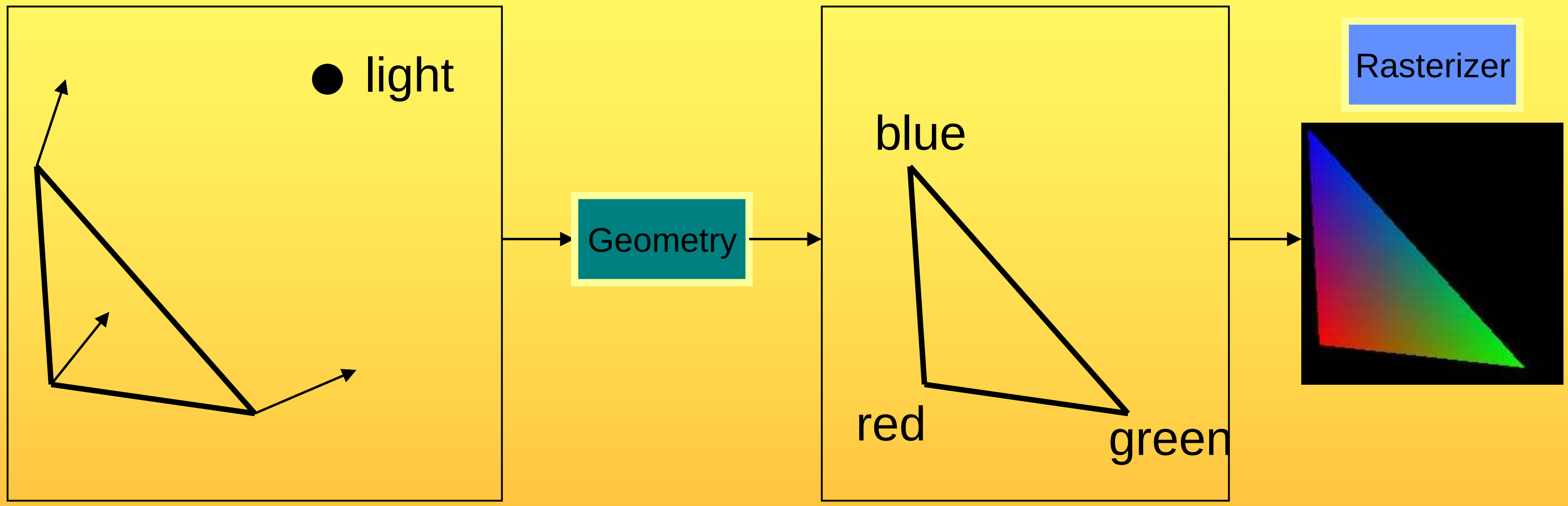
- One application of texturing is to ”glue” images onto geometrical object

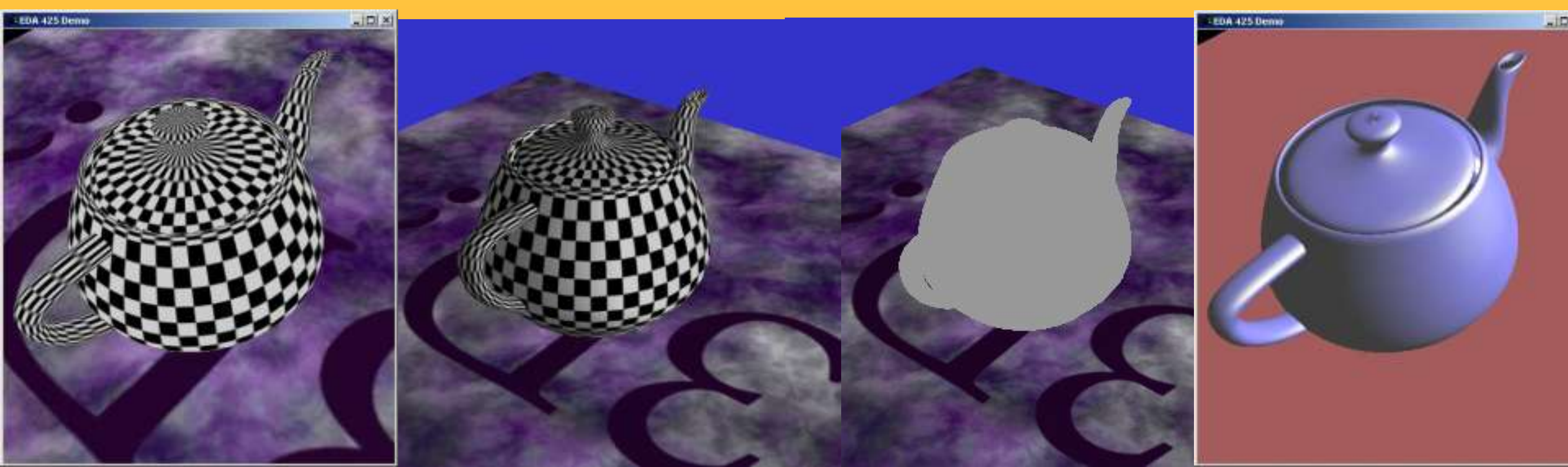


Texturing: Glue images onto geometrical objects

- Purpose: more realism, and this is a cheap way to do it

Lighting computation per triangle vertex

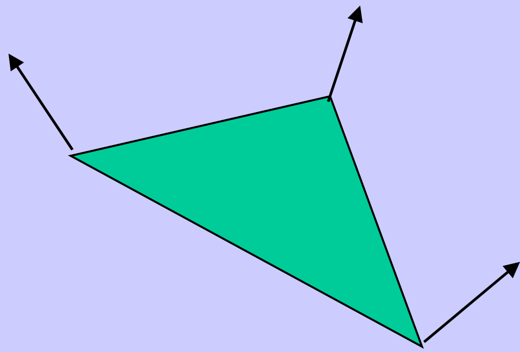




The Graphics Rendering Pipeline

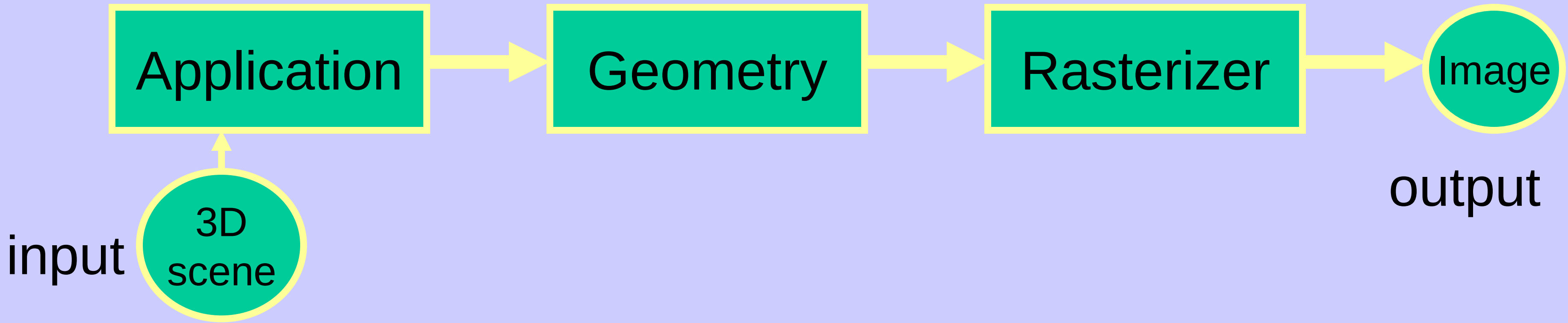
You say that you render a *"3D scene"*, but what is it?

- First, of all to take a picture, it takes a camera – a virtual one.
  - Decides what should end up in the final image
- A 3D scene is:
  - Geometry (triangles, lines, points, and more)
  - Light sources
  - Material properties of geometry
    - Colors, shader code ,
    - Textures (images to glue onto the geometry)
- A triangle consists of 3 vertices
  - A vertex is 3D position, and may include normals.



Lecture 1: Real-time Rendering
The Graphics Rendering Pipeline

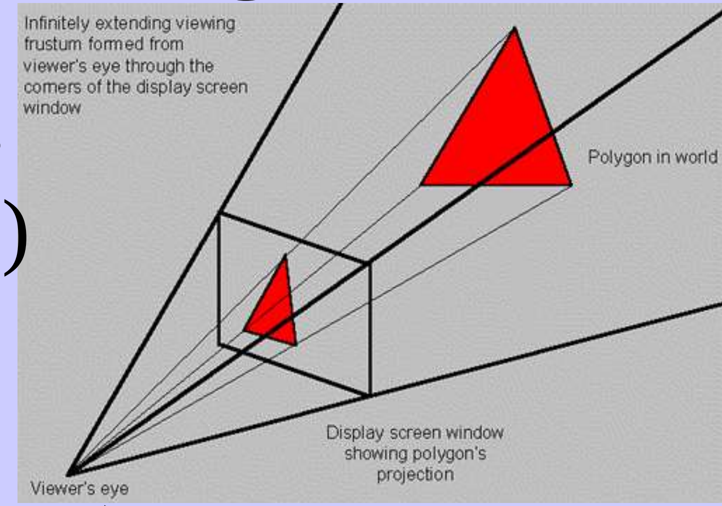
- The pipeline is the ”engine” that creates images from 3D scenes
- Three conceptual stages of the pipeline:
  - Application (executed on the CPU)
  - Geometry
  - Rasterizer



The APPLICATION stage

- Executed on the CPU
  - Means that the programmer decides what happens here
- Examples:
  - Collision detection
  - Speed-up techniques
  - Animation
- Most important task: feed geometry stage with the primitives (e.g. triangles) to render

The GEOMETRY stage



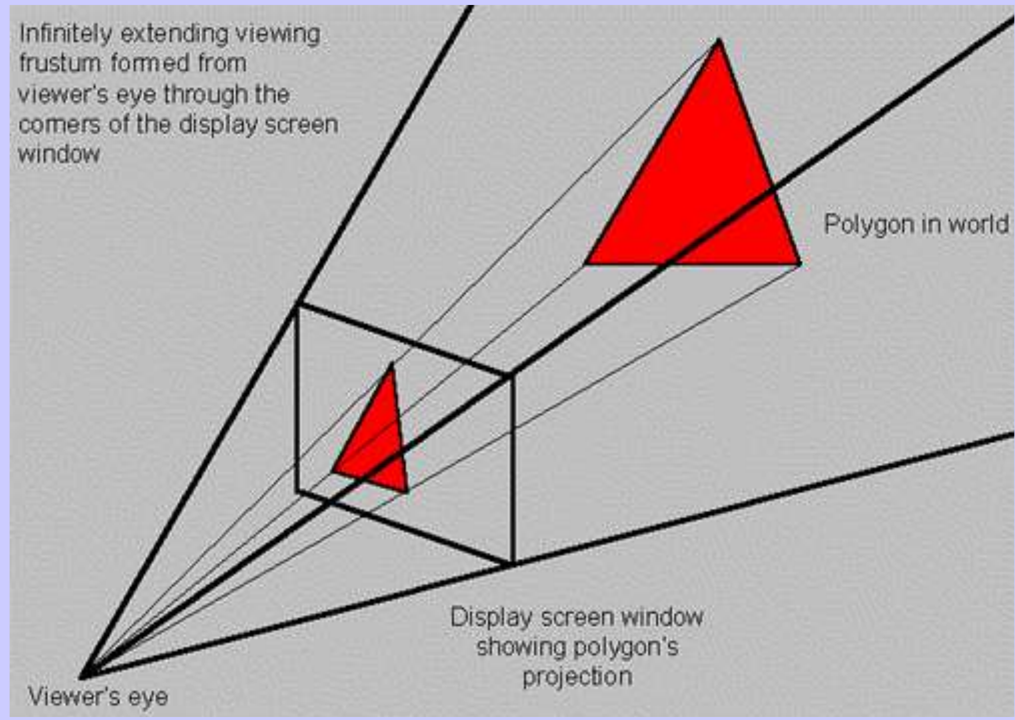
- Task: ”geometrical” operations on the input data (e.g. triangles)

- Allows:
  - Move objects (matrix multiplication)
  - Move the camera (matrix multiplication)
  - Lighting computations per triangle vertex
  - Project onto screen (3D to 2D)
  - Clipping (avoid triangles outside screen)
  - Map to window

The GEOMETRY stage

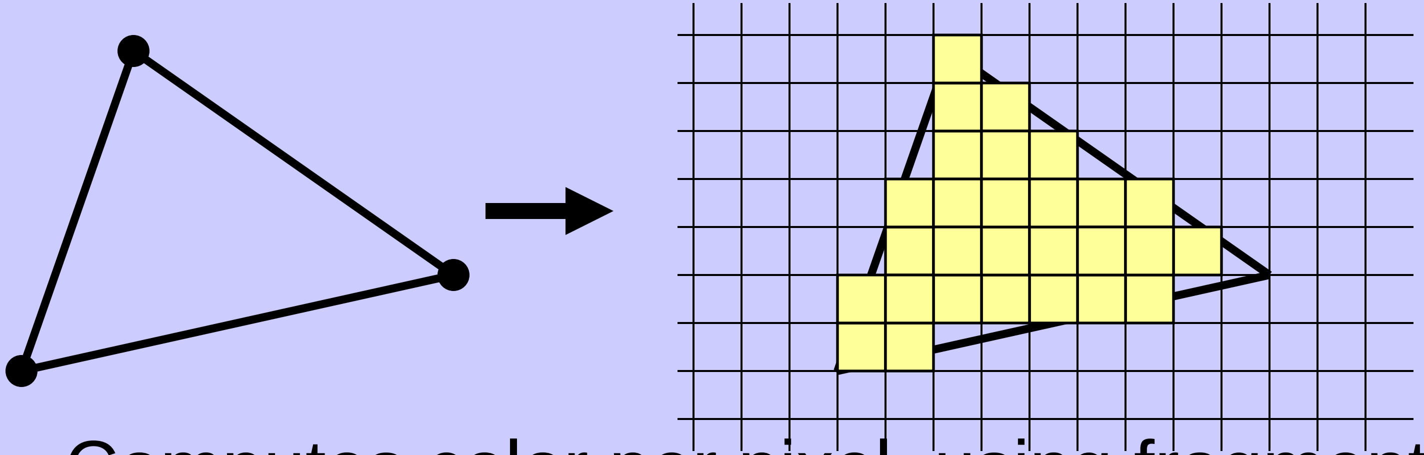
Model & View Transform → Vertex Shading → Projection → Clipping → Screen Mapping

