INFOGR – Computer Graphics

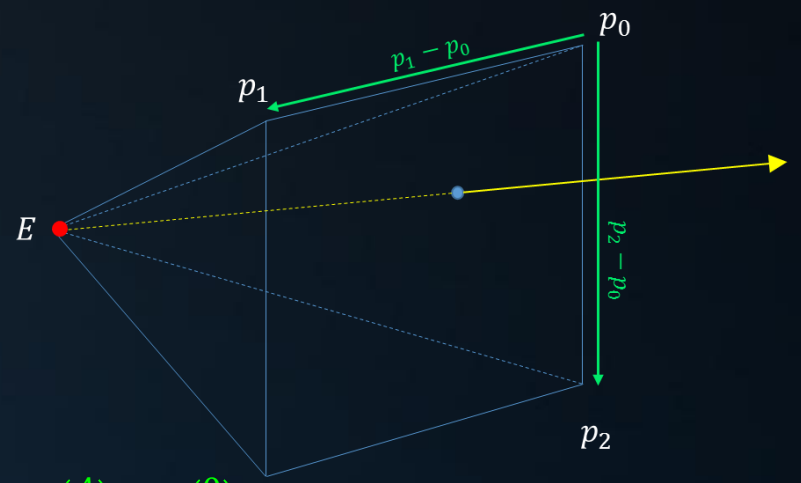
Jacco Bikker & Debabrata Panja - April-July 2017

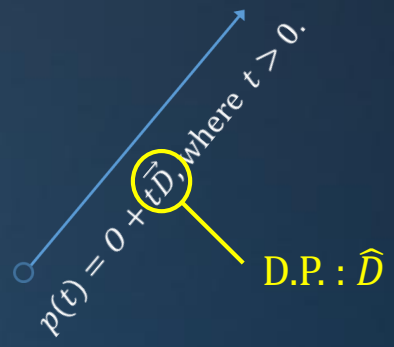
Lecture 7: “Accelerate”

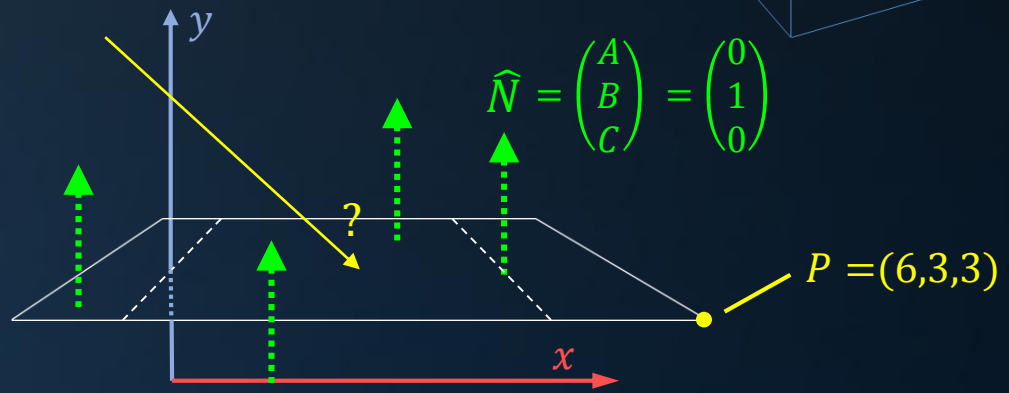
Welcome!

Recap

```
Color Trace( vec3 O, vec3 D )
{
   I, N, mat = IntersectScene( O, D );
   if (!I) return BLACK;
   return DirectIllumination( I, N ) * mat.diffuseColor;
}
```







$$Ax + By + Cz + D = 0$$

$$A6 + B3 + C3 + D = 0$$

$$0 * 6 + 1 * 3 + 0 * 3 + D = 0$$

$$3 + D = 0 \rightarrow D = -3 \rightarrow \boldsymbol{D = -(P \cdot \hat{N})}$$

Recap

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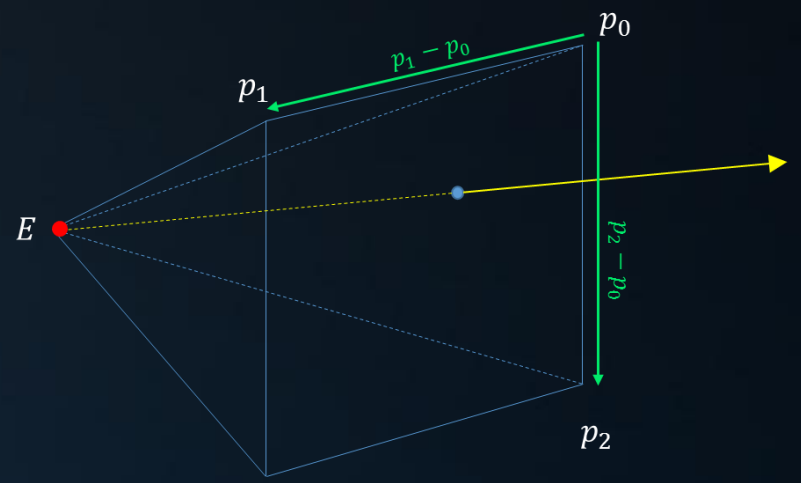

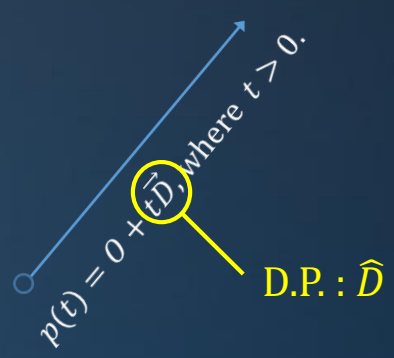

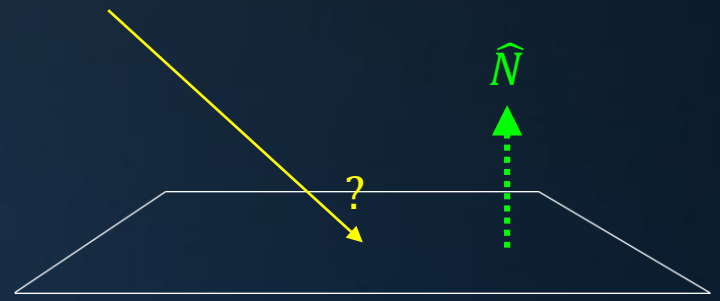

$$Ax + By + Cz + d = \hat{N} \cdot p + d = 0 \text{ and } p(t) = O + t\hat{D}$$

$$\hat{N} \cdot (O + t\hat{D}) + d = 0 \rightarrow \hat{N} \cdot O + \hat{N} \cdot (t\hat{D}) + d = 0$$

$$\hat{N} \cdot (t\hat{D}) = -(\hat{N} \cdot O + d) \rightarrow t = -(\hat{N} \cdot O + d)/(\hat{N} \cdot \hat{D})$$

Recap

Schlick:

