Game Technology

Lecture 3 – 24.10.2015
Software Rendering

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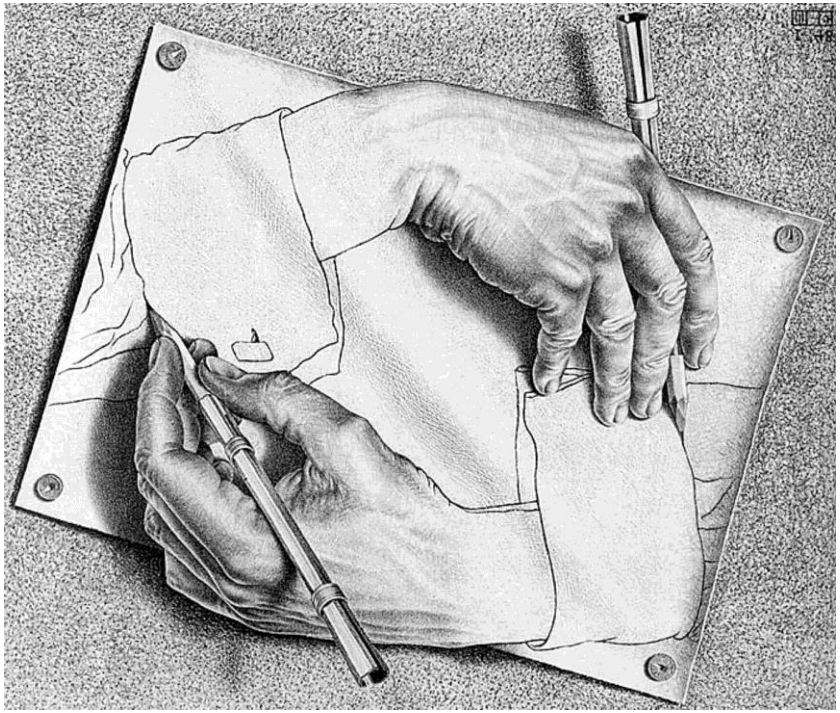

Dr.-Ing. Florian Mehm

Prof. Dr.-Ing. Ralf Steinmetz
KOM - Multimedia Communications Lab

2D Rendering

Super Mario Land, 1989

Positioning

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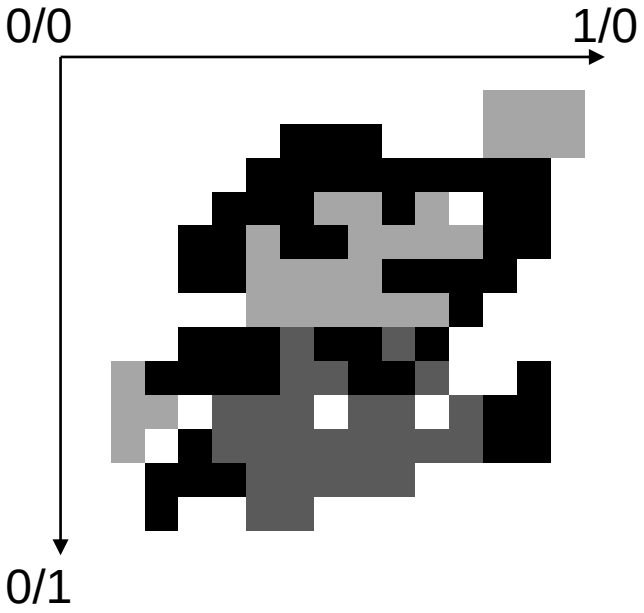
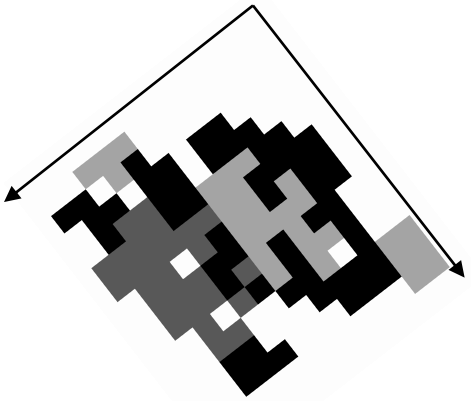
Nice property: No need to do heavy calculations on input pixels