- (Instances)
- Vertex Shader
  - – A program executed per vertex
    - Transformations
    - Projection
    - E.g., color per vertex
- Clipping
- Screen Mapping



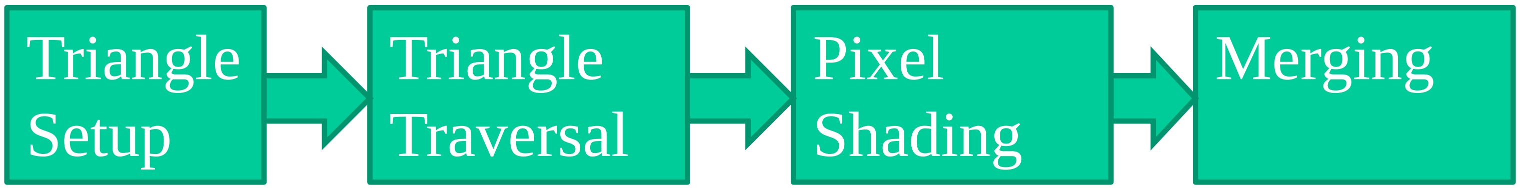
The RASTERIZER stage

- Main task: take output from GEOMETRY and turn into visible pixels on screen



- Computes color per pixel, using fragment shader (=pixel shader)
  - textures, (light sources, normal), colors and various other per-pixel operations
- And visibility is resolved here: sorts the primitives in the z-direction

The rasterizer stage



Triangle Setup:

- collect three vertices + vertex shader output (incl. normals) and make one triangle.

Triangle Traversal

- Scan conversion

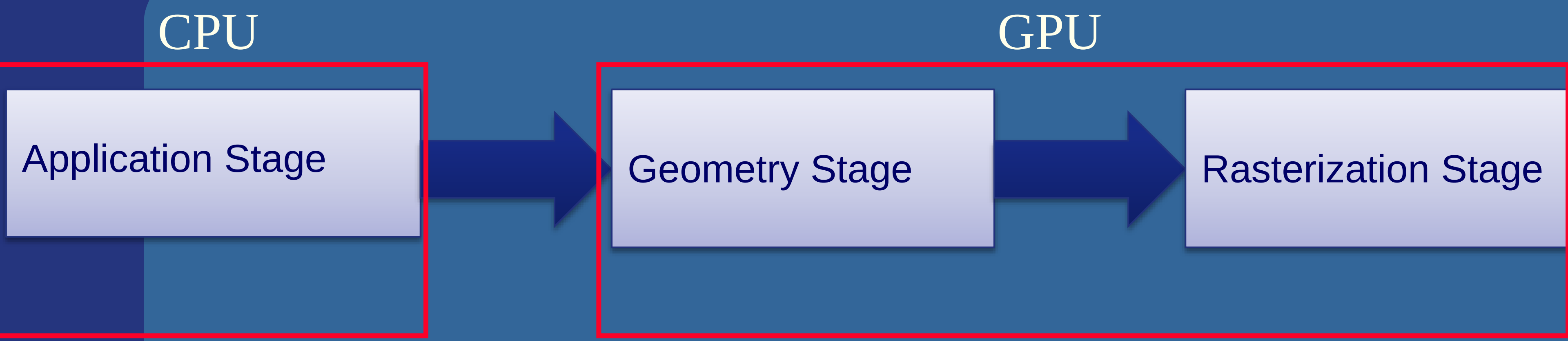
Pixel Shading

- Compute pixel color

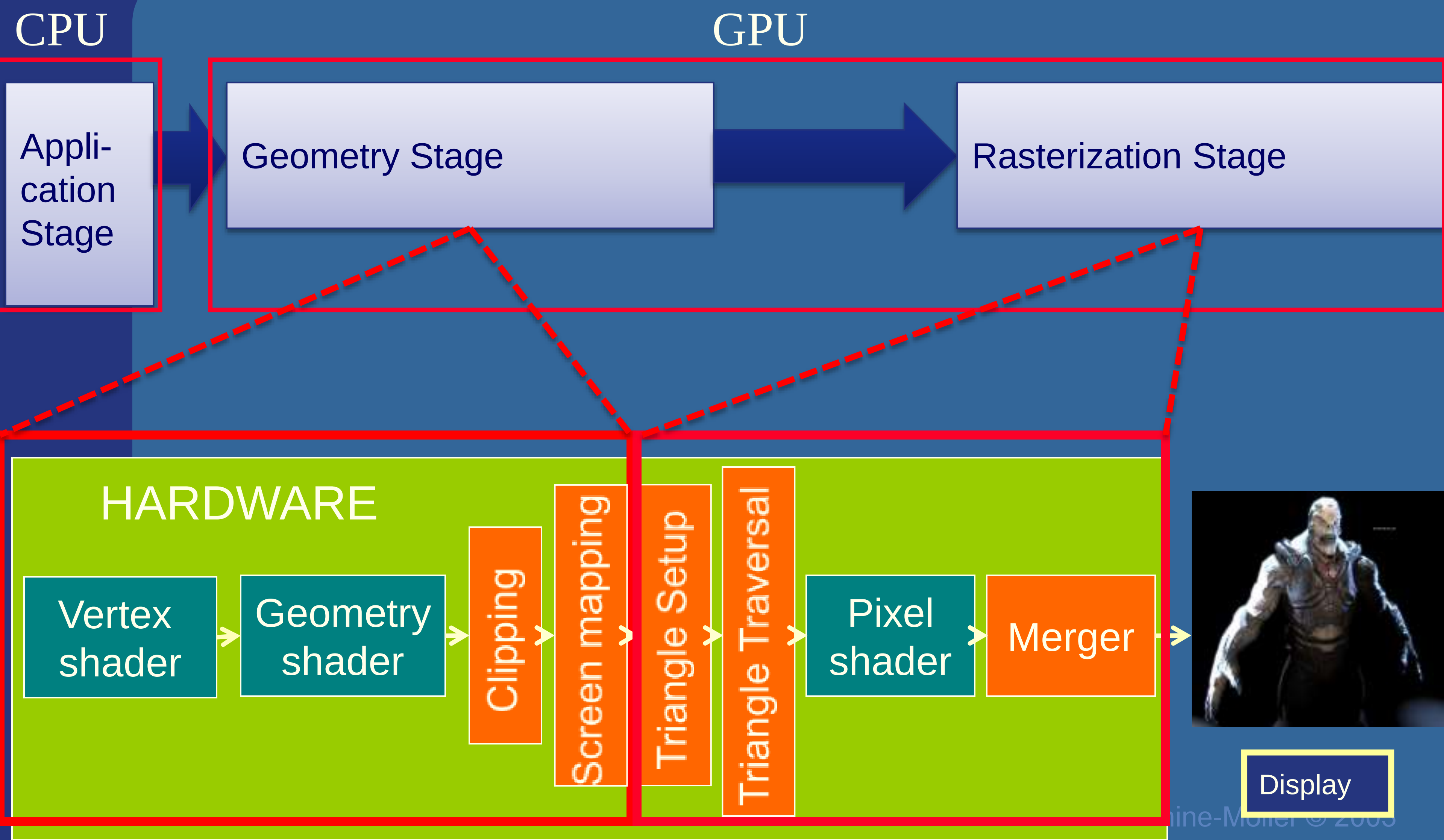
Merging:

- output color to screen

Rendering Pipeline and Hardware



Rendering Pipeline and Hardware

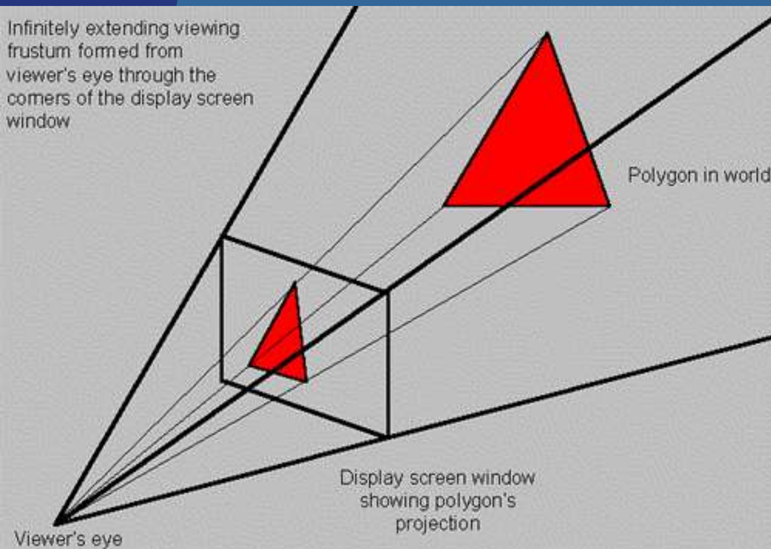


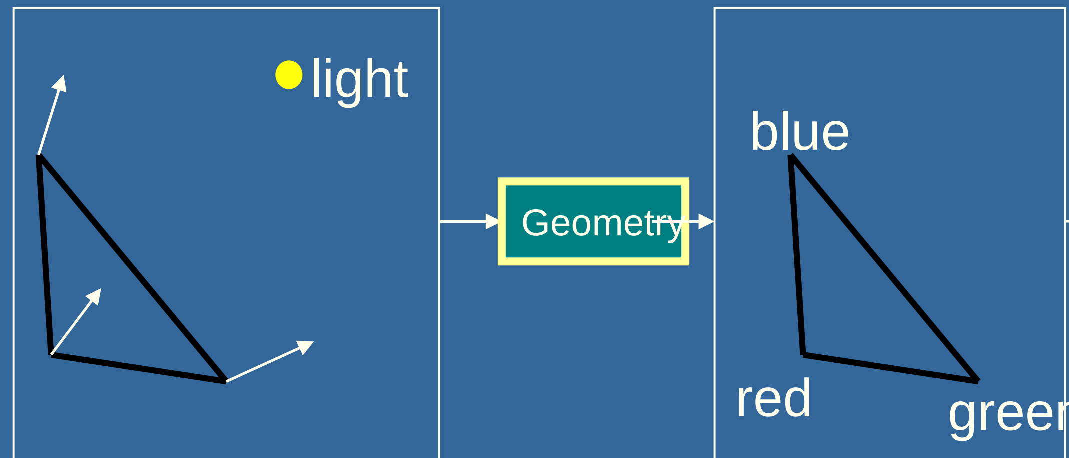
Hardware design

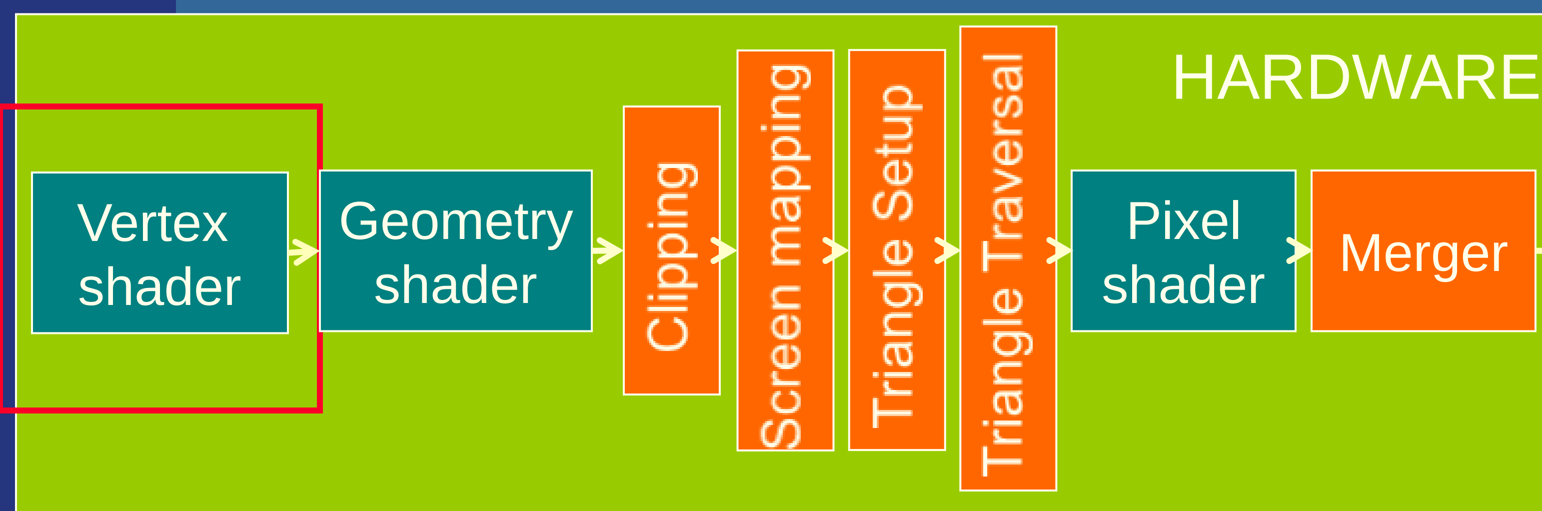
Geometry Stage

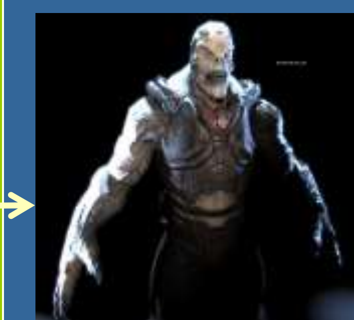
Vertex shader:

- Lighting (colors)
- Screen space positions









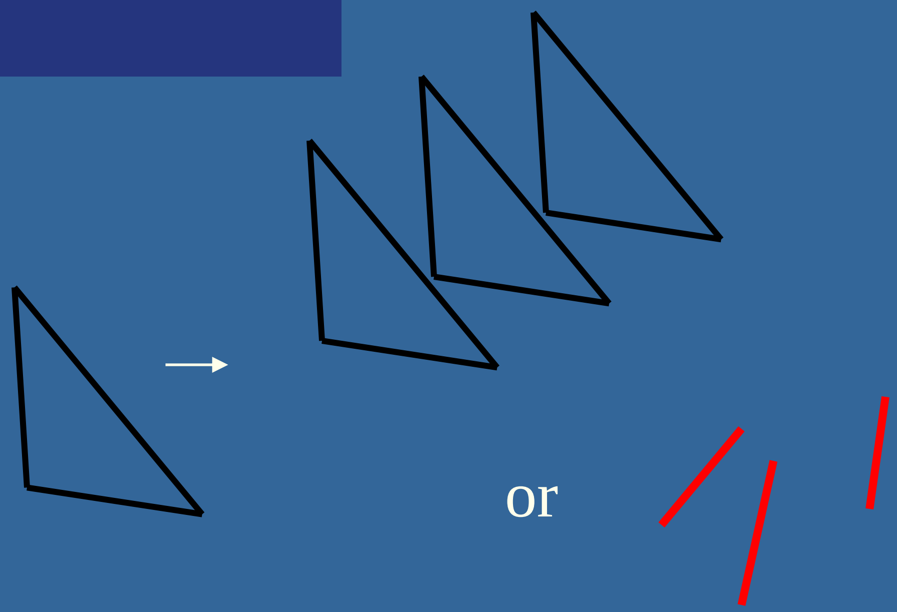
Display

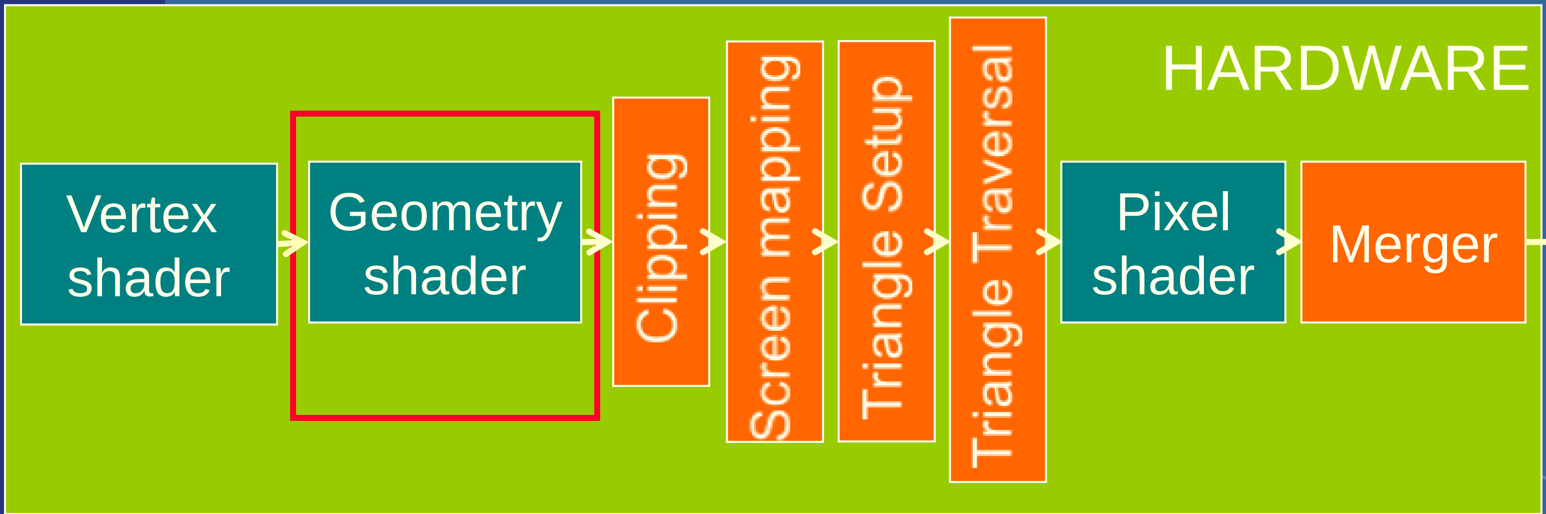
Hardware design

Geometry Stage

Geometry shader:

- One input primitive
- Many output primitives



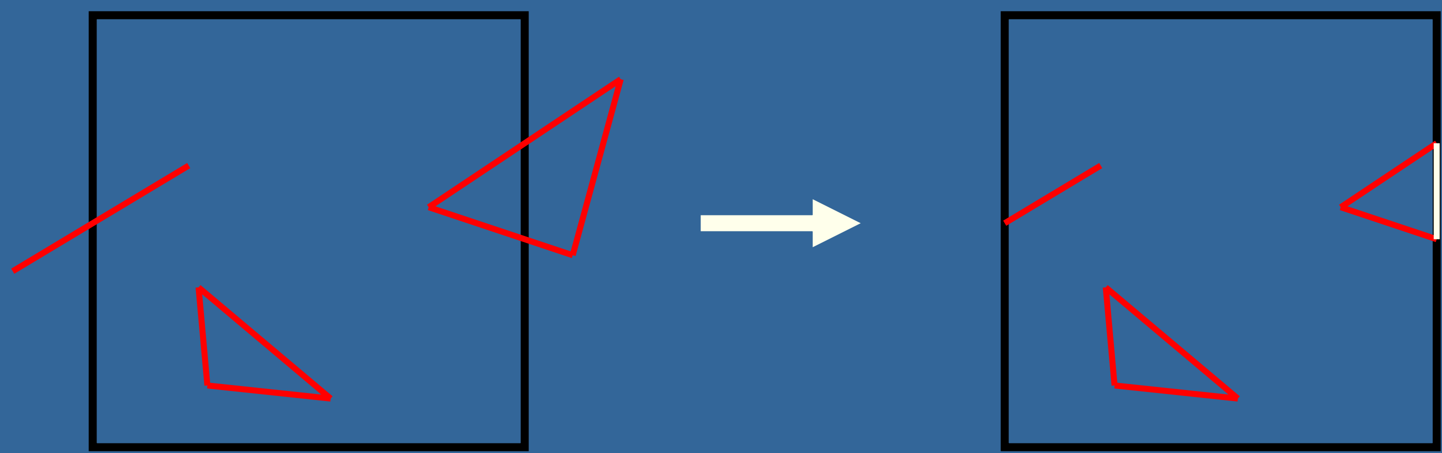


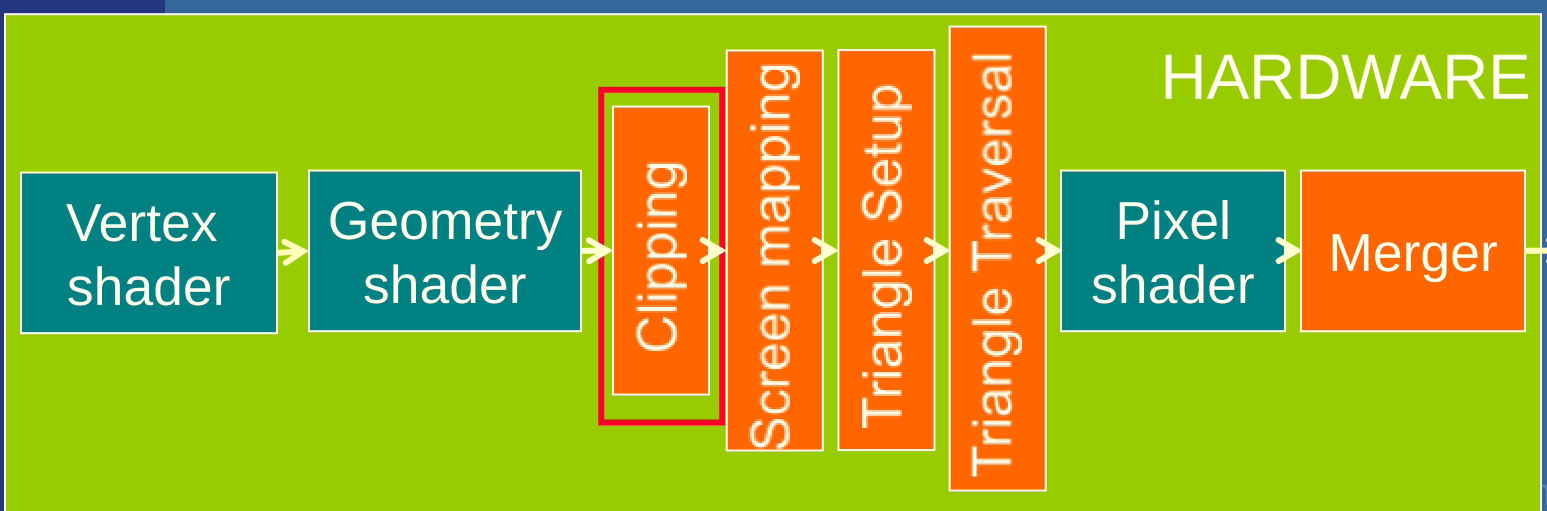
Display

Hardware design

Geometry Stage

Clips triangles against the unit cube (i.e., ”screen borders”)





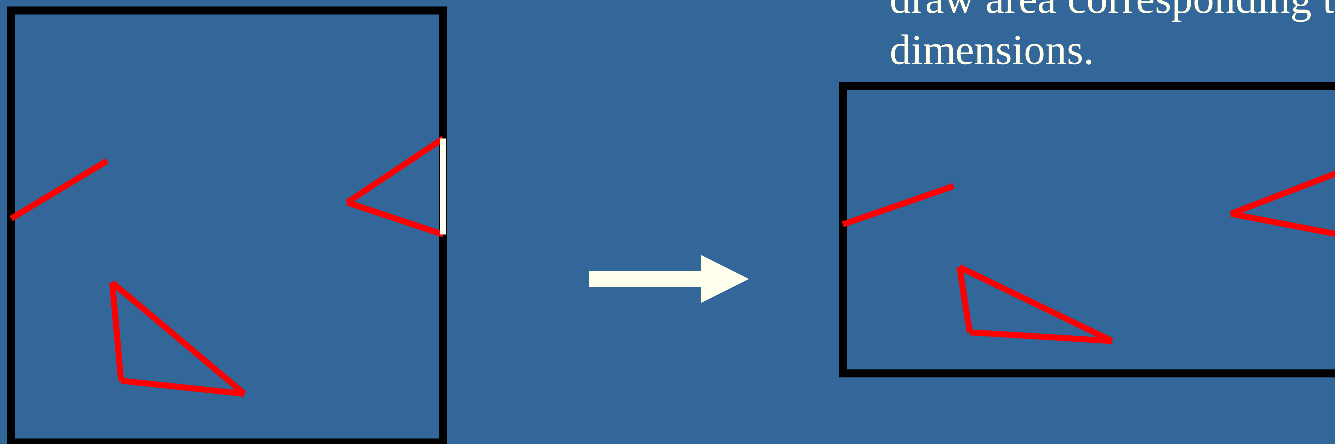
Display

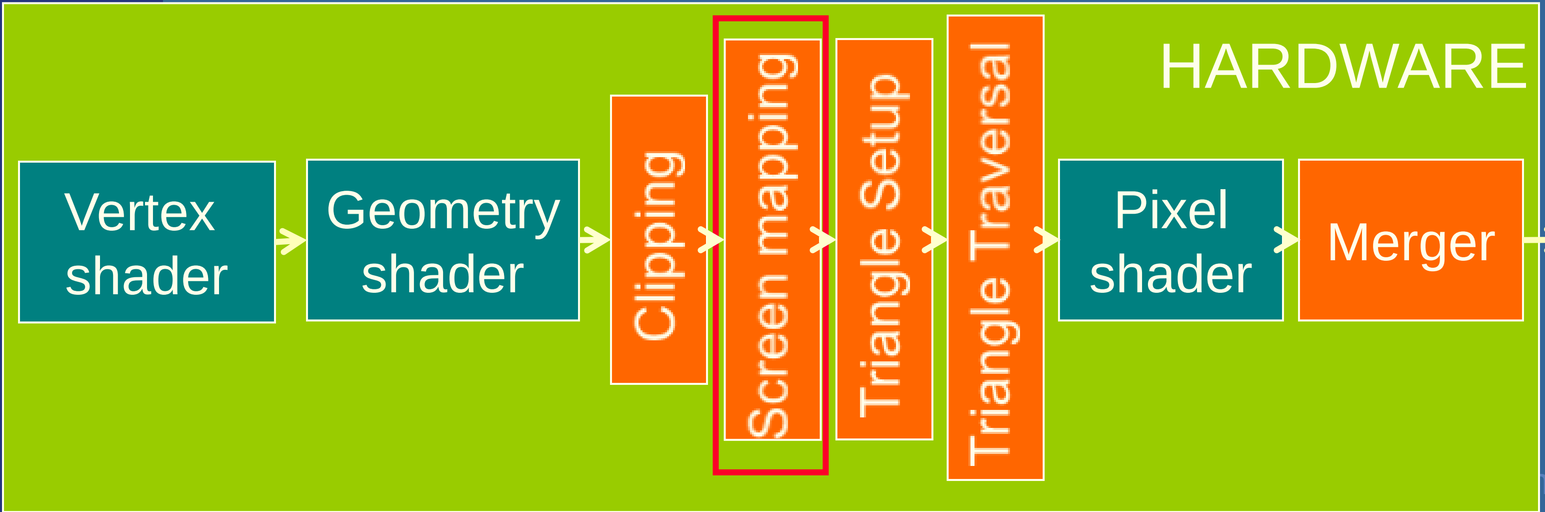
Hardware design

Rasterizer Stage

Maps window size to unit cube

Geometry stage always operates inside a unit cube [-1,-1,-1]-[1,1,1]
Next, the rasterization is made against a draw area corresponding to window dimensions.