$$F_r = R_0 + (1 - R_0)(1 - cos\theta)^5,$$
$$R_0 = \left(\frac{n_1 - n_2}{n_1 + n_2}\right)^2.$$

```
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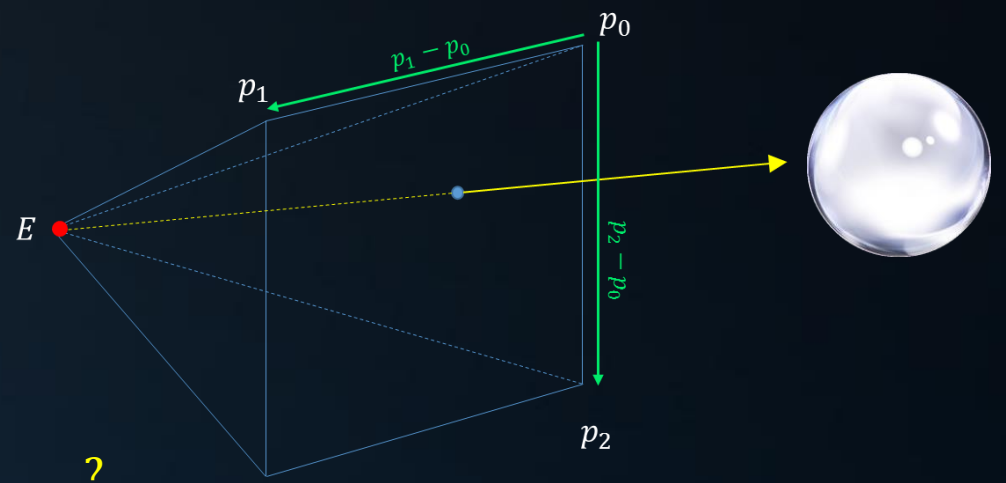
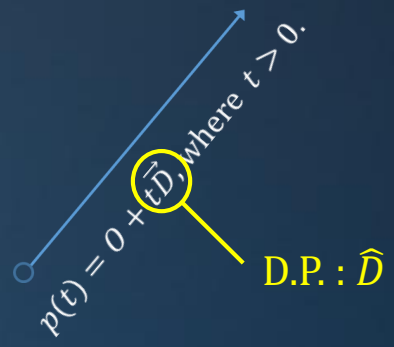
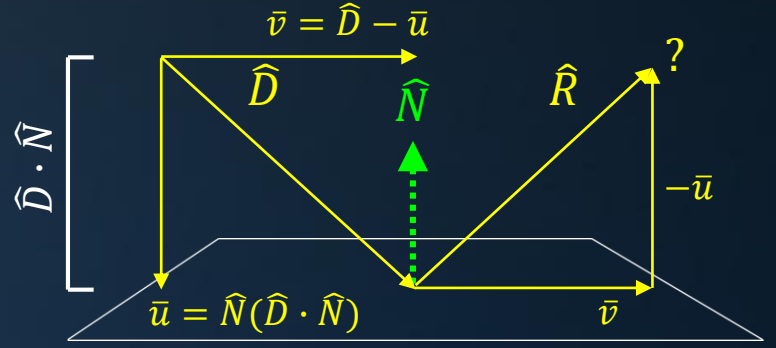
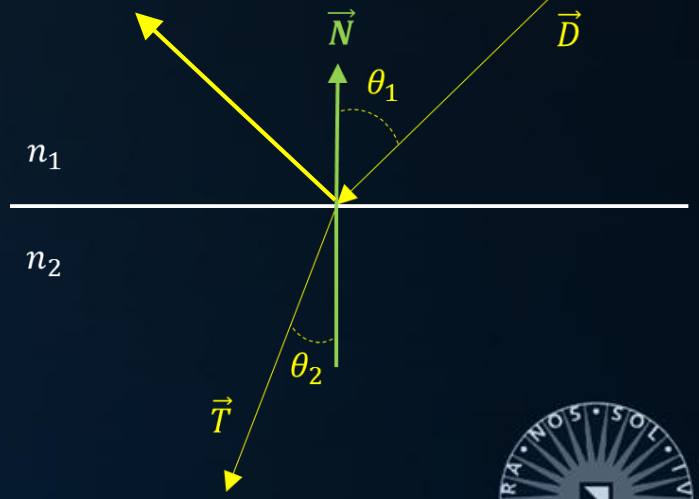






$$\frac{n_1}{n_2} sin\theta_1 = sin\theta_2 \Leftrightarrow sin\theta_1 \leq \frac{n2}{n1}$$



$$k = 1 - \left(\frac{n_1}{n_2}\right)^2 \left(1 - cos\theta_1{}^2\right)$$

$$\vec{T} = \begin{cases} TIR, & for\ k < 0 \\ \frac{n_1}{n_2}\vec{D} + \vec{N}\left(\frac{n_1}{n_2} cos\theta_1 - \sqrt{k}\right), & for\ k \geq 0 \end{cases}$$

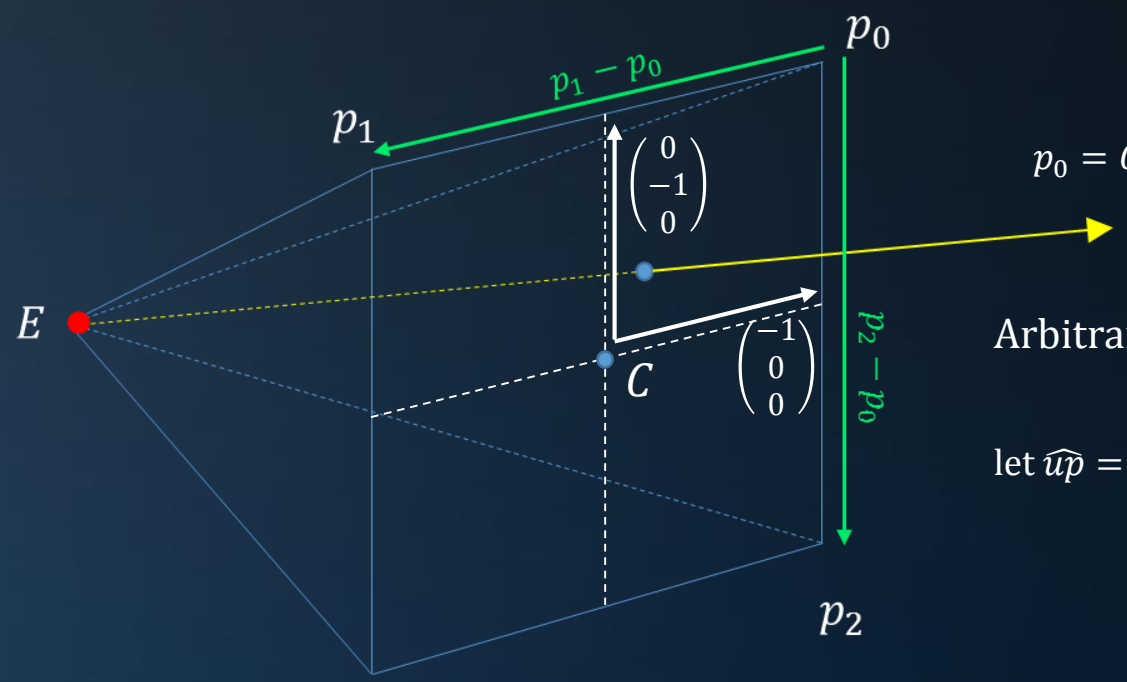
$$R = \bar{v} - \bar{u}$$
$$R = (\hat{D} - \bar{u}) - \bar{u}$$
$$R = (\hat{D} - \hat{N}(\hat{D} \cdot \hat{N})) - \hat{N}(\hat{D} \cdot \hat{N})$$
$$R = \hat{D} - 2\hat{N}(\hat{D} \cdot \hat{N})$$

Camera looks straight ahead along z:

$$\hat{V} = \begin{pmatrix} 0 \\ 0 \\ 1 \end{pmatrix} or\ \hat{V} = \begin{pmatrix} 0 \\ 0 \\ -1 \end{pmatrix}$$

$$C = E + d\hat{V}$$

$$p_0 = C + \begin{pmatrix} -1 \\ -1 \\ 0 \end{pmatrix}, p_1 = C + \begin{pmatrix} 1 \\ -1 \\ 0 \end{pmatrix}, p_2 = C + \begin{pmatrix} -1 \\ 1 \\ 0 \end{pmatrix}$$



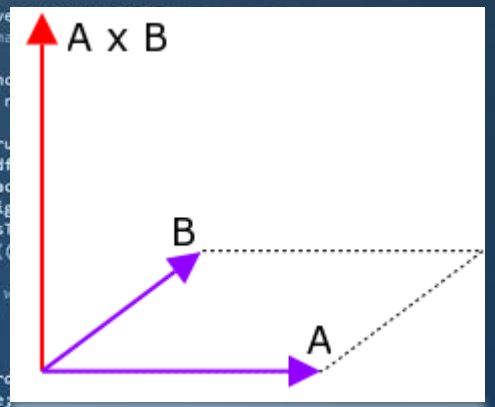
Arbitrary $\hat{V}$:

let $\widehat{up} = \begin{pmatrix} 0 \\ 1 \\ 0 \end{pmatrix}$. Then:

$$\hat{r} = \frac{\widehat{up} \times \hat{V}}{\|\widehat{up} \times \hat{V}\|} \qquad \hat{r} = \frac{\hat{V} \times \widehat{up}}{\|\hat{V} \times \widehat{up}\|}$$

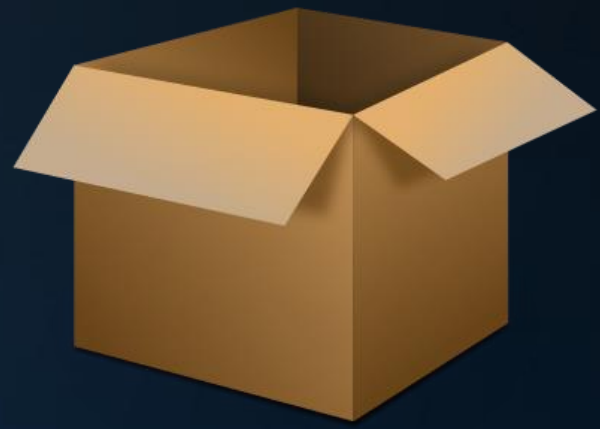
$$\hat{u} = \frac{\hat{r} \times \hat{V}}{\|\hat{r} \times \hat{V}\|} \qquad \hat{u} = \hat{r} \times \hat{V}$$

$$p_0 = C - \hat{r} + \hat{u}$$
$$p_1 = C + \hat{r} + \hat{u}$$
$$p_2 = C - \hat{r} - \hat{u}$$



Today’s Agenda:

- Efficiency
- Boxes, AABBs & Groupings
- To Rasterization
- 3D Engine Overview
- Textures



Efficiency

Measuring Performance

Stopwatch class:

Using System.Diagnostics.Stopwatch;

Useful property:

- `long ElapsedMilliseconds { get; }`

Methods:

- `Reset`
- `Start`
- `Stop`

Note:

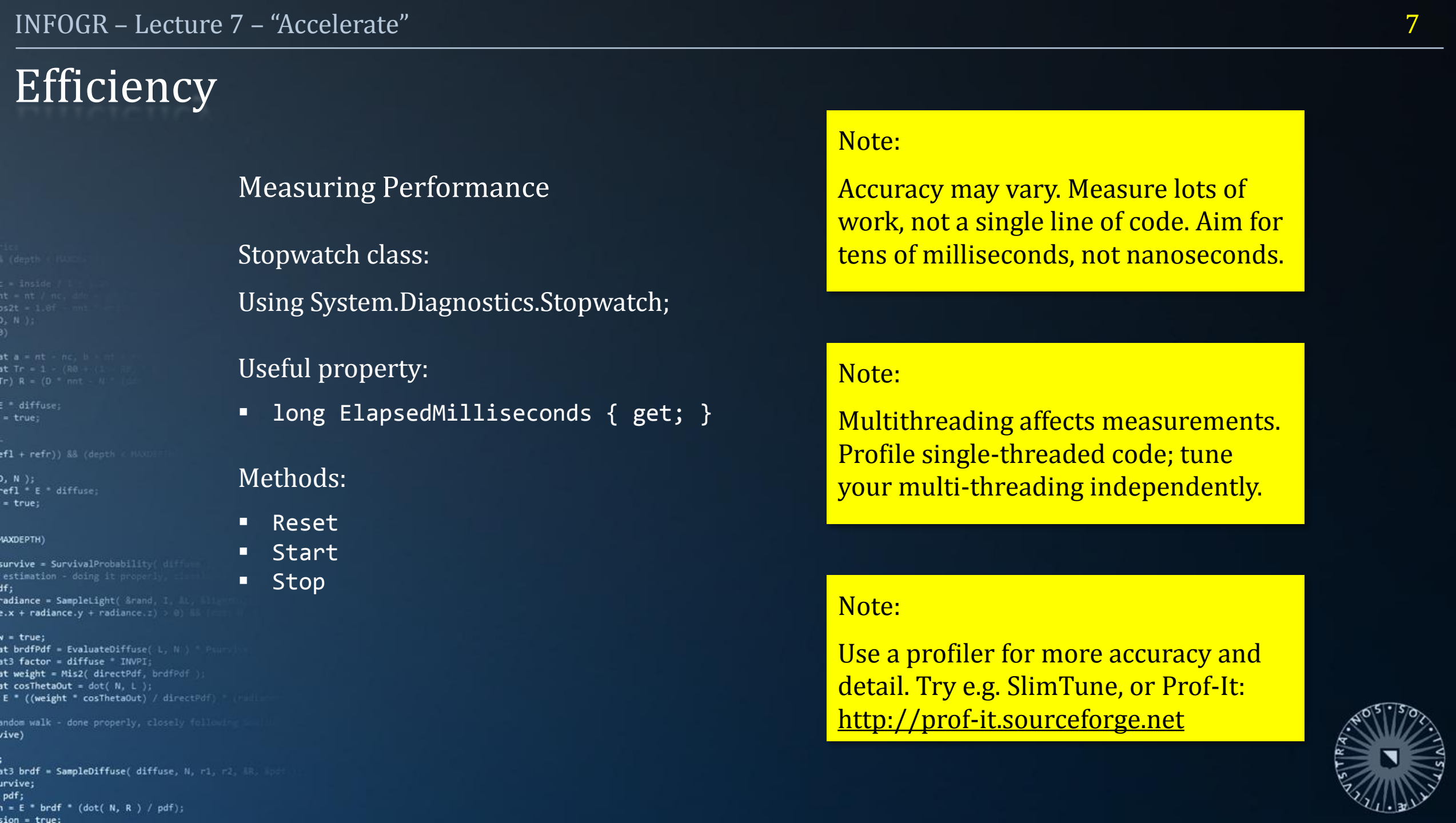
Accuracy may vary. Measure lots of work, not a single line of code. Aim for tens of milliseconds, not nanoseconds.

Note:

Multithreading affects measurements. Profile single-threaded code; tune your multi-threading independently.

Note:

Use a profiler for more accuracy and detail. Try e.g. SlimTune, or Prof-It: http://prof-it.sourceforge.net



Efficiency

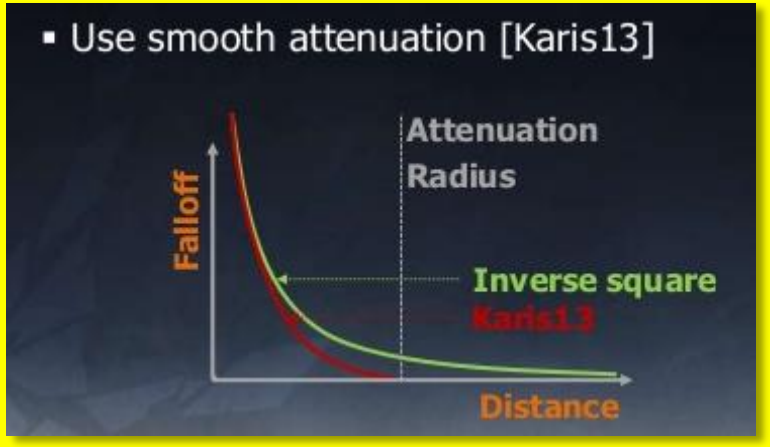
Optimization Primer

Some things to keep in mind:

- Float or double
- Don’t do work you don’t need to do
  - Early out
  - Reduce precision
  - Lights with finite radius
  - Things that can’t occlude light

$$attenuation = \frac{saturate\left(1 - \left(\frac{distance}{radius}\right)^4\right)^2}{distance^2 + 1}$$

From:
Real Shading in Unreal Engine 4, Karis, 2013
(also used in Frostbite).



Efficiency

Optimization Primer

Some things to keep in mind:

- Float or double
- Don’t do work you don’t need to do
- Precalculate
  - Loop hoisting
  - Vertex shaders

Loop hoisting:
Take expressions that do not rely on the loop counter outside the loop.