Can „blit“ the image from one memory region to the screen buffer

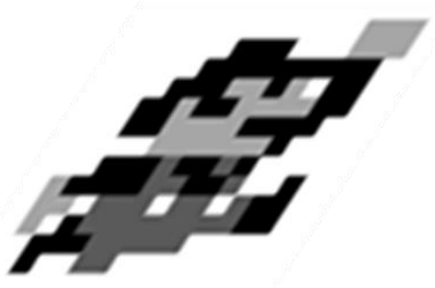
Scaling



Rotations



Shearing



Fonts

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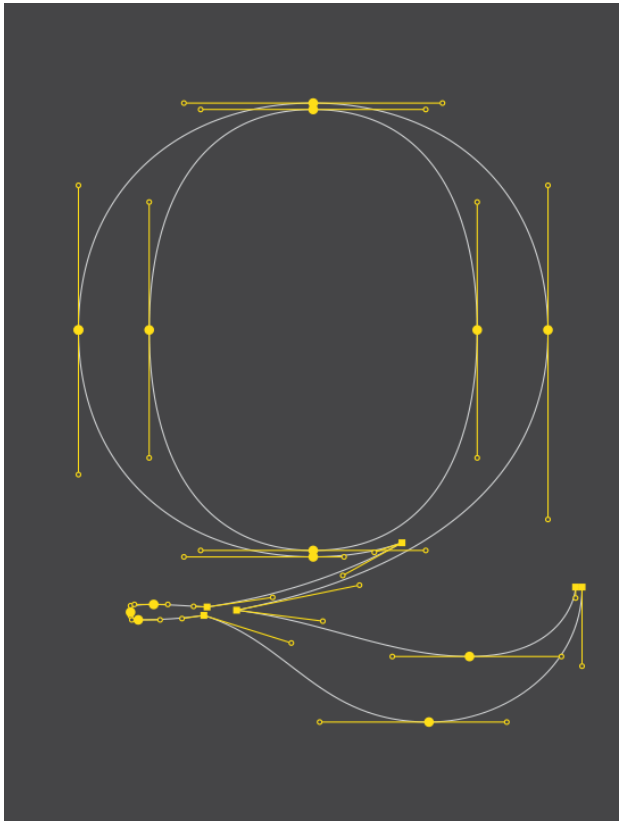
TrueType format