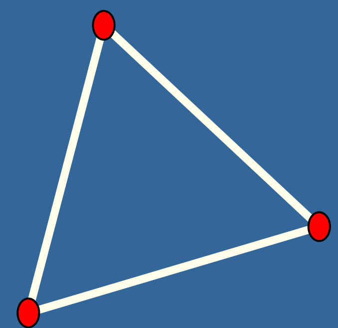


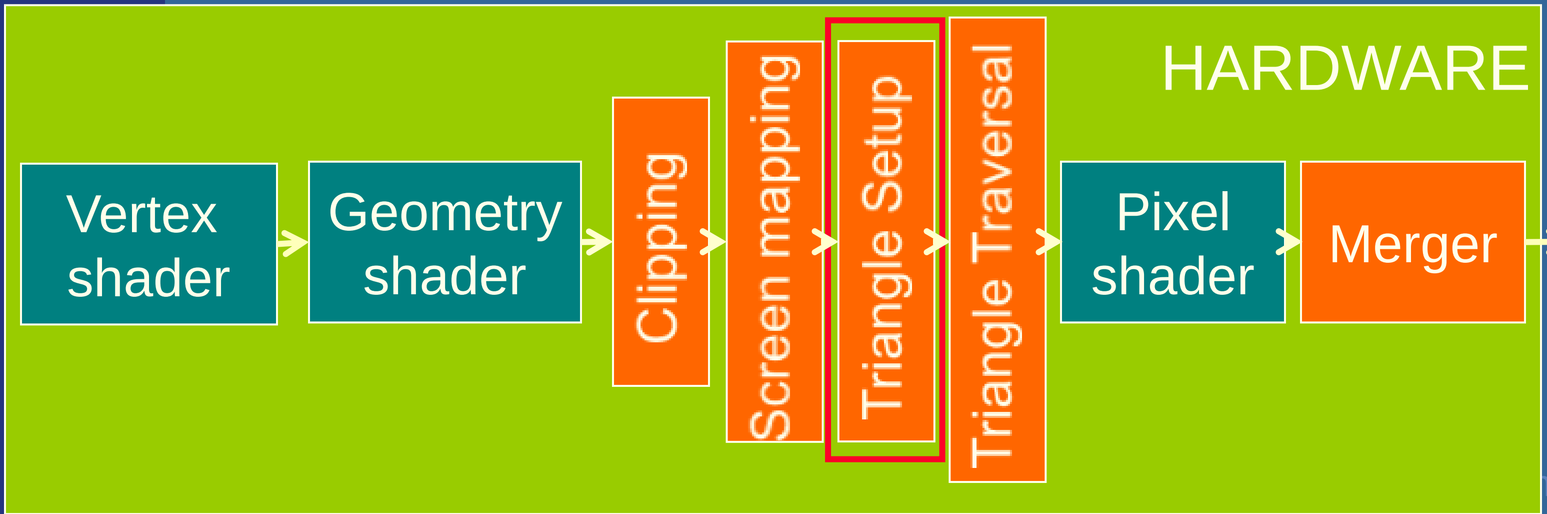
Display

Hardware design

Rasterizer Stage

Collects three vertices into one triangle



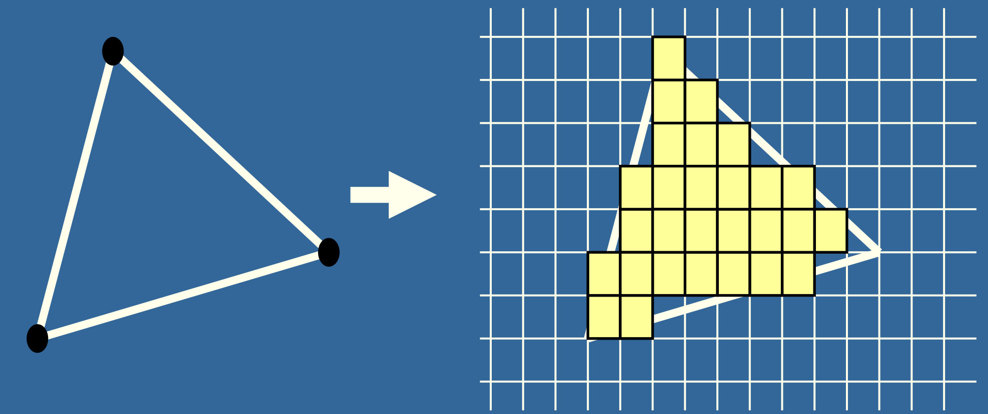


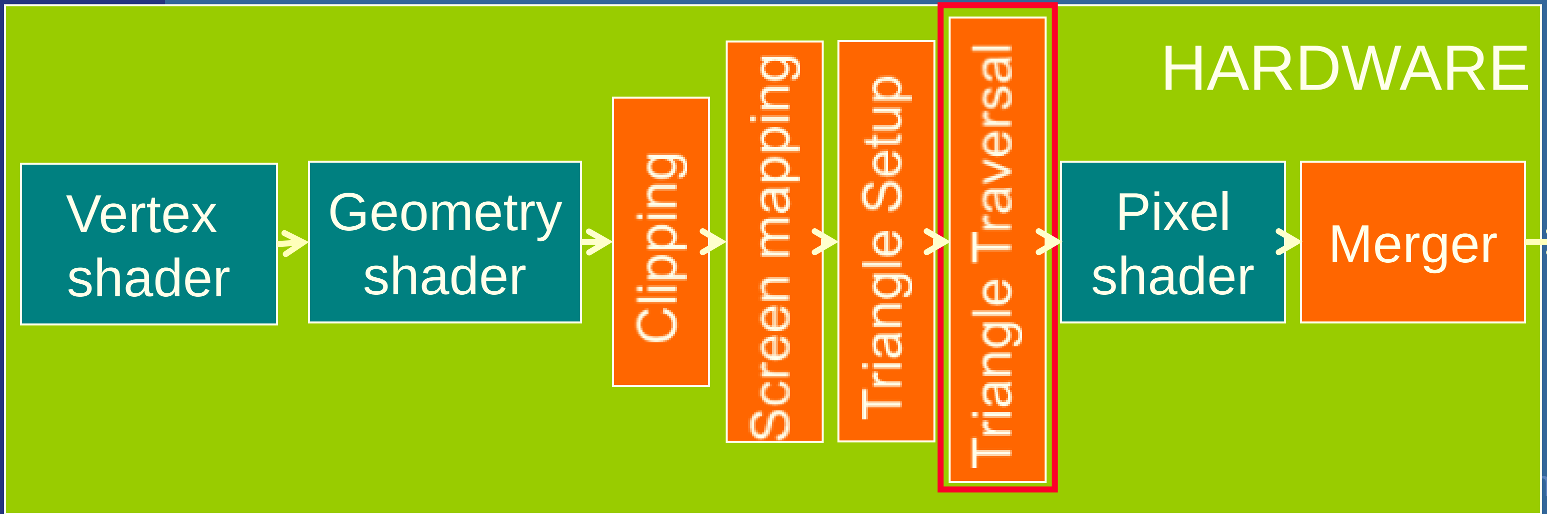
Display

Hardware design

Rasterizer Stage

Creates the fragments/pixels for the triangle

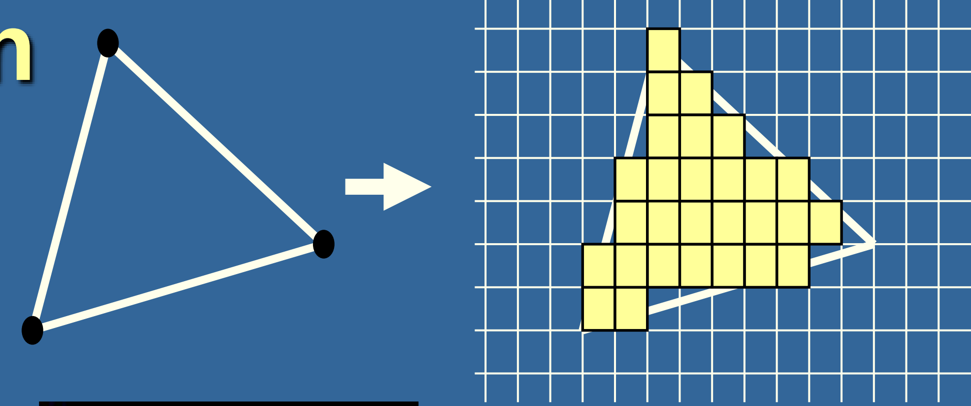


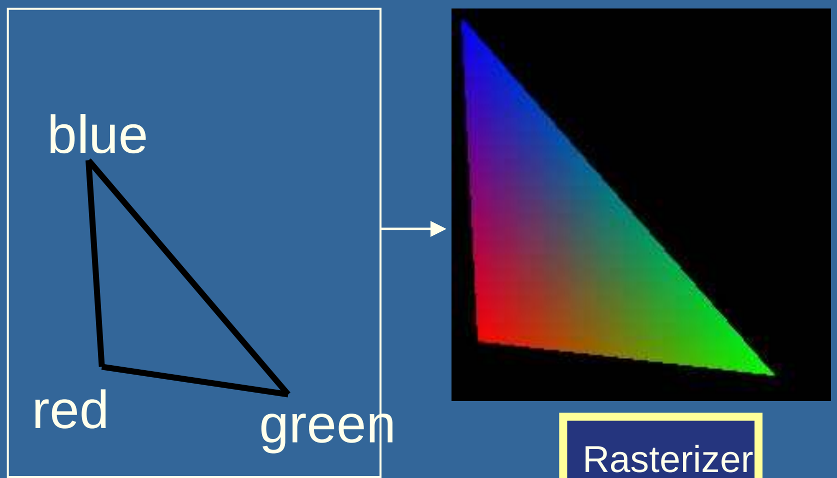


Display

Hardware design

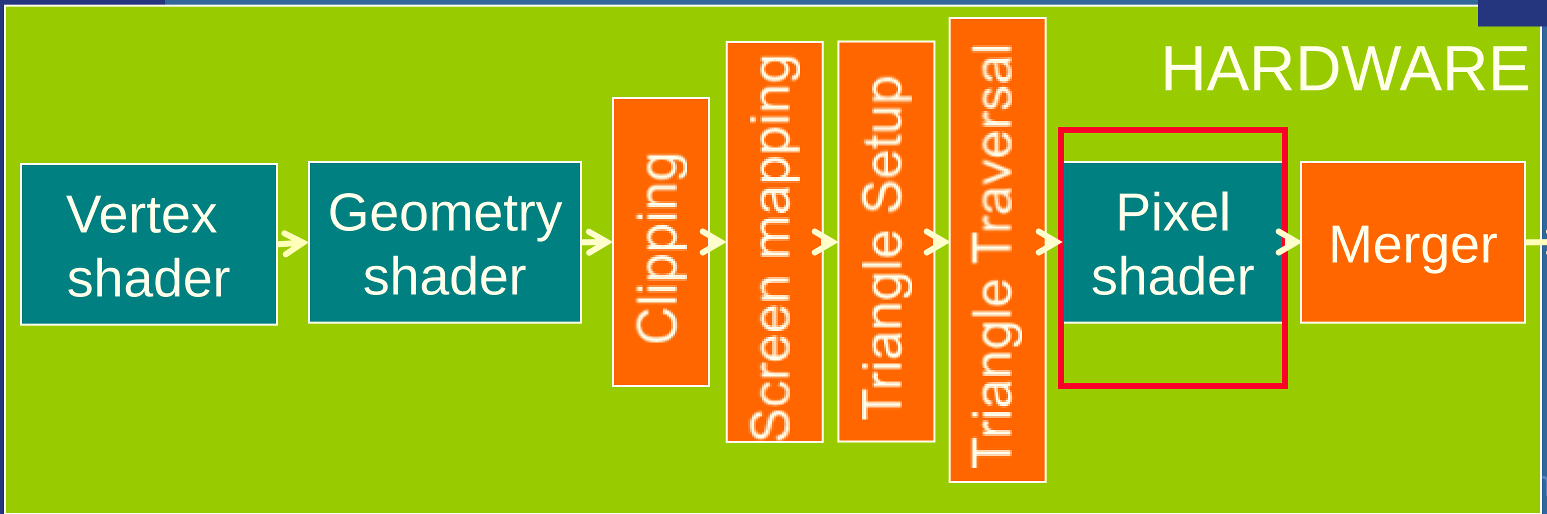
Rasterizer Stage





Pixel Shader:
Compute color using:

- Textures
- Interpolated data (e.g. Colors + normals) from vertex shader



Display

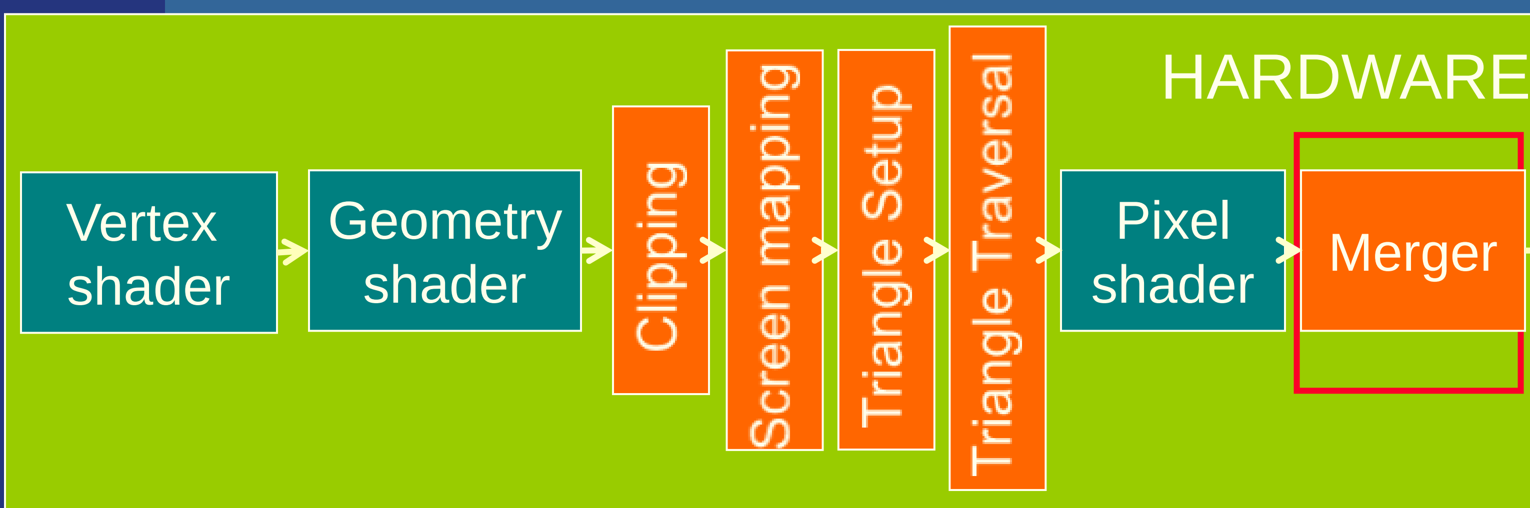
Hardware design

Rasterizer Stage

The merge units update the frame buffer with the pixel's color

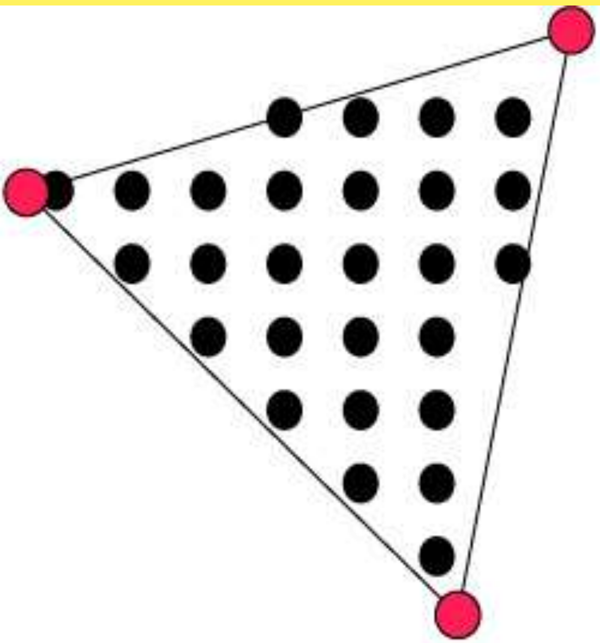
Frame buffer:

- Color buffers
- Depth buffer
- Stencil buffer



Display

What is vertex and fragment (pixel) shaders?



- Vertex shader: reads from textures
- Fragment shader: reads from textures, writes to pixel color
- Memory: Texture memory (read + write) typically 500 Mb – 4 GB
- Program size: the smaller the faster
- Instructions: mul, rcp, mov,dp, rsq, exp, log, cmp, jnz…

For each vertex, a vertex program (vertex shader) is executed

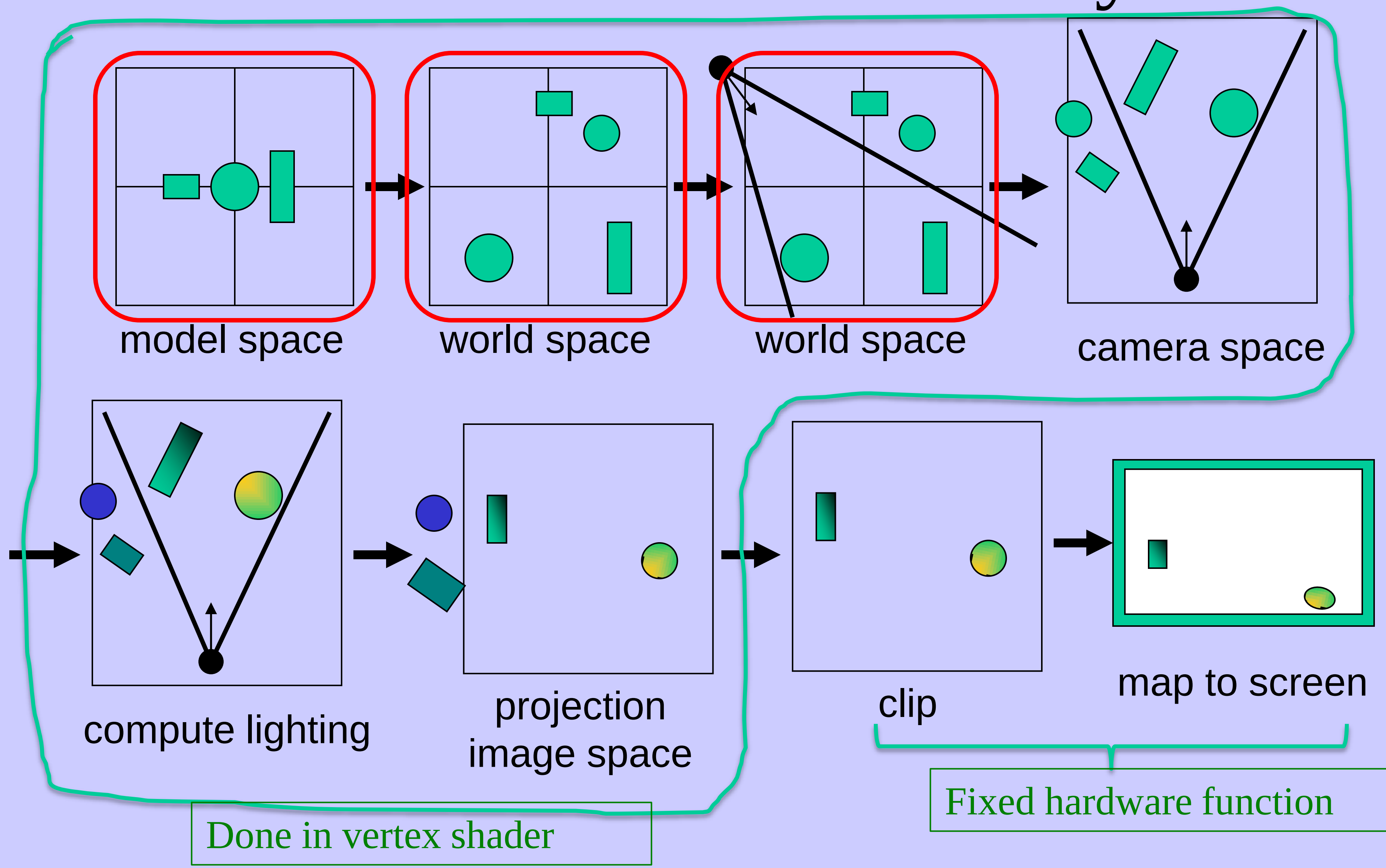
For each fragment (pixel) a fragment program (fragment shader) is executed

Rewind!
Let’s take a closer look

- The programmer ”sends” down primtives to be rendered through the pipeline (using API calls)
- The geometry stage does per-vertex operations
- The rasterizer stage does per-pixel operations
- Next, scrutinize geometry and rasterizer

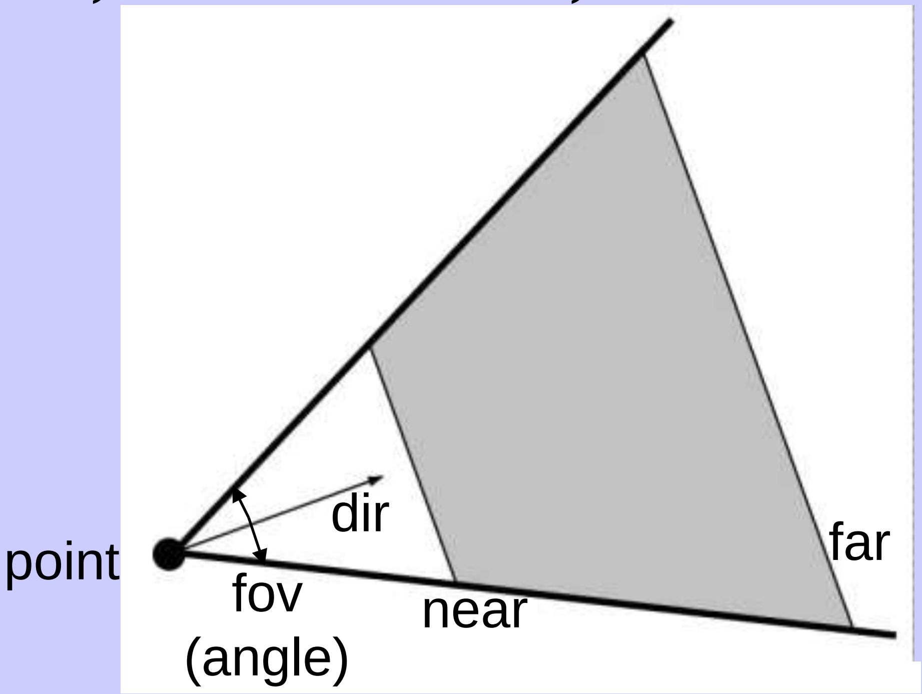
Application → Geometry → Rasterizer

GEOMETRY - Summary



Virtual Camera

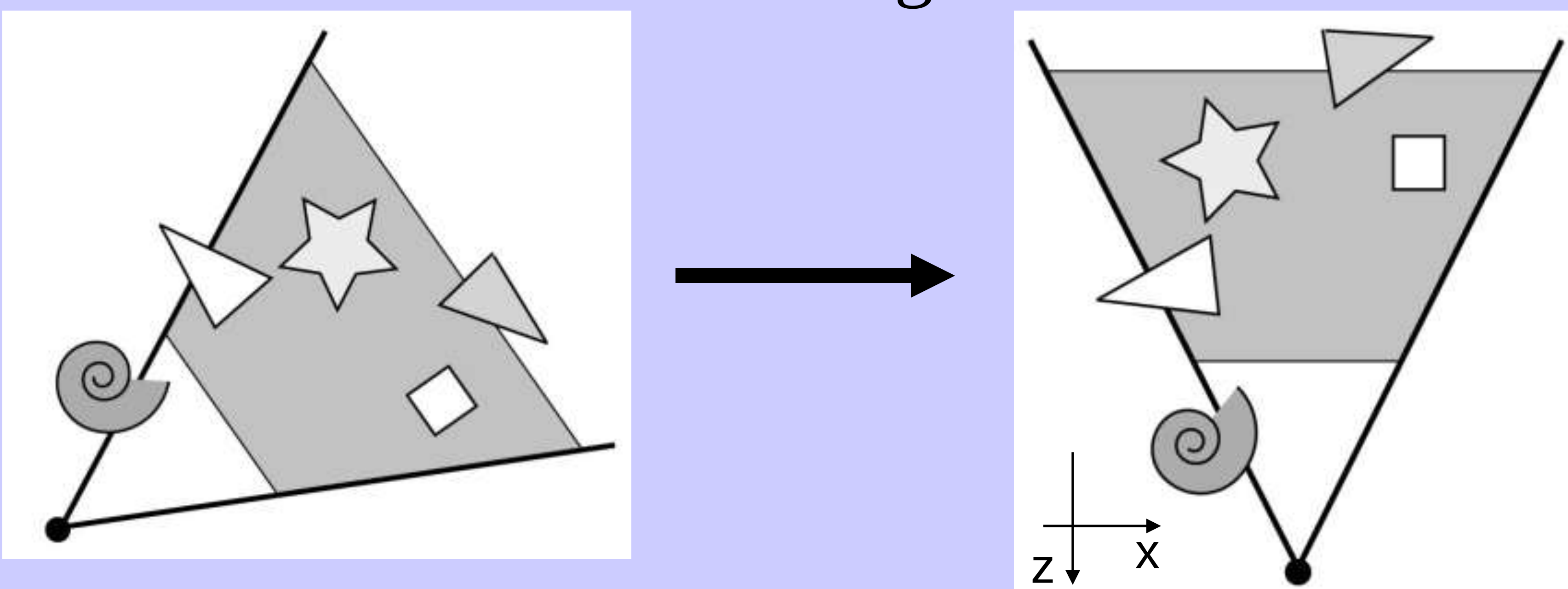
- Defined by position, direction vector, up vector, field of view, near and far plane.