```
for( int i = 0; i < lights; i++ ) {
   vec3 N = intersection->GetNormal();
   vec3 L = light[i]->pos –
            intersection->pos;
   L.Normalize();
   if (dot( L, N ) > 0) {
      …
   }
}
```

➔

```
vec3 N = intersection->GetNormal();
for( int i = 0; i < lights; i++ ) {
   vec3 L = light[i]->pos –
            intersection->pos;
   if (dot( L, N ) > 0) {
      L.Normalize();
      …
   }
}
```

Efficiency

Optimization Primer

Some things to keep in mind:

- Float or double
- Don’t do work you don’t need to do
- Precalculate
- Expensive operations
  - sin, cos
  - sqrt
  - /
  - *
  - +, -

Look-up tables:

If you need sin/cos, it’s often much faster to use a look-up table.

```
float sintab[3600], costab[3600];
for( int i = 0; i < 3600; i++ )
{
   sintab[i] = Math.Sin( i / 10 );
   costab[i] = Math.Cos( i / 10 );
}

…

float s = sintab[(int)(a * 10)];
float c = costab[(int)(a * 10)];
```

Efficiency

Optimization Primer

Some things to keep in mind:

- Float or double
- Don’t do work you don’t need to do
- Precalculate
- Expensive operations
- Programming Language
  - C#/C++
  - C++/Asm

Efficiency

Perceived Performance

Incremental Rendering

1. Real-time preview:

- Depth map
- Depth map plus materials
- Render without recursive reflections
- Render with very limited recursion

Still not real-time?

- Render half-res
- Adaptive resolution
- Optimize the application a bit

Efficiency

Perceived Performance

Incremental Rendering

2. Stationary camera:

- Render with normal recursion

Keep the application responsive:

Render lines of pixels until a certain number of milliseconds has passed; continue in the next frame.

Efficiency

Perceived Performance

Incremental Rendering

3. ‘Photograph mode’ :

- Invoked with a key
- Render with extreme recursion
- Use anti-aliasing
- Add screenshot feature

Keep the application responsive!

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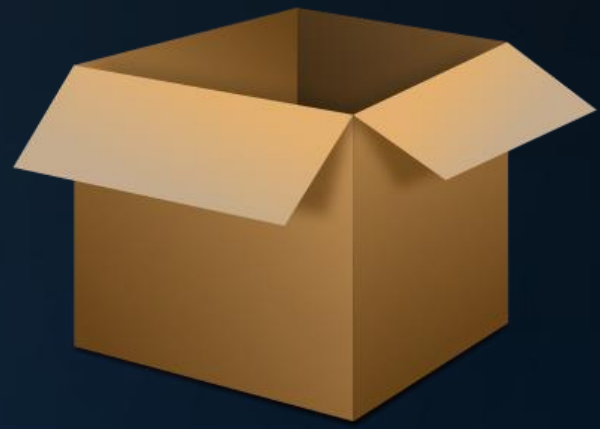
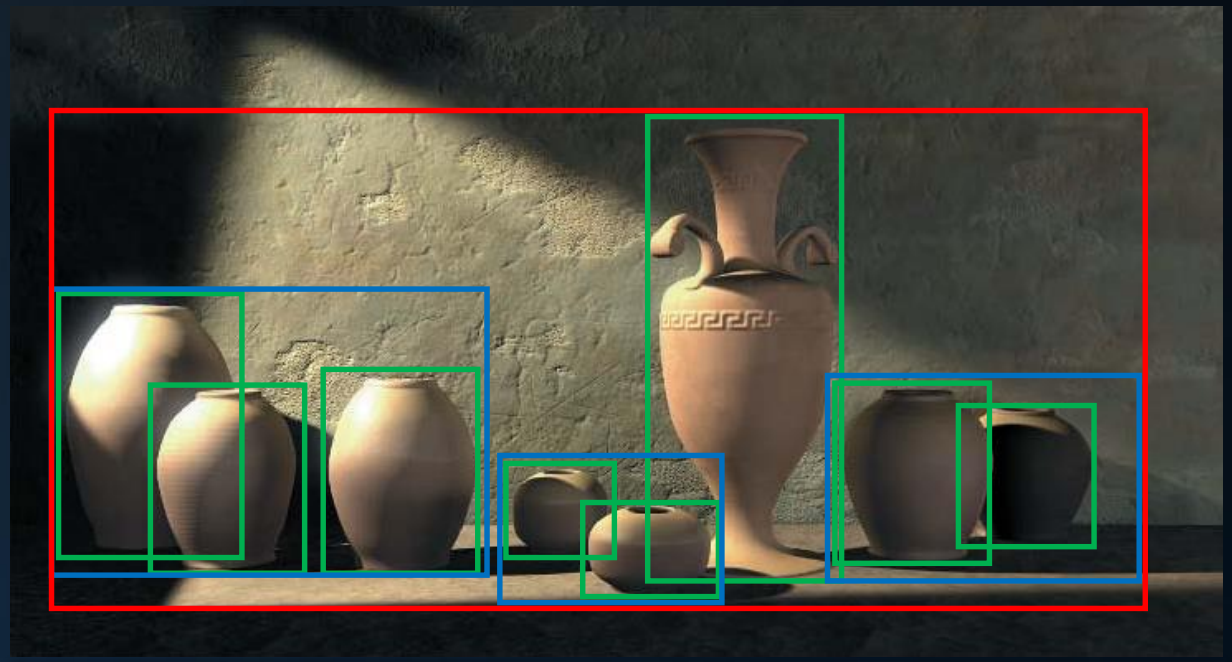


Boxes

Hierarchical Grouping

Using AABBs, we can recursively group objects.

- A ray that misses a green box will not check the triangles inside it;
- A ray that misses a blue box will skip the two green boxes inside it;
- A ray that misses the red box doesn’t hit anything at all.

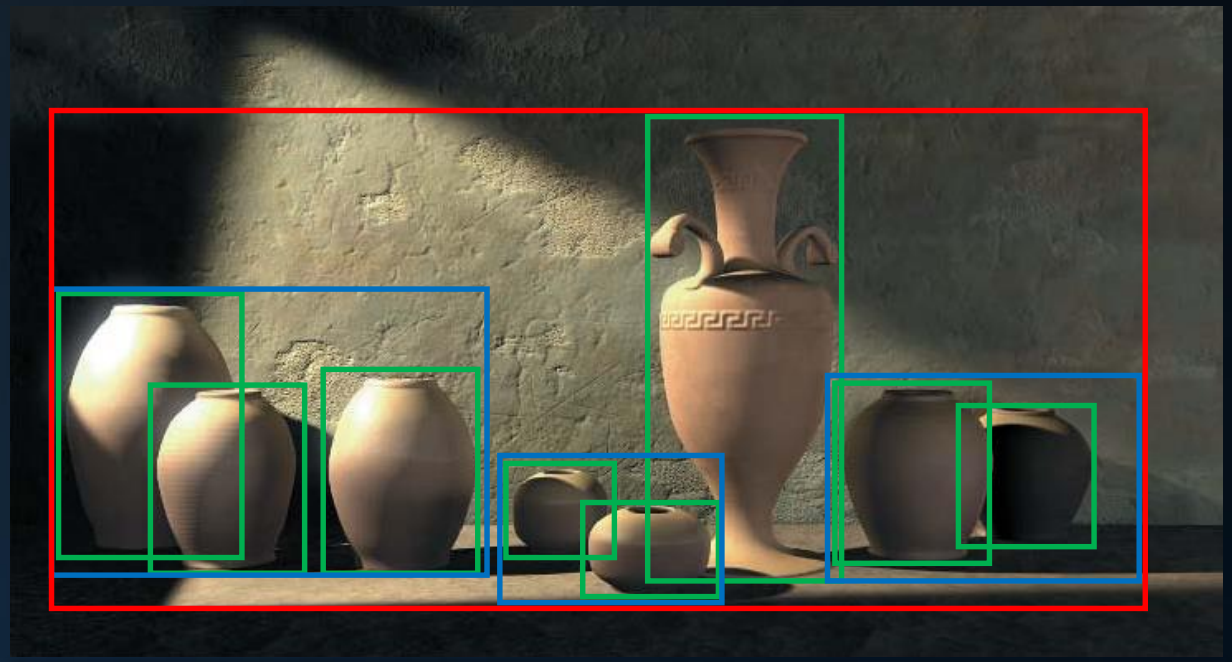


Boxes

Hierarchical Grouping

In a rasterization-based world:

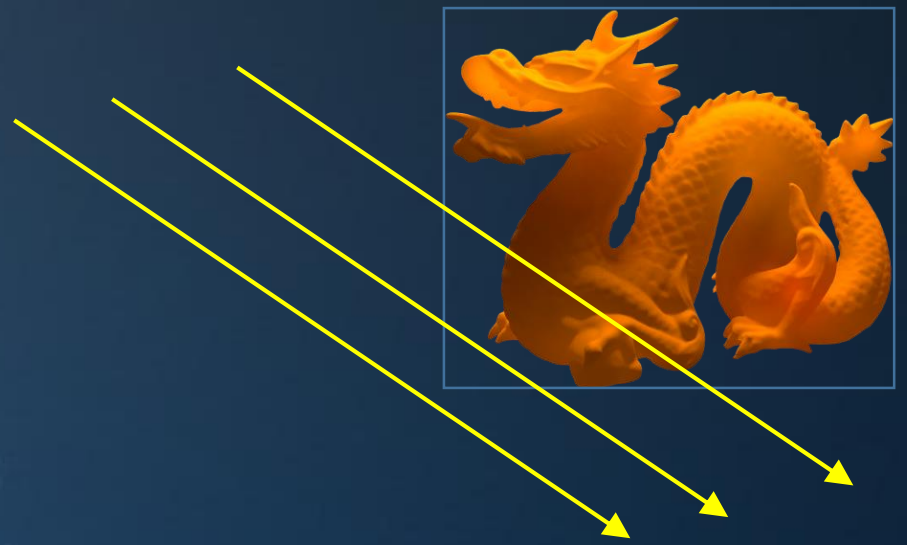
- If a green box is outside the view frustum, we don’t have to render the triangles inside it;
- If a blue box is outside the view frustum, we don’t have to test the green boxes inside it;
- If the red box is outside the view frustum, we don’t see anything.

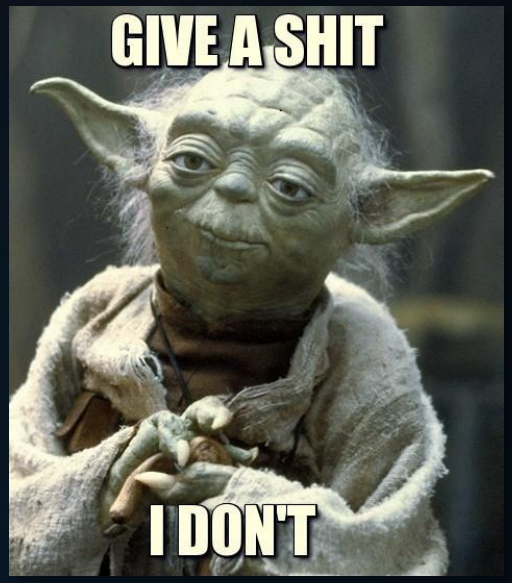


Boxes

Why Do We Care

We can use an AABB to quickly discard objects.



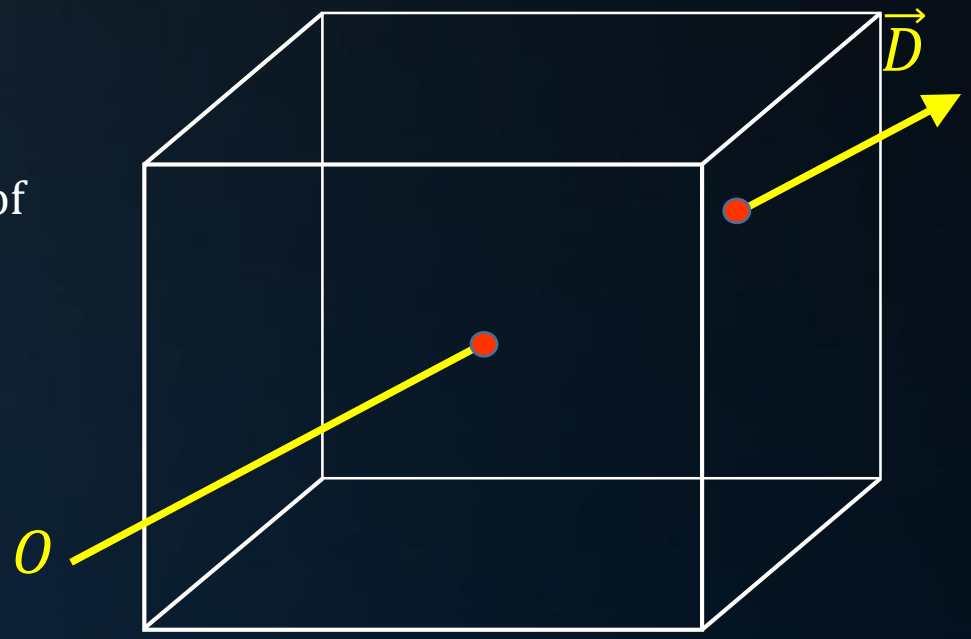


Boxes

Intersecting a Box

Basic ray/box intersection:

1. Intersect the ray with each of the 6 planes;
2. Keep the intersections that are on the same side of the remaining planes;
3. Determine the closest intersection point.



Boxes

Special Case: AABB

AABB: *Axis Aligned Bounding Box*.

Slab test:

Intersect the ray against pairs of planes.

$t_{min} = +\infty, t_{max} = -\infty$

$t_{min} = \max(t_{min}, \min(t1, t2))$

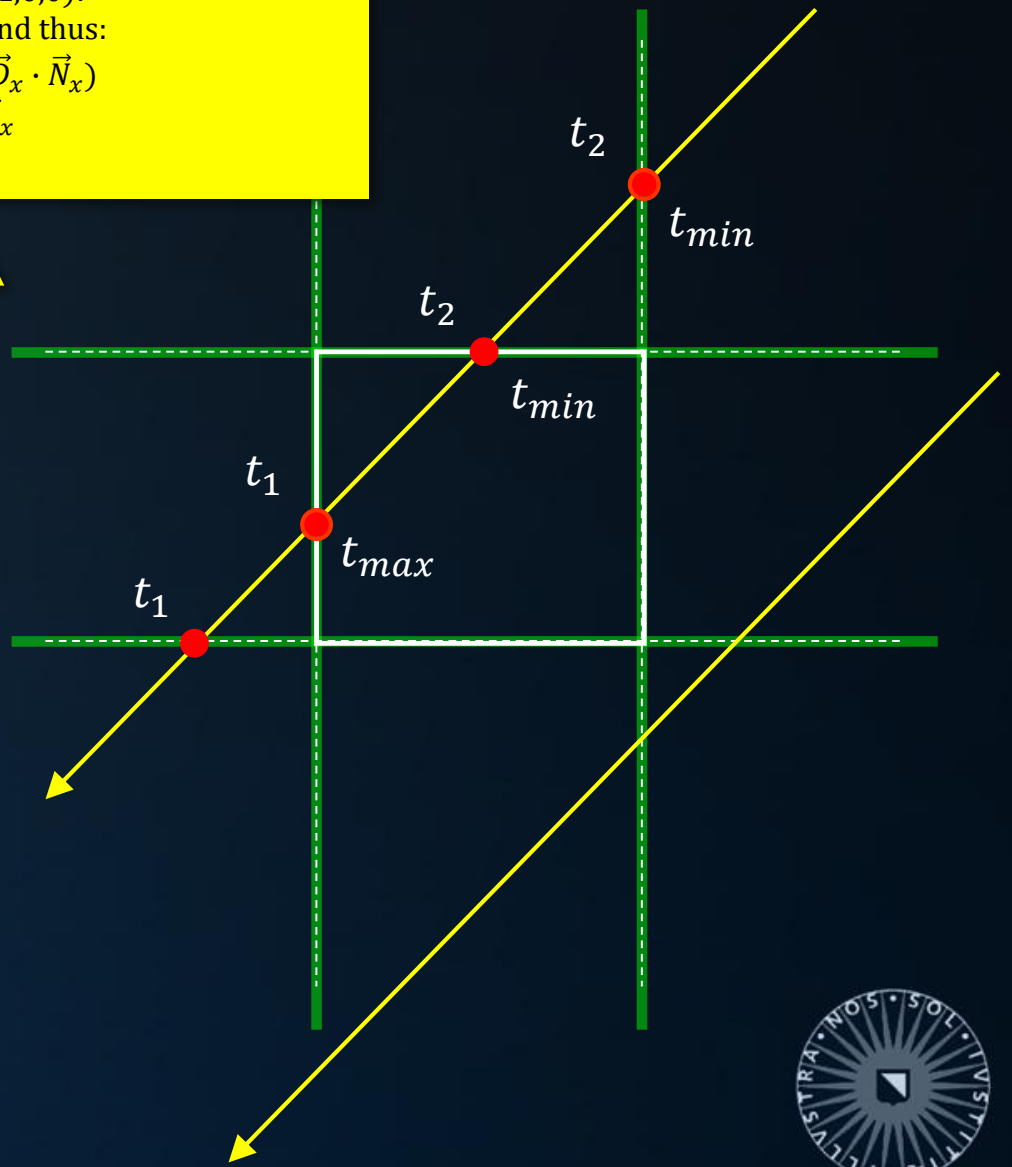
$t_{max} = \min(t_{max}, \max(t1, t2))$

intersection if: $t_{min} < t_{max}$

Since the box is axis aligned, calculating t is cheap:

$$t = -(O \cdot \vec{N} + d)/(\vec{D} \cdot \vec{N})$$
$$= -(O_x \cdot \vec{N}_x + d)/(\vec{D}_x \cdot \vec{N}_x)$$
$$= (x_{plane} - O_x)/\vec{D}_x$$

$d = -(\vec{N} \cdot P)$, where P is a point on the plane.
In this case, for $\vec{N} = (1,0,0)$:
$d = -P_x = -x_{plane}$, and thus:
$t = -(O_x \cdot \vec{N}_x + d)/(\vec{D}_x \cdot \vec{N}_x)$
$= -(O_x - x_{plane})/\vec{D}_x$
$=(x_{plane} - O_x)/\vec{D}_x$



Boxes

Special Case: AABB

In pseudo-code:

```
bool intersection( box b, ray r )
{
    float tx1 = (b.min.x - r.O.x) / r.D.x;
    float tx2 = (b.max.x - r.O.x) / r.D.x;

    float tmin = min( tx1, tx2 );
    float tmax = max( tx1, tx2 );