- Line segments and Bézier curves
- Kerning
  - VA
- Pixel snapping

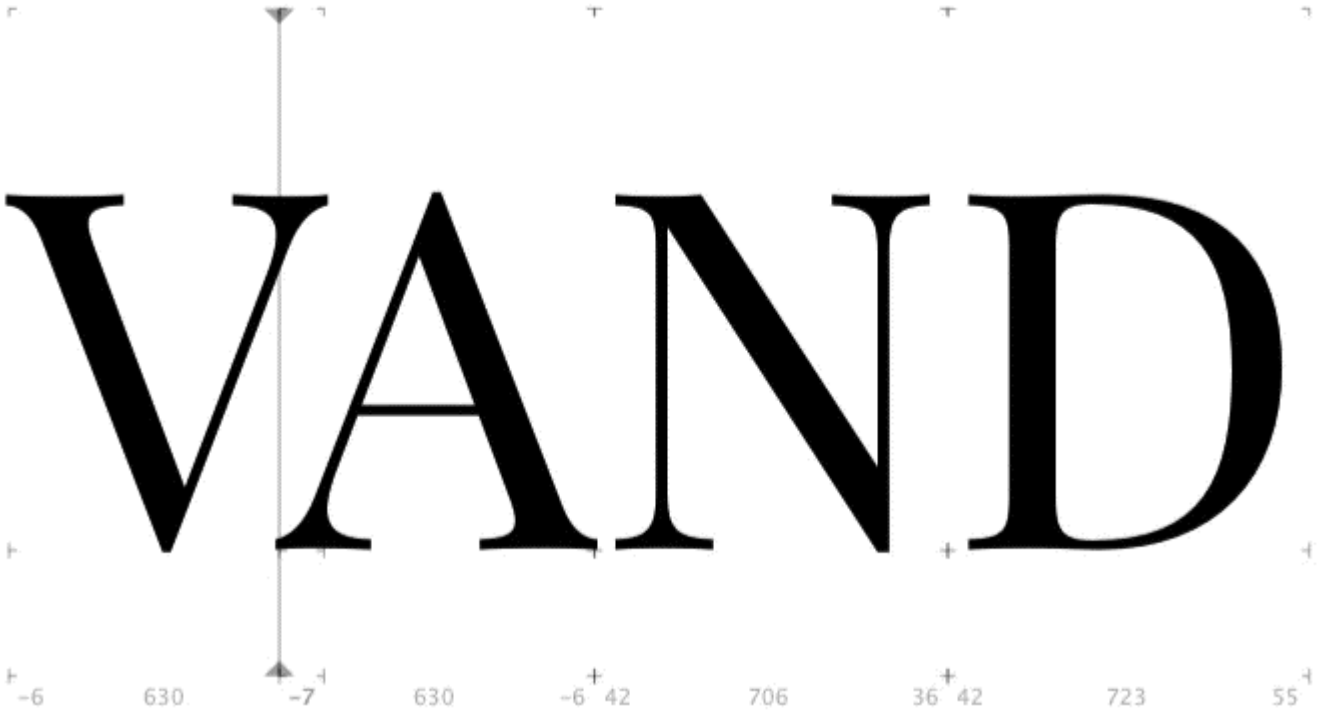
„TrueType systems include a virtual machine that executes programs inside the font”

Unicode

- More than 110,000 characters



„VA“



Subpixel Rendering

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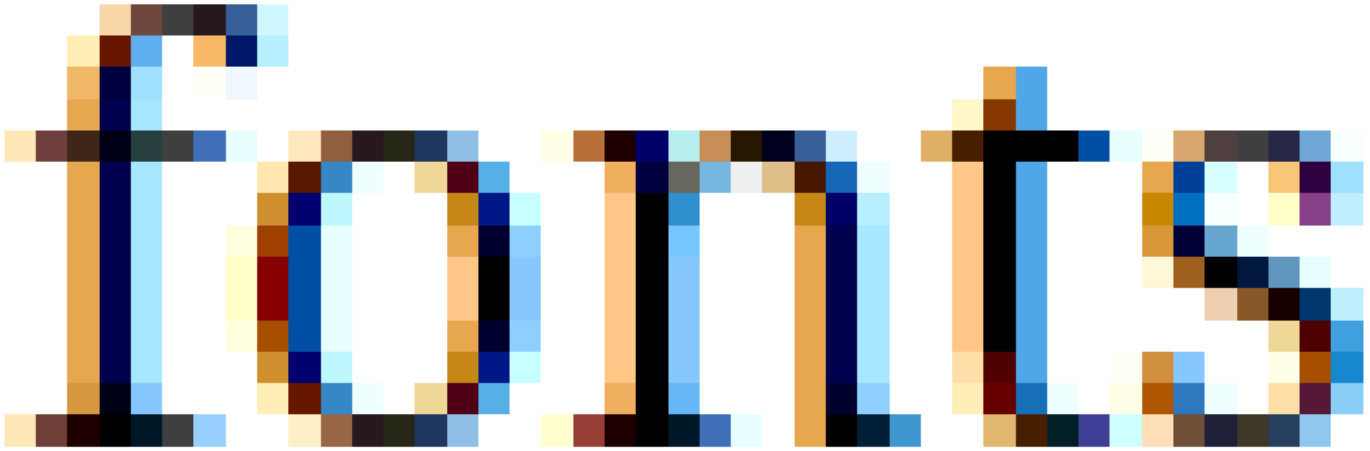