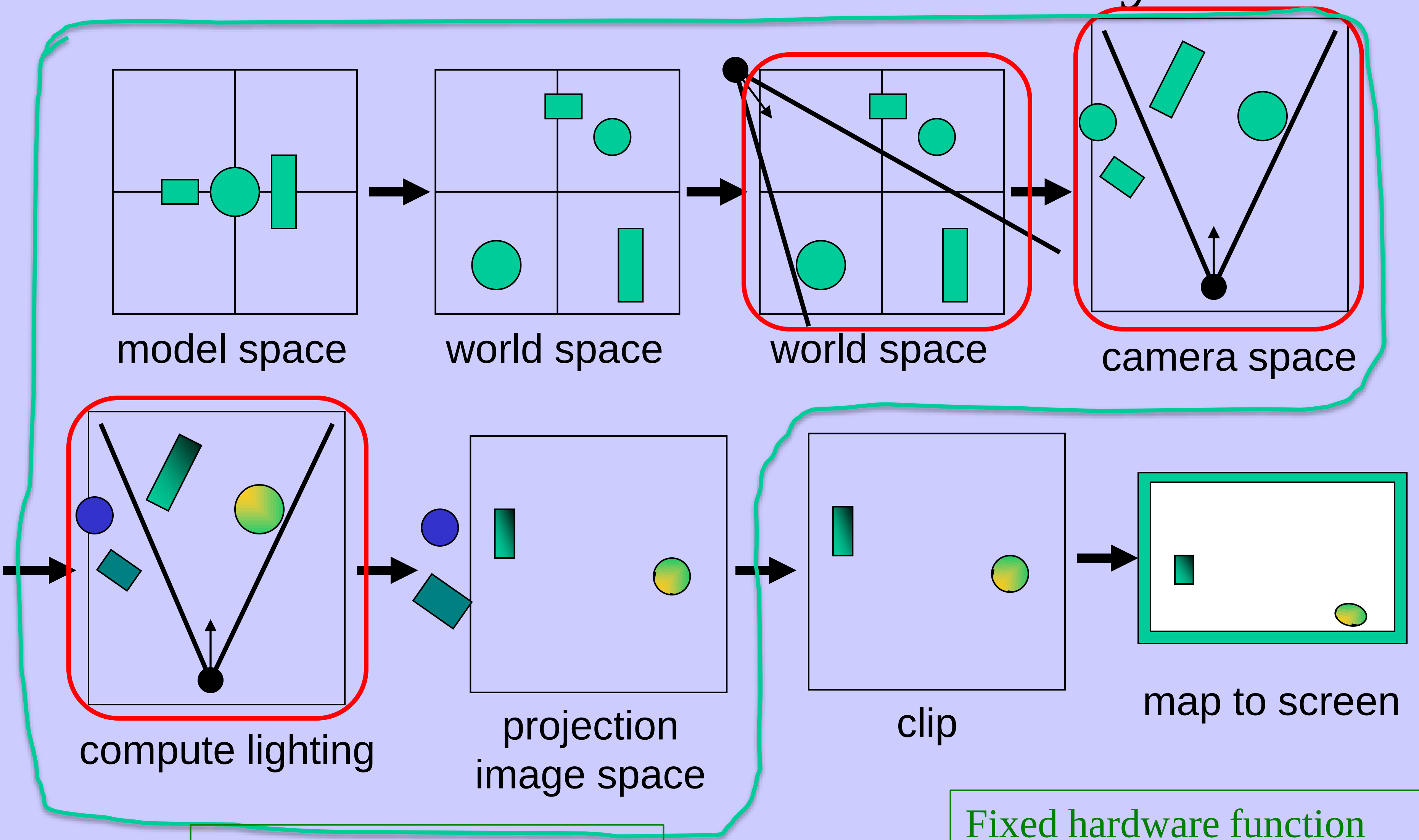
- Create image of geometry inside gray region
- Used by OpenGL, DirectX, ray tracing, etc.

GEOMETRY - The view transform

- You can move the camera in the same manner as objects
- But apply inverse transform to objects, so that camera looks down negative z-axis



GEOMETRY - Summary

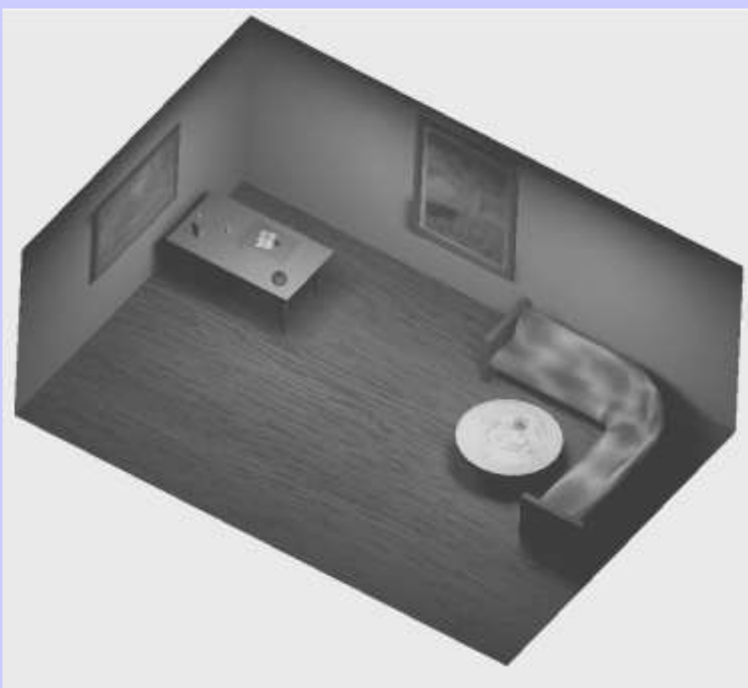


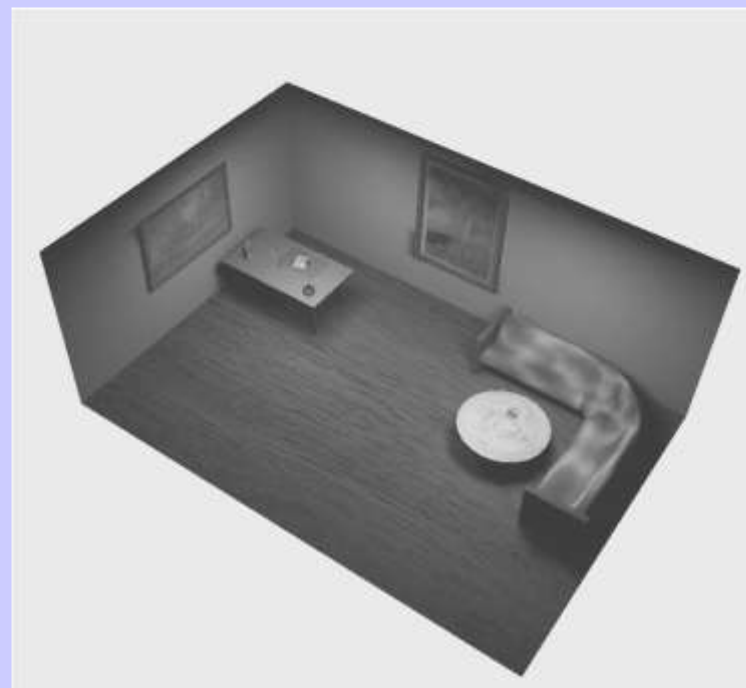
Done in vertex shader

Fixed hardware function

GEOMETRY - Projection

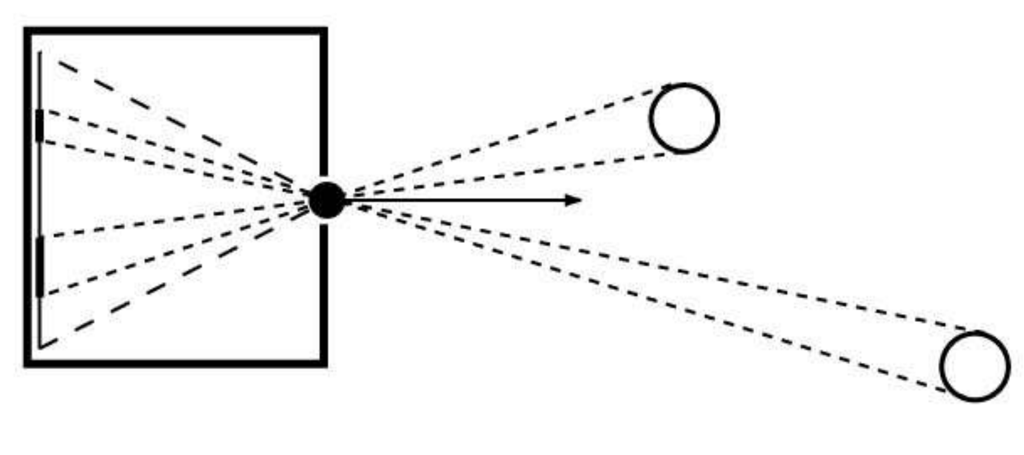
- Two major ways to do it
  - Orthogonal (useful in few applications)
  - Perspective (most often used)
    - Mimics how humans perceive the world, i.e., objects' apparent size decreases with distance

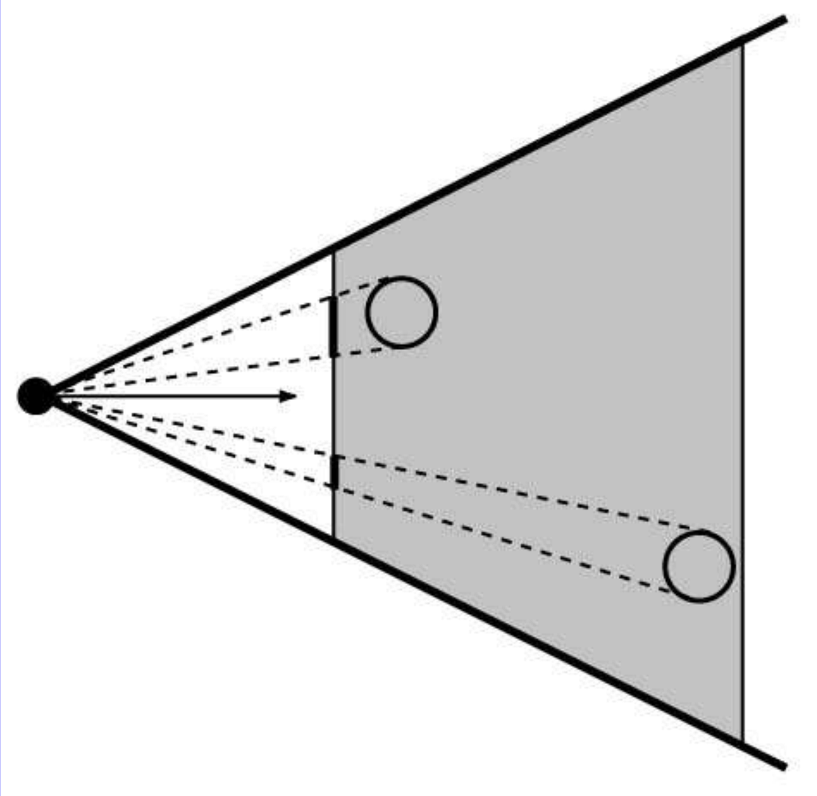




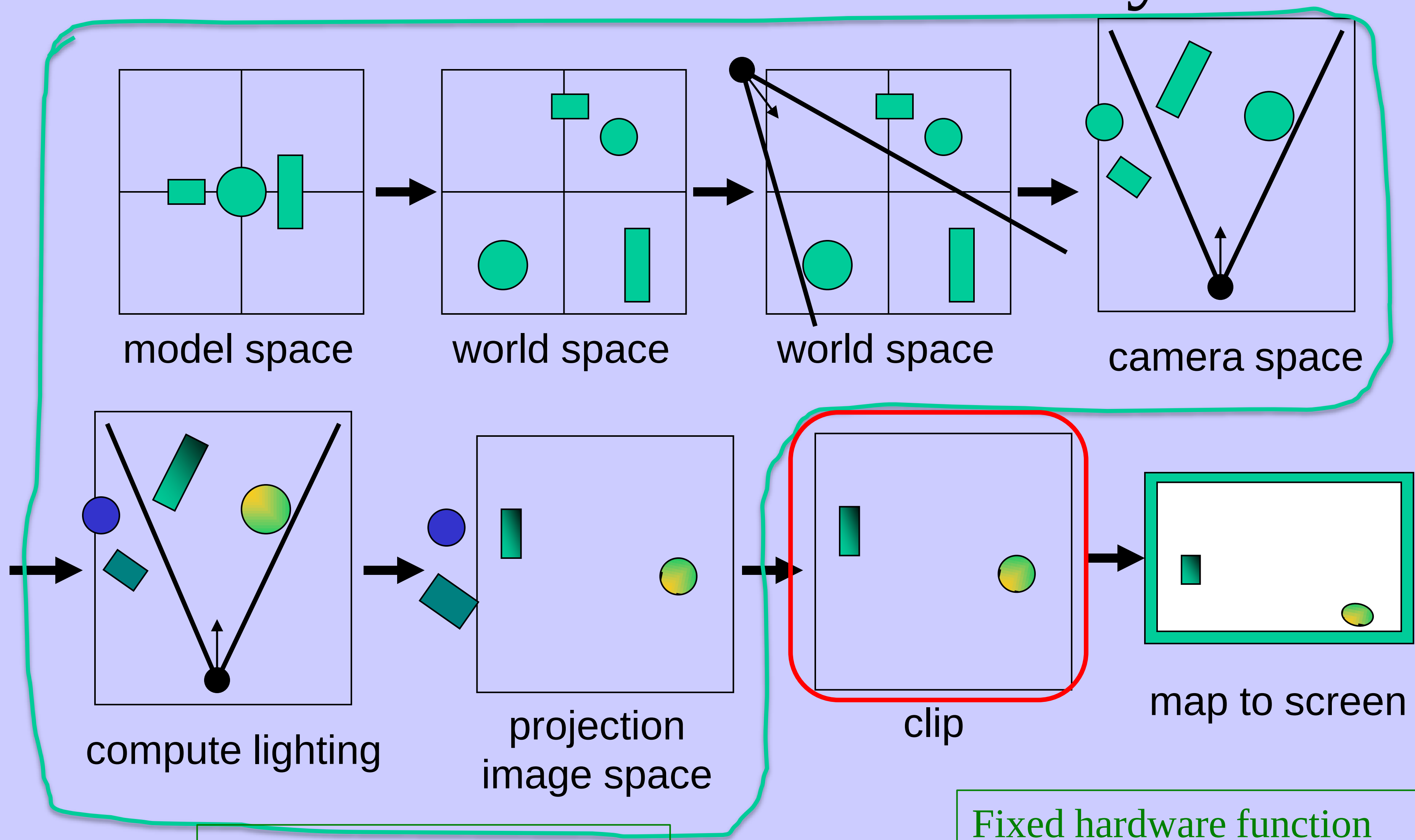
GEOMETRY - Projection

- Also done with a matrix multiplication!
- Pinhole camera (left), analog used in CG (right)