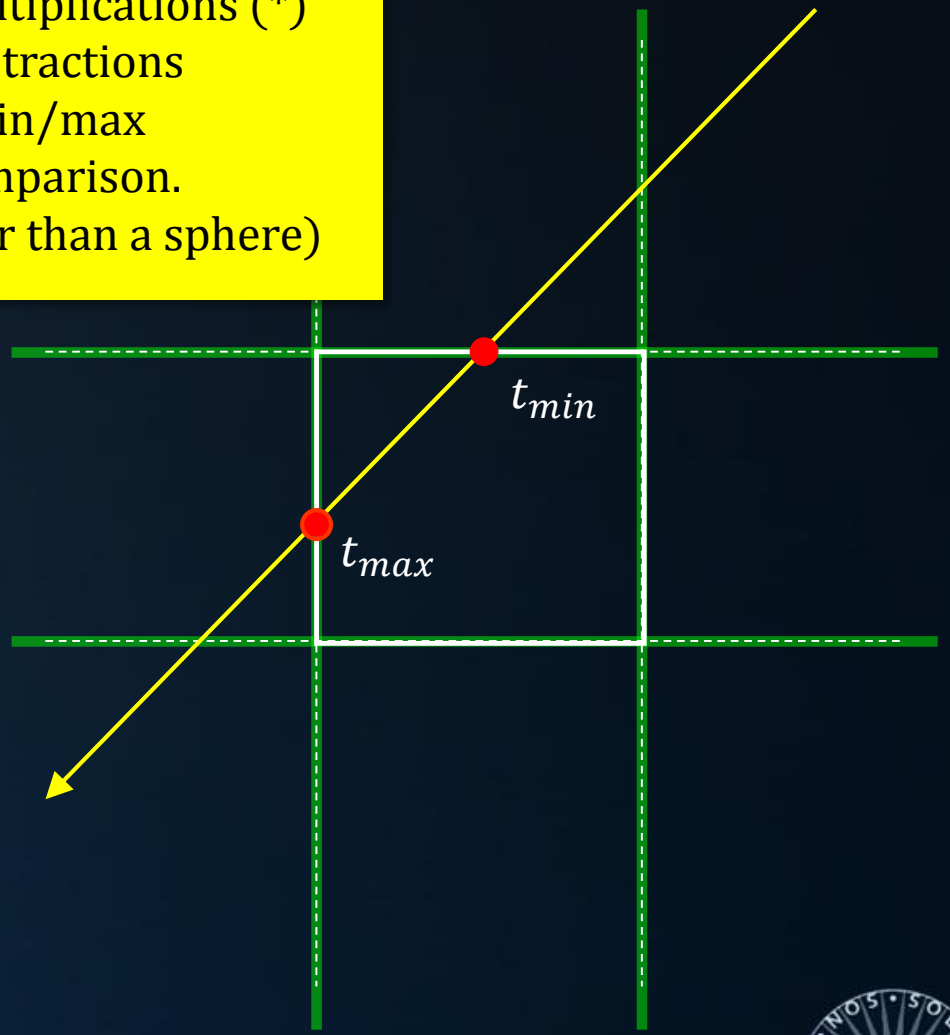
    float ty1 = (b.min.y - r.O.y) / r.D.y;
    float ty2 = (b.max.y - r.O.y) / r.D.y;

    tmin = max( tmin, min(ty1, ty2 ) );
    tmax = min( tmax, max(ty1, ty2 ) );