GEOMETRY - Summary



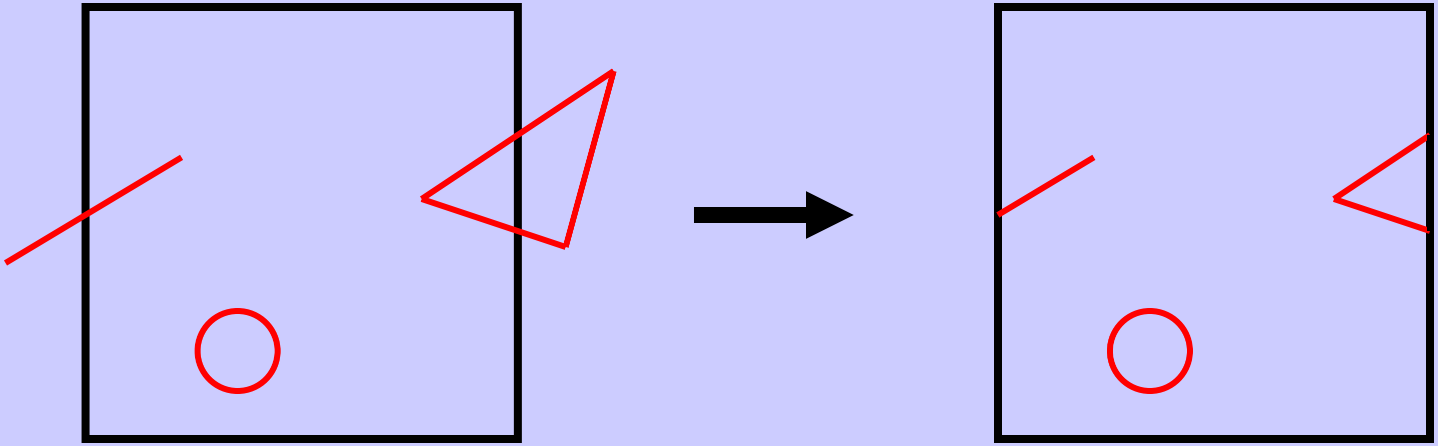
Done in vertex shader

Fixed hardware function

GEOMETRY

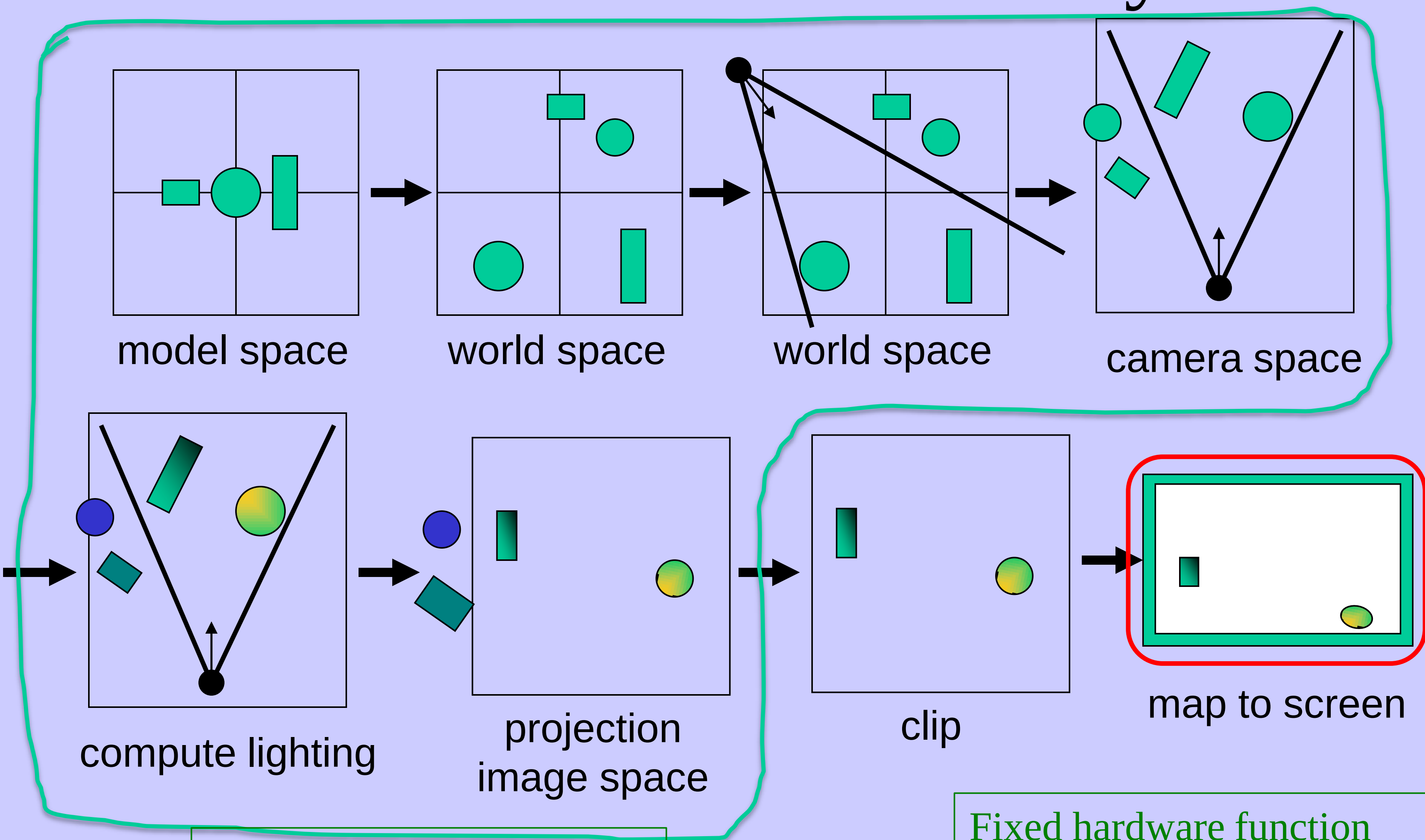
Clipping and Screen Mapping

- Square (cube) after projection
- Clip primitives to square



- Screen mapping, scales and translates the square so that it ends up in a rendering window
- These ”screen space coordinates” together with Z (depth) are sent to the rasterizer stage

GEOMETRY - Summary



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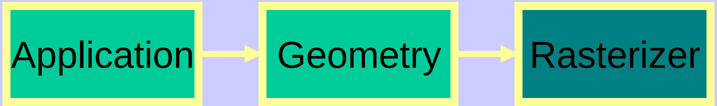
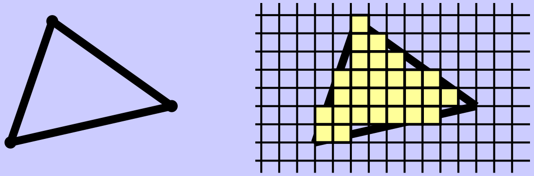
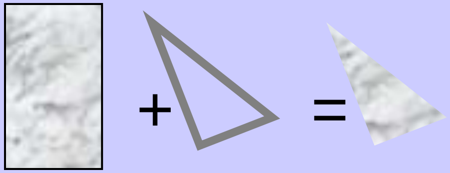
Fixed hardware function

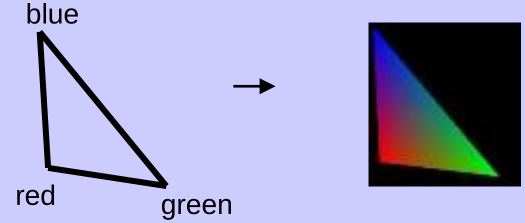


The RASTERIZER in more detail



- Scan-conversion
  - Find out which pixels are inside the primitive
- Fragment shaders
  - E.g. put textures on triangles
  - Use interpolated data over triangle
  - and/or compute per-pixel lighting



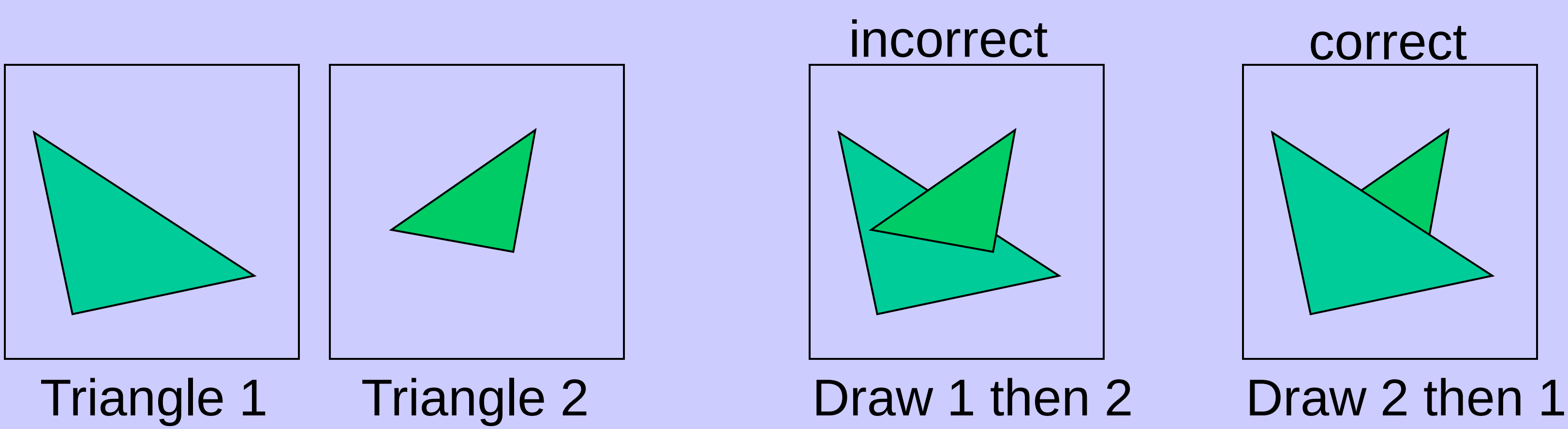


- Z-buffering
  - Make sure that what is visible from the camera really is displayed
- Doublebuffering

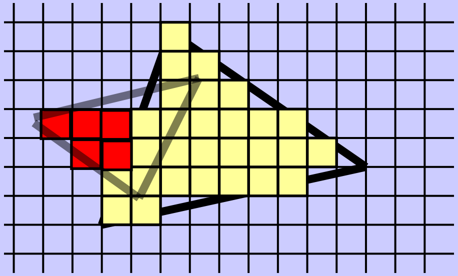
The RASTERIZER

Z-buffering

- A triangle that is covered by a more closely located triangle should not be visible
- Assume two equally large tris at different depths

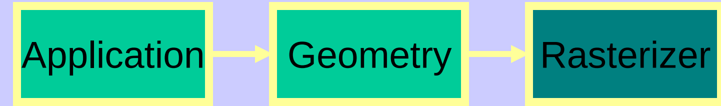


The RASTERIZER
Z-buffering



- Would be nice to avoid sorting…
- The Z-buffer (aka depth buffer) solves this
- Idea:
  - Store z (depth) at each pixel
  - When rasterizing a triangle, compute z at each pixel on triangle
  - Compare triangle's z to Z-buffer z-value
  - If triangle's z is smaller, then replace Z-buffer and color buffer
  - Else do nothing
- Can render in any order

The RASTERIZER double-buffering



- The monitor displays one image at a time
- Top of screen – new image

  Bottom – old image

  No control of split position
- And even worse, we often clear the screen before generating a new image
- A better solution is ”double buffering”
  - (Could instead keep track of rasterpos and vblank).