    return tmax >= tmin;
}
```

Intersecting a box in 3D:
- 6 multiplications (*)
- 6 subtractions
- 10 min/max
- 1 comparison.

(cheaper than a sphere)



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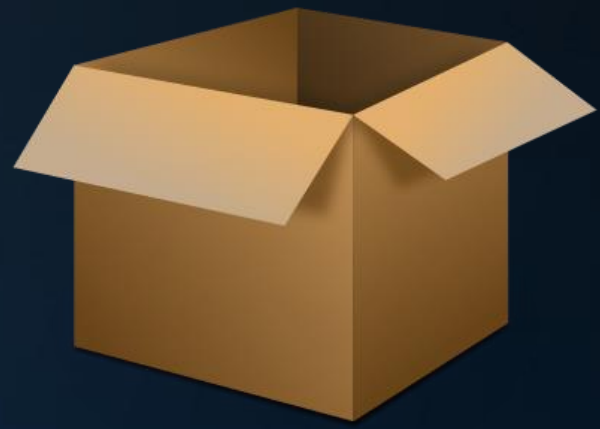
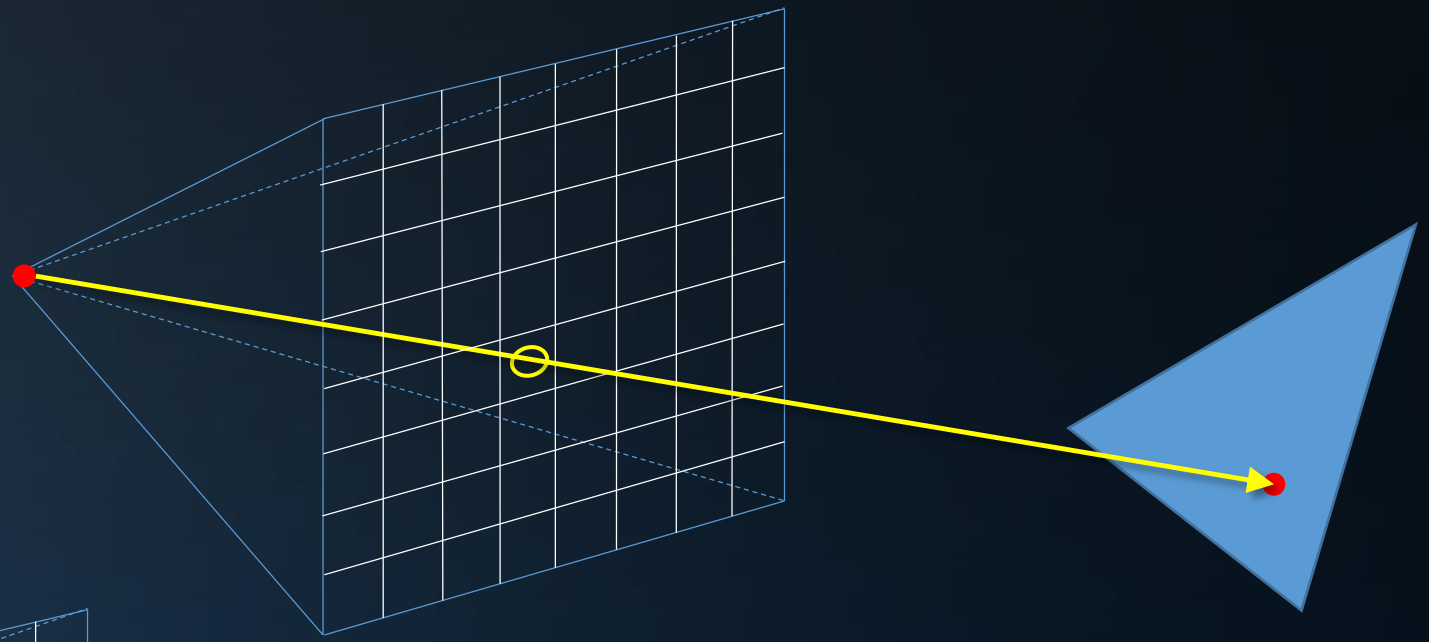
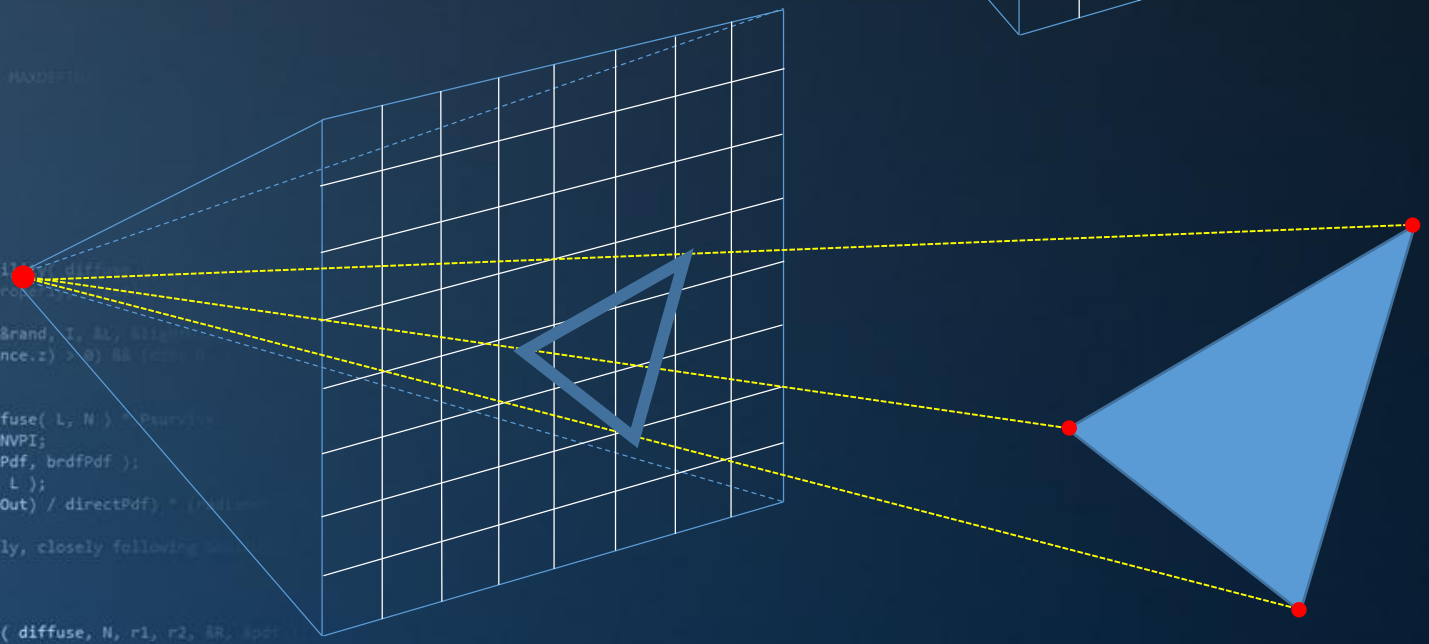


Rasterization

Primary Rays

Ray tracing versus Rasterization





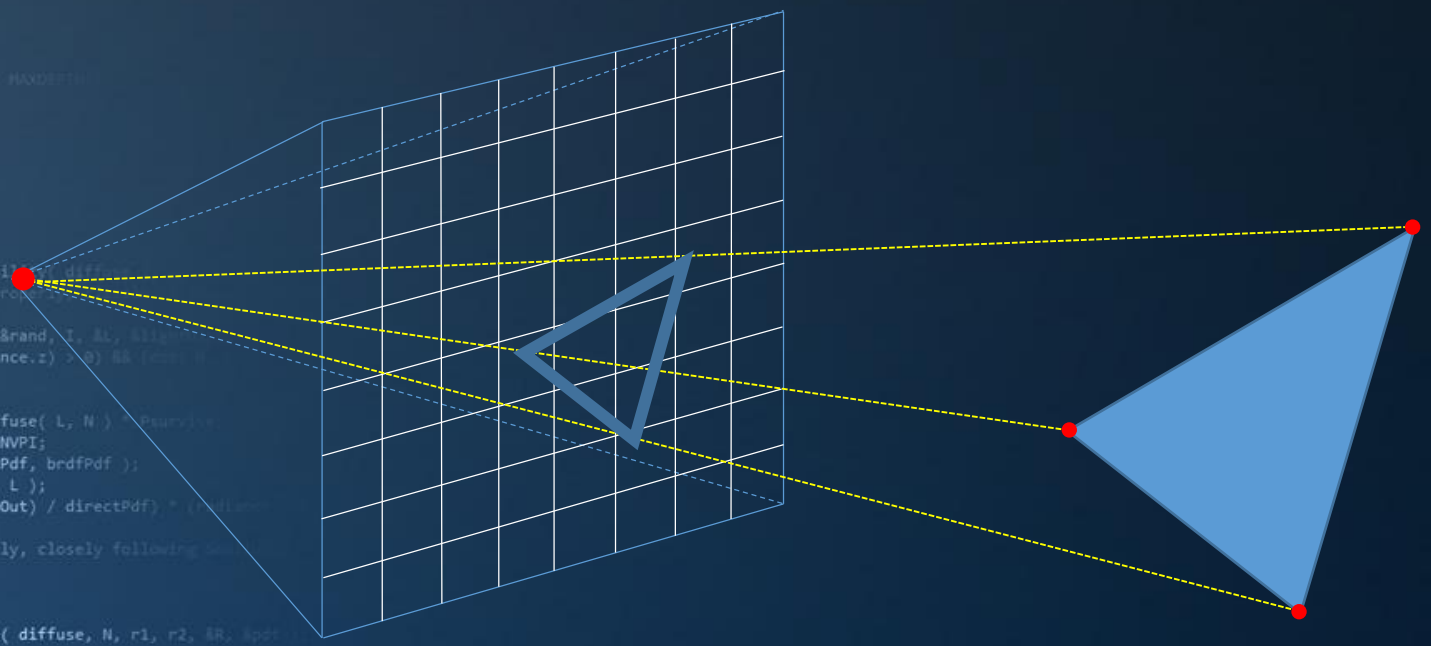
Rasterization

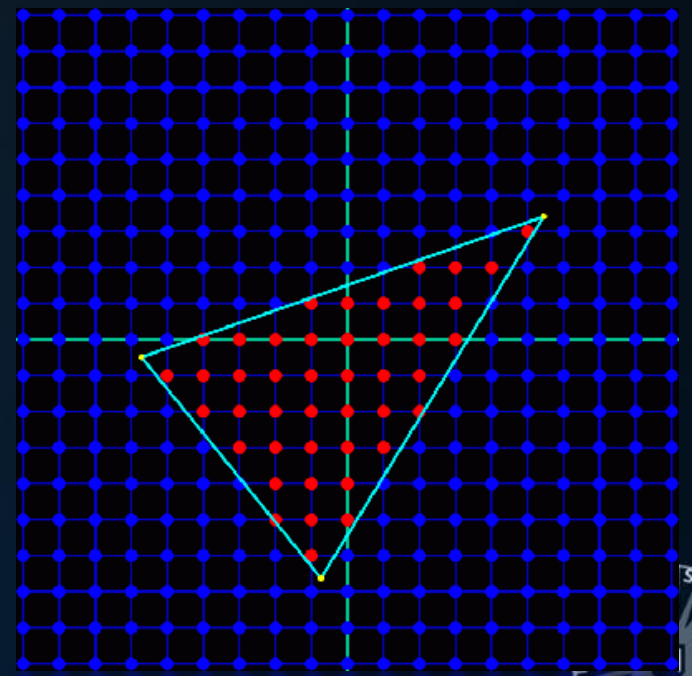
Primary Rays

Ray tracing versus Rasterization

Rasterization:

1. Transform primitive into camera space
2. Project vertices into 2D screen space
3. Determine which pixels are affected
4. Use z-buffer to sort (pixels of) primitives
5. Clip against screen boundaries





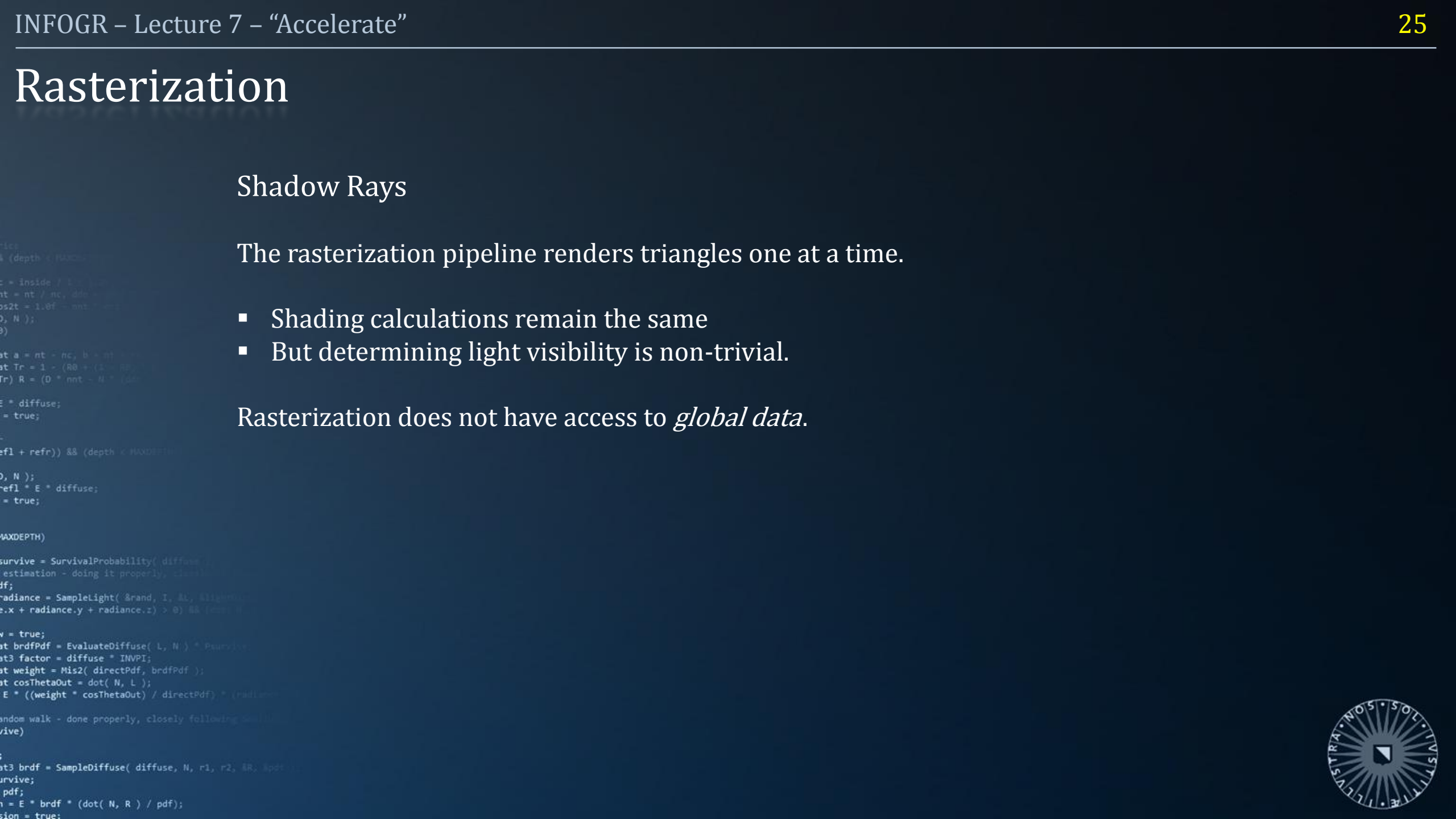
Rasterization

Shadow Rays

The rasterization pipeline renders triangles one at a time.

- Shading calculations remain the same
- But determining light visibility is non-trivial.

Rasterization does not have access to *global data*.



Rasterization

Spaces

Ray tracing typically happens in a single 3D coordinate system.

In rasterization, we use many coordinate systems:

- Camera space
- Clip space
- 2D screen space
- Model space
- Tangent space

We need efficient tools to get from one space to another. We will make extensive use of matrices to do this.

Rasterization

Common Concepts

Many things remain the same:

- Normal interpolation
- Shading
- Texture mapping
- The camera
- Boxes.

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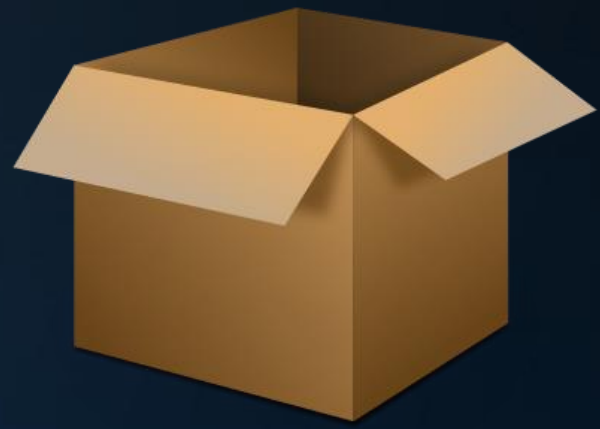


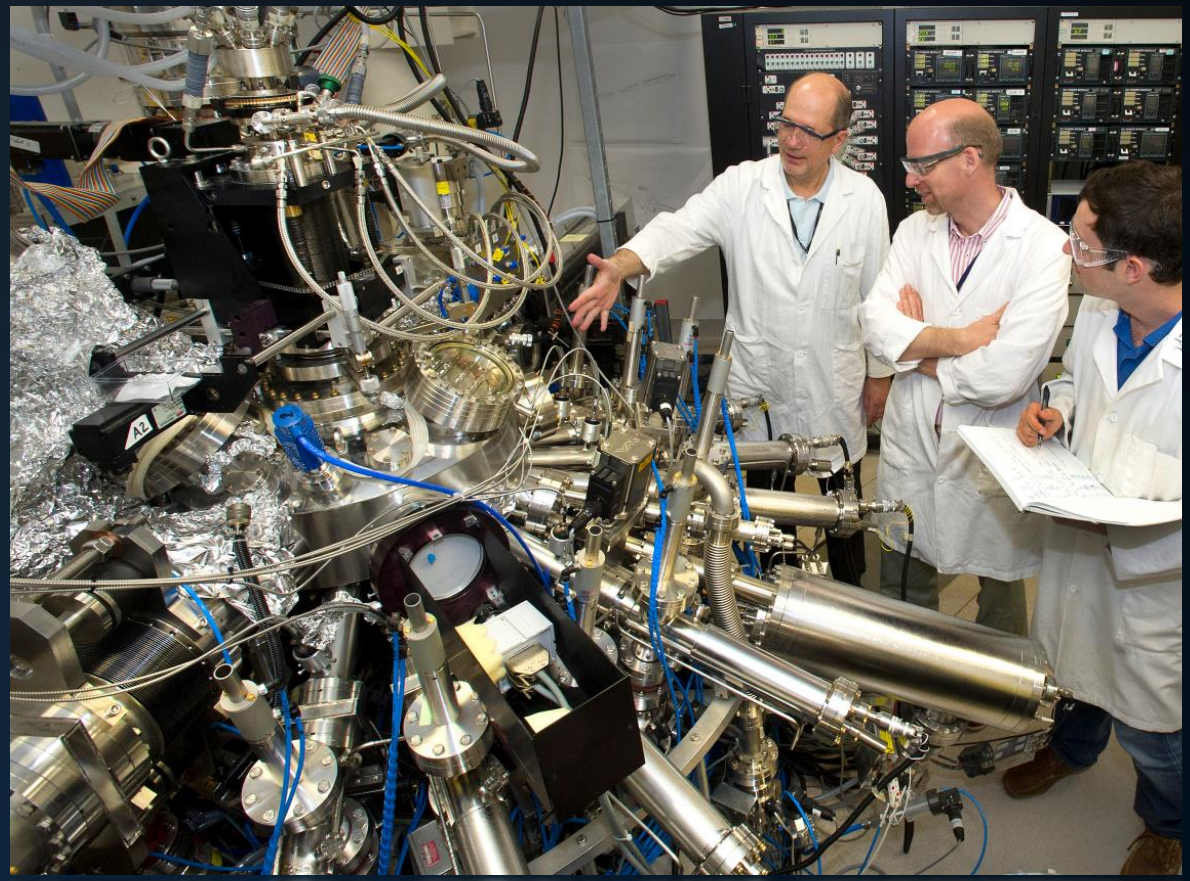
3D Engine

Topics covered so far:

Basics:
- Rasters
- Vectors
- Color representation

Ray tracing:
- Light transport
- Camera setup
- Textures

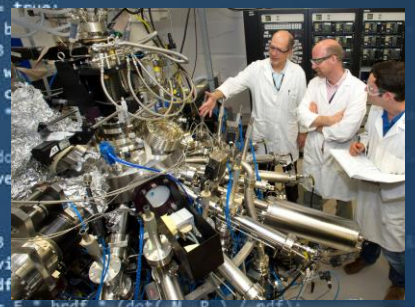
Shading:
- N dot L
- Distance attenuation
- Pure specular



3D Engine

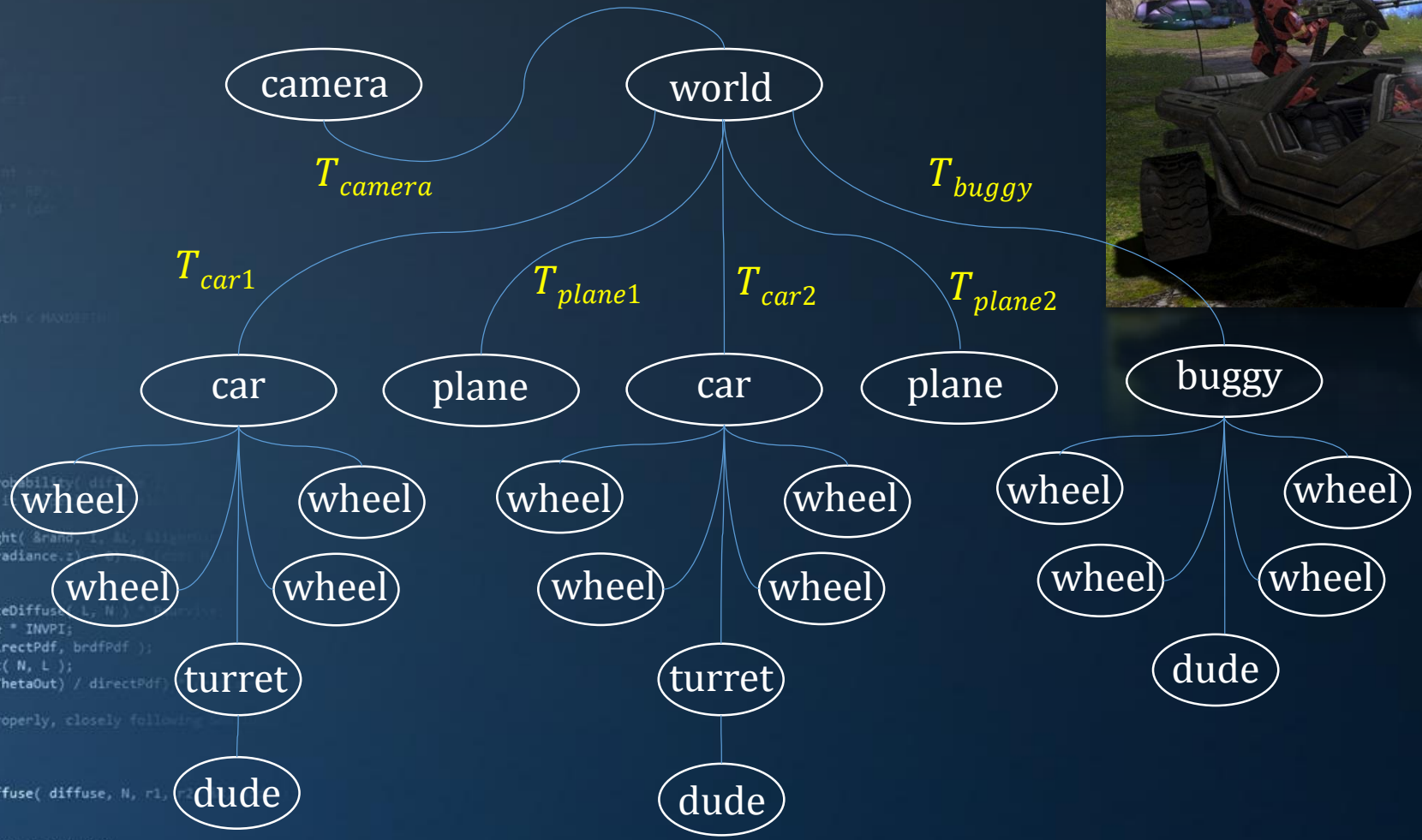
Rendering – Functional overview

1. Transform:
   translating / rotating / scaling meshes
2. Project:
   calculating 2D screen positions
3. Rasterize:
   determining affected pixels
4. Shade:
   calculate color per affected pixel



3D Engine

Rendering – Data Overview



3D Engine

Rendering – Data Overview