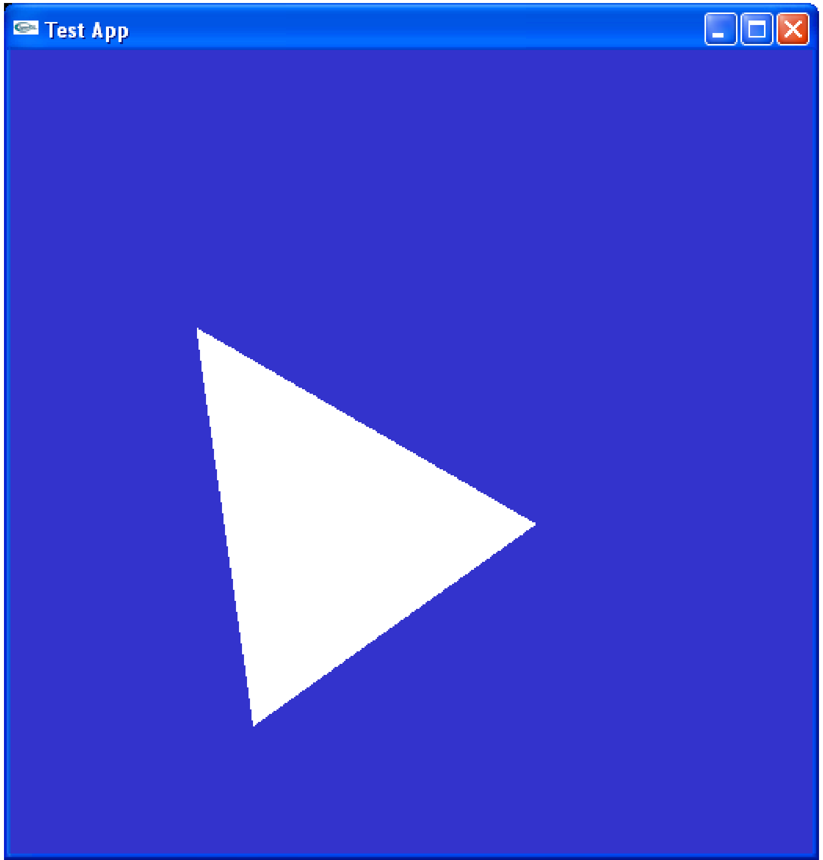
The RASTERIZER double-buffering

- Use two buffers: one front and one back
- The front buffer is displayed
- The back buffer is rendered to
- When new image has been created in back buffer, swap front and back

OpenGL

A Simple Program
Computer Graphics version of "Hello World"

Generate a triangle on a solid background

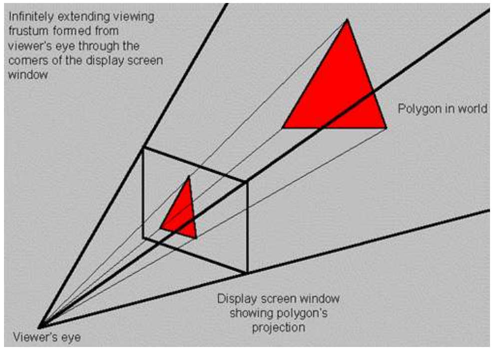


Simple Application...

```
int main(int argc, char *argv[])
{
    glutInit(&argc, argv);

    /* open window of size 512x512 with double buffering, RGB colors, and Z-
    buffering */
    glutInitDisplayMode(GLUT_DOUBLE | GLUT_RGB | GLUT_DEPTH);
    glutInitWindowSize(512,512);
    glutCreateWindow("Test App");

    /* the display function is called once when the gluMainLoop is called,
     * but also each time the window has to be redrawn due to window
     * changes (overlap, resize, etc).  */
    glutDisplayFunc(display);        // Set the main redraw function


    glutMainLoop();  /* start the program main loop */
    return 0;
}
```

```
void display(void)
{
	glClearColor(0.2,0.2,0.8,1.0);      // Set clear color  - for background
	glClear(GL_COLOR_BUFFER_BIT | GL_DEPTH_BUFFER_BIT); // Clears the color buffer and the z-buffer

	int w = glutGet((GLenum)GLUT_WINDOW_WIDTH);
	int h = glutGet((GLenum)GLUT_WINDOW_HEIGHT);
	glViewport(0, 0, w, h);                         // Set viewport (OpenGL draws with this resolution)

	glDisable(GL_CULL_FACE);
	drawScene();

	glutSwapBuffers();                    // swap front and back buffer. This frame will now been displayed.
}
```

```
static void drawScene(void)
{
    // Shader Program
    glUseProgramObjectARB( shaderProgram );   // Set the shader program to use for this draw call
    CHECK_GL_ERROR();

    glBindVertexArray(vertexArrayObject);          // Tells which vertex arrays to use
    CHECK_GL_ERROR();

    glDrawArrays( GL_TRIANGLES, 0, 3 );        // Render the three first vertices as a triangle
    CHECK_GL_ERROR();
}
```



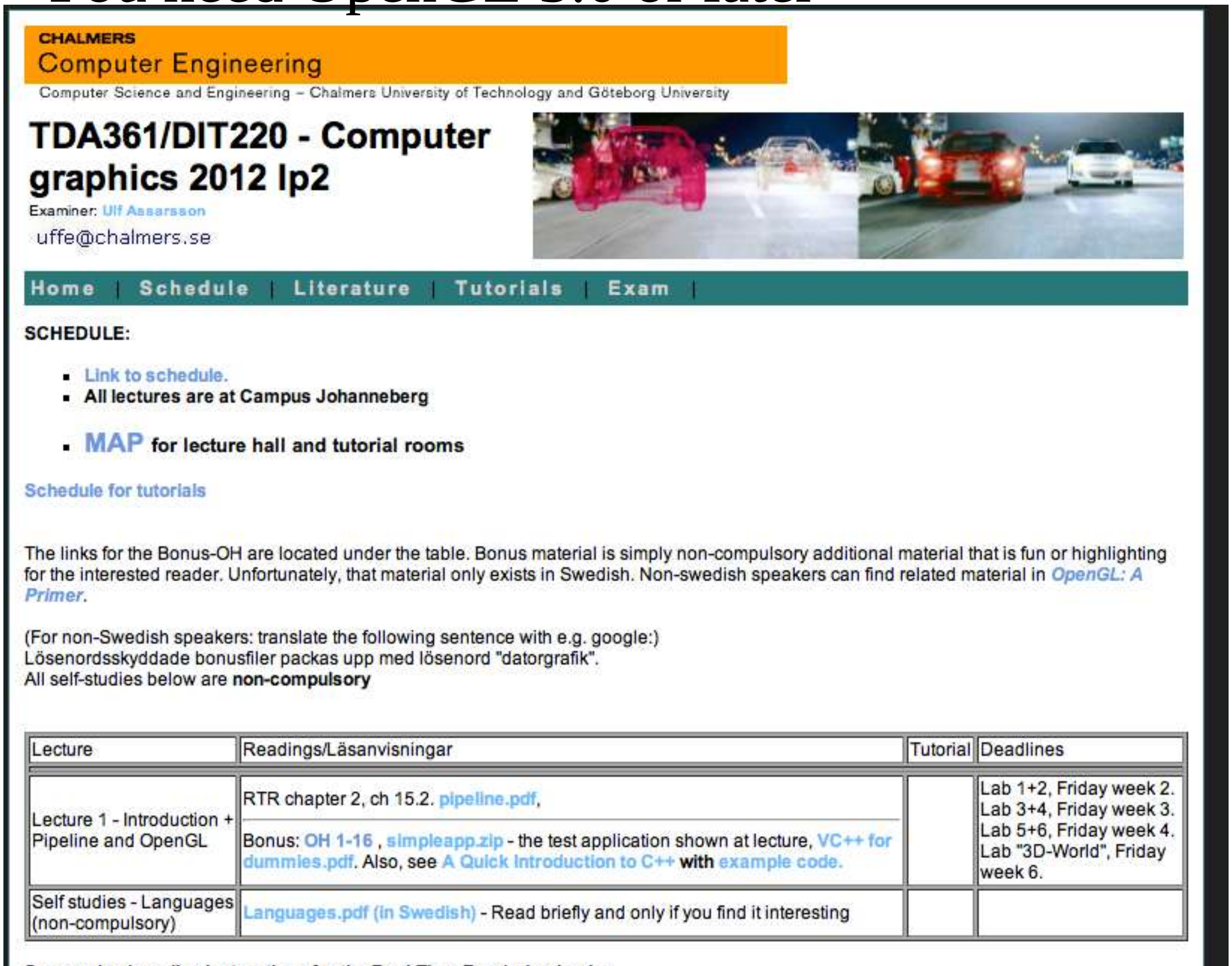
Shaders

```
// Vertex Shader
#version 130

in  vec3 vertex;
in  vec3 color;
out vec3 outColor;
uniform mat4 modelViewProjectionMatrix;

void main()
{
	gl_Position = modelViewProjectionMatrix*vec4(vertex,1);
	outColor = color;
}
```

```
// Fragment Shader:
#version 130
in  vec3 outColor;
out vec4 fragColor;

void main()
{
	fragColor =
	vec4(outColor,1);
}
```

Demonstration of SimpleApp

- Available on course homepage in Schedule.
- You need OpenGL 3.0 or later



CHALMERS
Computer Engineering
Computer Science and Engineering – Chalmers University of Technology and Göteborg University

TDA361/DIT220 - Computer graphics 2012 lp2

Examiner: Ulf Assarsson
uffe@chalmers.se

Home | Schedule | Literature | Tutorials | Exam |

SCHEDULE:

- Link to schedule.
- **All lectures are at Campus Johanneberg**
- **MAP for lecture hall and tutorial rooms**

Schedule for tutorials

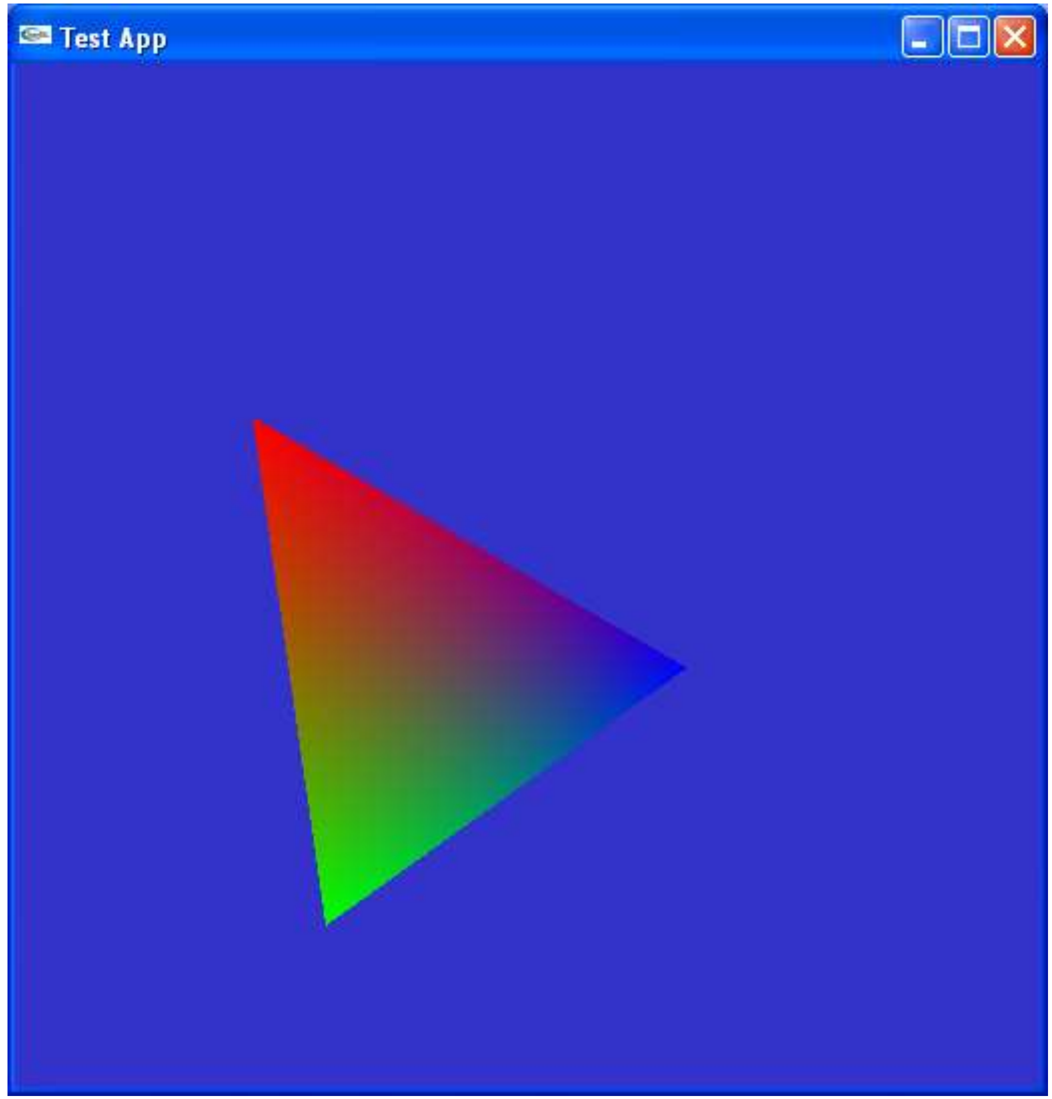
The links for the Bonus-OH are located under the table. Bonus material is simply non-compulsory additional material that is fun or highlighting for the interested reader. Unfortunately, that material only exists in Swedish. Non-swedish speakers can find related material in *OpenGL: A Primer*.

(For non-Swedish speakers: translate the following sentence with e.g. google:)
Lösenordsskyddade bonusfiler packas upp med lösenord "datorgrafik".
All self-studies below are **non-compulsory**

Lecture	Readings/Läsanvisningar	Tutorial	Deadlines
Lecture 1 - Introduction + Pipeline and OpenGL	RTR chapter 2, ch 15.2. pipeline.pdf, Bonus: OH 1-16 , simpleapp.zip - the test application shown at lecture, VC++ for dummies.pdf. Also, see A Quick Introduction to C++ **with** example code.		Lab 1+2, Friday week 2. Lab 3+4, Friday week 3. Lab 5+6, Friday week 4. Lab "3D-World", Friday week 6.
Self studies - Languages (non-compulsory)	Languages.pdf (in Swedish) - Read briefly and only if you find it interesting		

Cool application

Starts looking good!



Repetition

- What is important:
  - Understand the Application-, Geometry- and Rasterization Stage

- See you on Friday 9:00

THE END