Objects are organized in a hierarchy: the *scenegraph*.

In this hierarchy, objects have translations and orientations relative to their parent node.

Relative translations and orientations are specified using matrices.

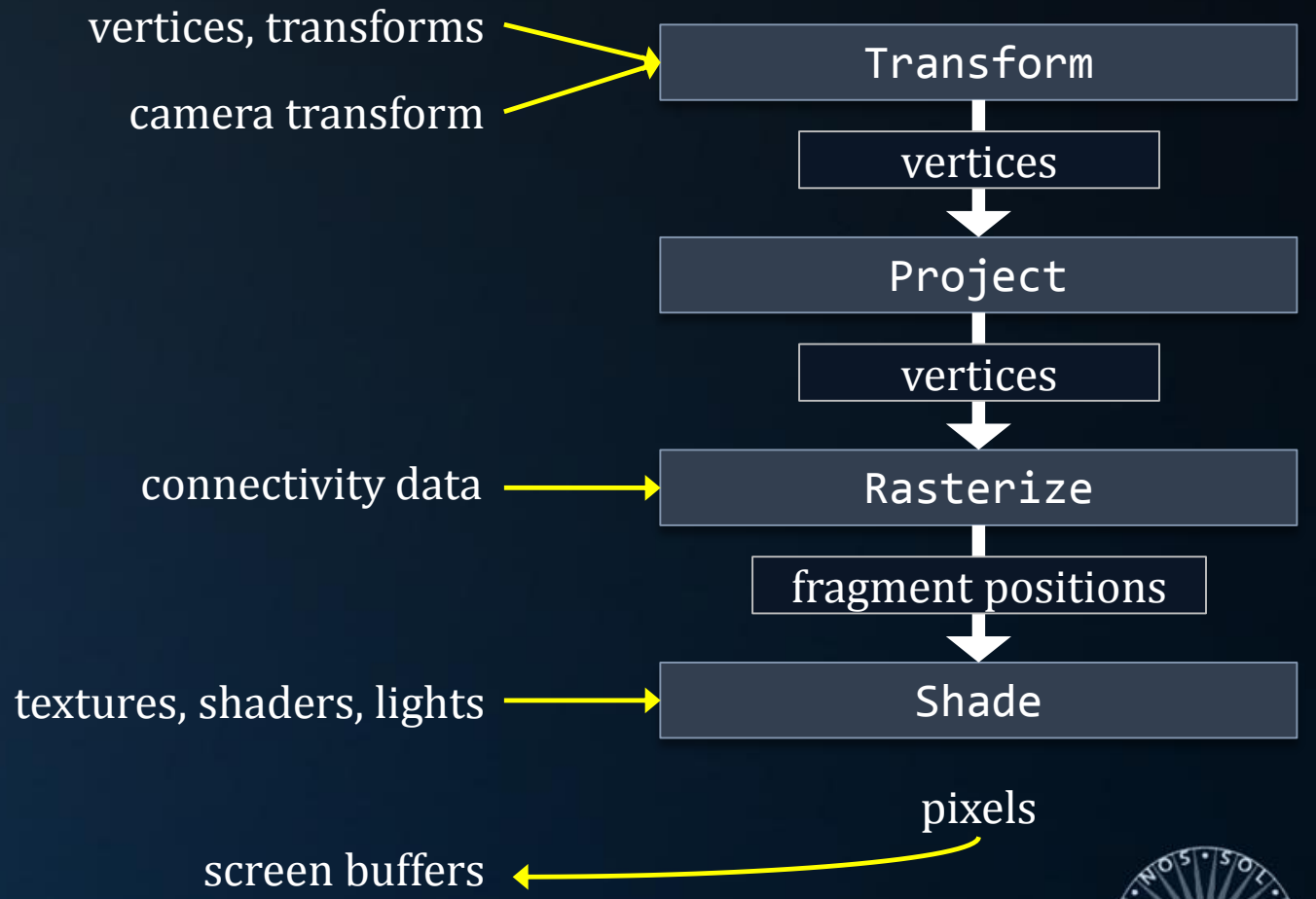
Mesh vertices are defined in a coordinate system known as *object space*.

3D Engine

Rendering – Data Overview

Transform takes our meshes from object space (3D) to camera space (3D).

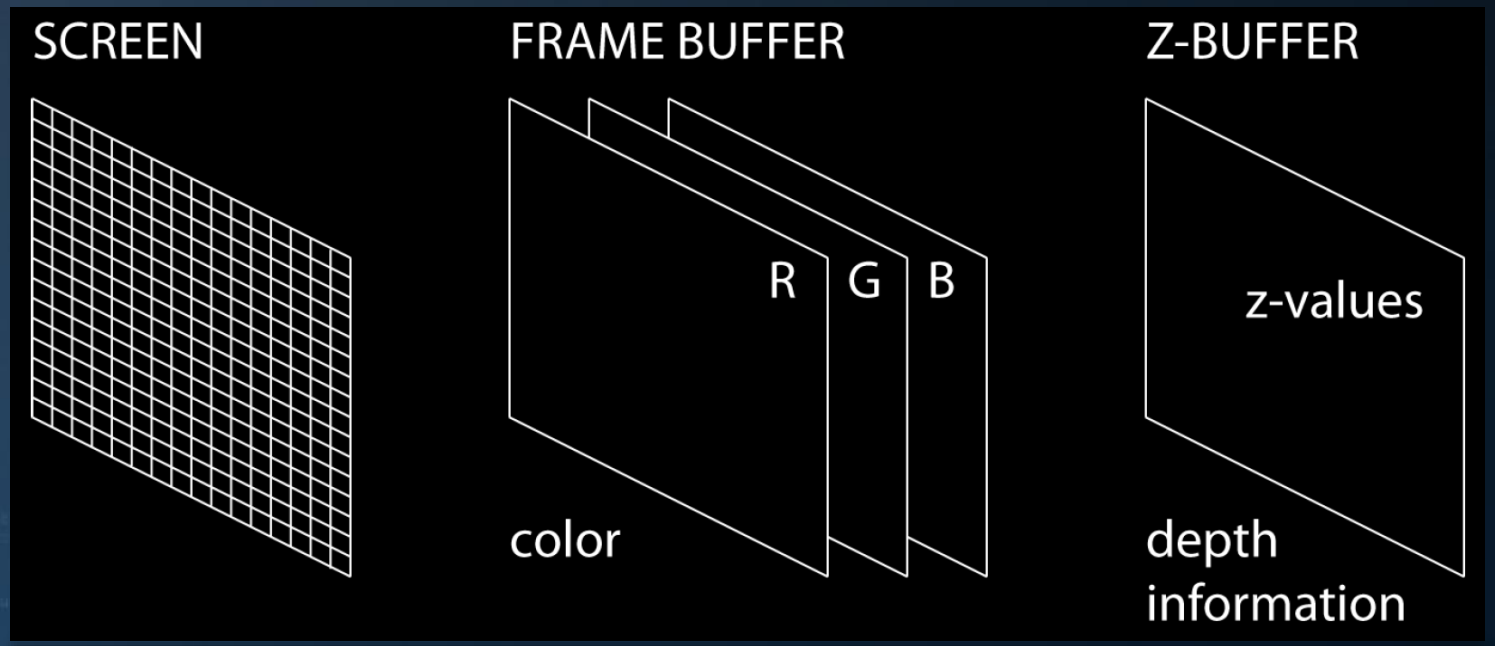
Project takes the vertex data from camera space (3D) to screen space (2D).



3D Engine

Rendering – Data Overview

The screen is represented by (at least) two buffers:



3D Engine

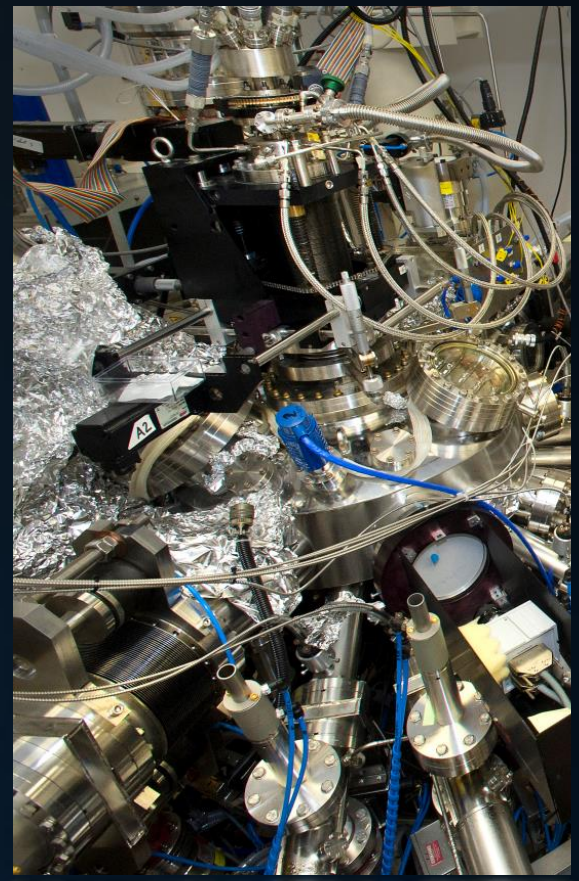
Rendering – Components

Scenegraph
- Culling — *Lecture 10*

Vertex transform pipeline
- Matrices to convert from one space to another — *Lecture 9*
- Perspective — *Lecture 11*

Rasterization
- Interpolation
- Clipping — *Lecture 14*
- Depth sorting: z-buffer — *Lecture 14*

Shading
- Light / material interaction — *P2*
- Complex materials — *P3*



3D Engine

Transformations

Rendering a scene graph is done using a recursive function:

```
void SGNode::Render( mat4& M )
{
   mat4 M’ = M_local * M;
   mesh->Rasterize( M’ );
   for( int i = 0; i < childCount; i++ )
      child[i]->Render( M’ );
};
```

Here, matrix concatenation is part of the recursive flow.

3D Engine

Transformations

To transform meshes to world space, we call SGNode::Render with an identity matrix.

To transform meshes to camera space, we call it with the *inverse* transform of the camera.

Remember: the world revolves around the viewer; instead of turning the viewer, we turn the world in the opposite direction.

```
void SGNode::Render( mat4& M )
{
   mat4 M’ = M_local * M;
   mesh->Rasterize( M’ );
   for( int i = 0; i < childCount; i++ )
      child[i]->Render( M’ );
};
```

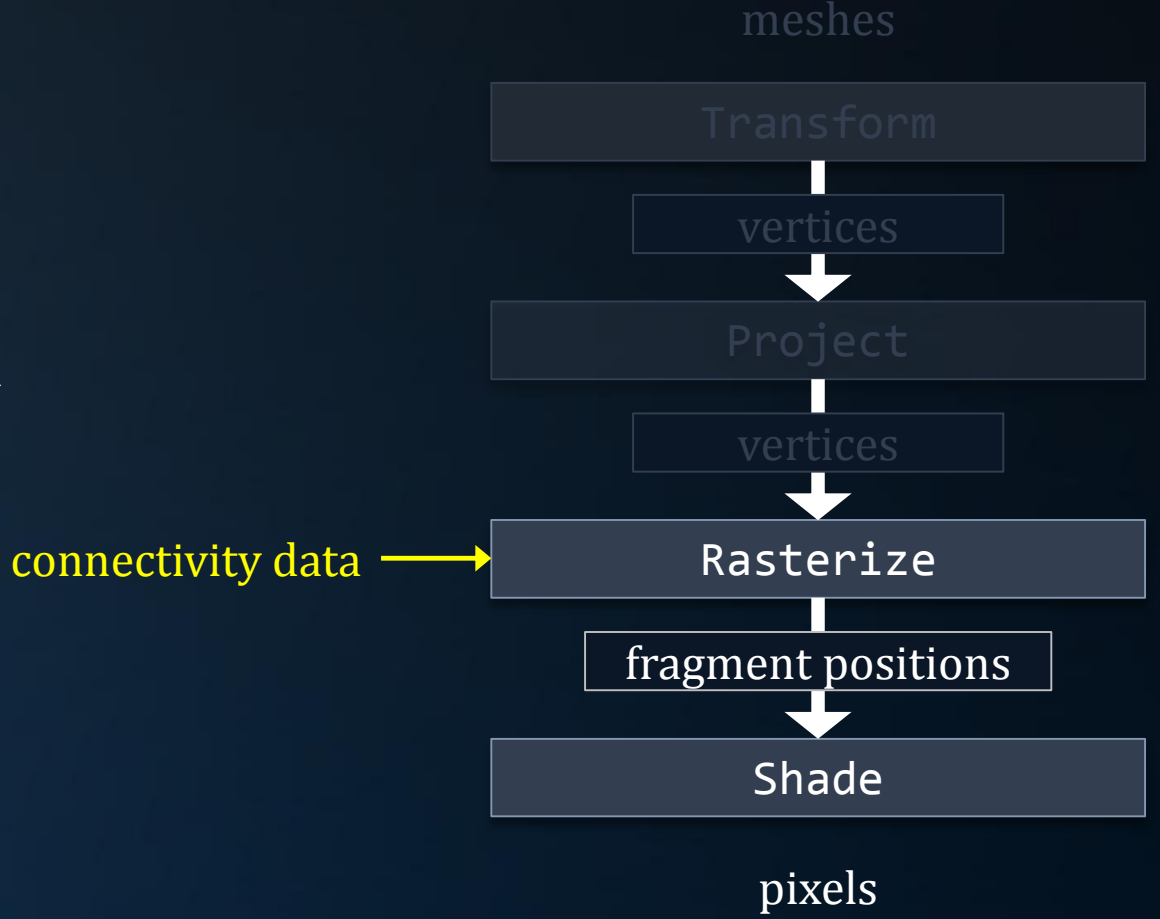
3D Engine

After projection

The output of the projection stage is a stream of vertices for which we know 2D screen positions.

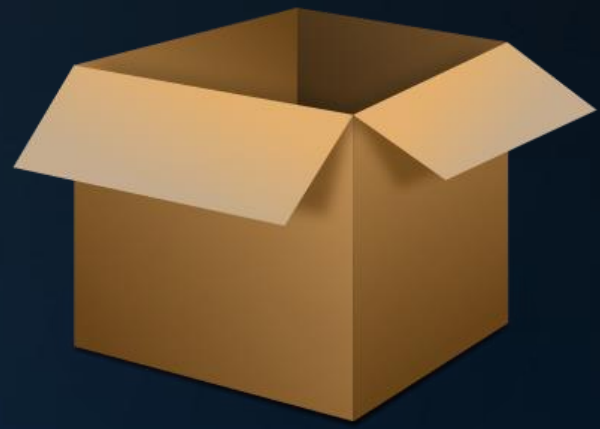
The vertex stream must be combined with connectivity data to form triangles.

‘Triangles’ on a raster consist of a collection of pixels, called *fragments.*



Today’s Agenda:

- Efficiency
- Boxes, AABBs & Groupings
- To Rasterization
- 3D Engine Overview
- Textures



INFOGR – Computer Graphics

Jacco Bikker & Debabrata Panja - April-July 2017

END OF lecture 7: “Accelerate”

Next lecture: “OpenGL”