Bitmap Fonts

Font Libs

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Freetype

http://www.freetype.org

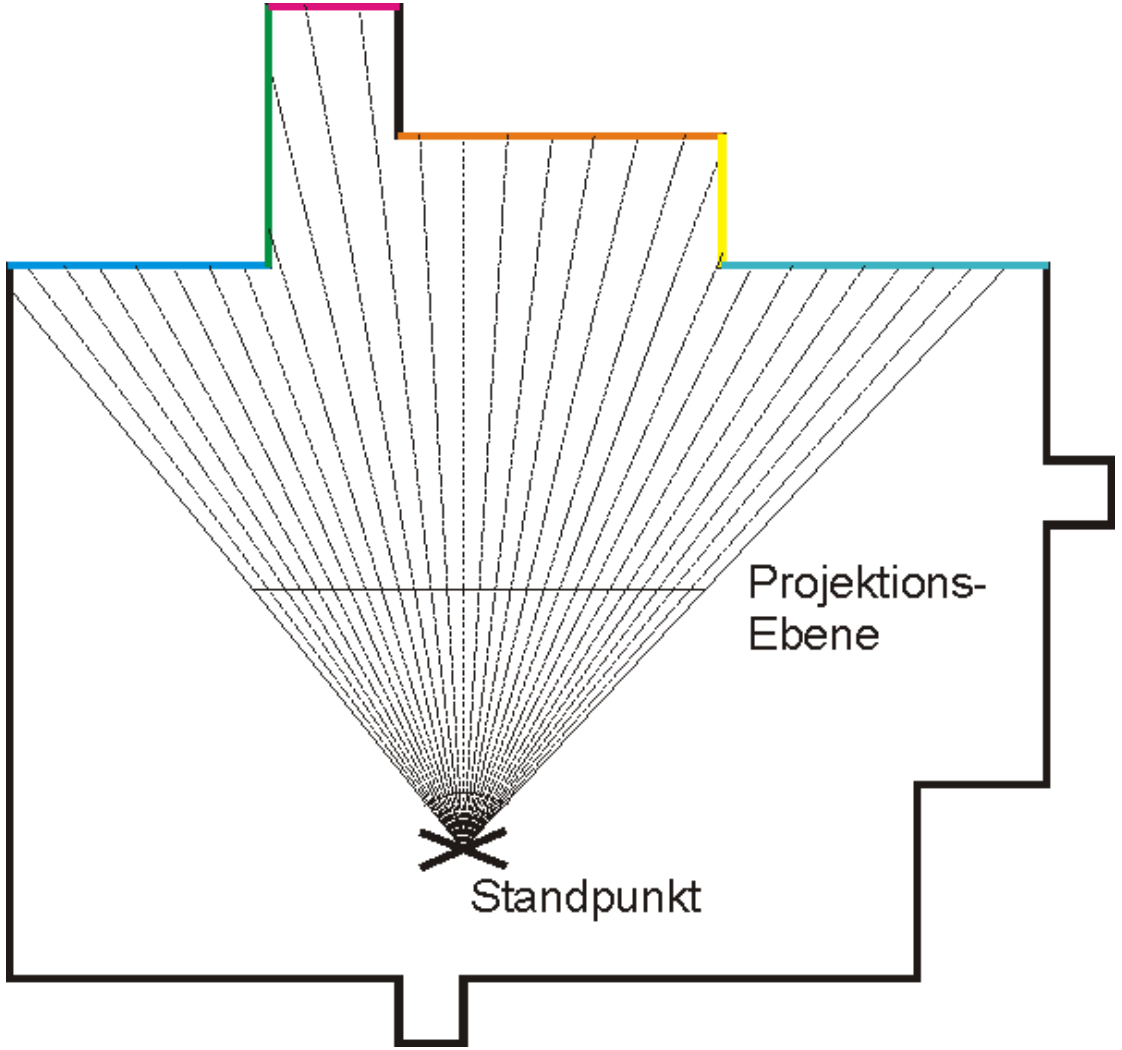
stb_truetype

https://github.com/nothings/stb

„Raycasting“

Catacomb 3-D, 1991

„Raycasting“



„Raycasting“

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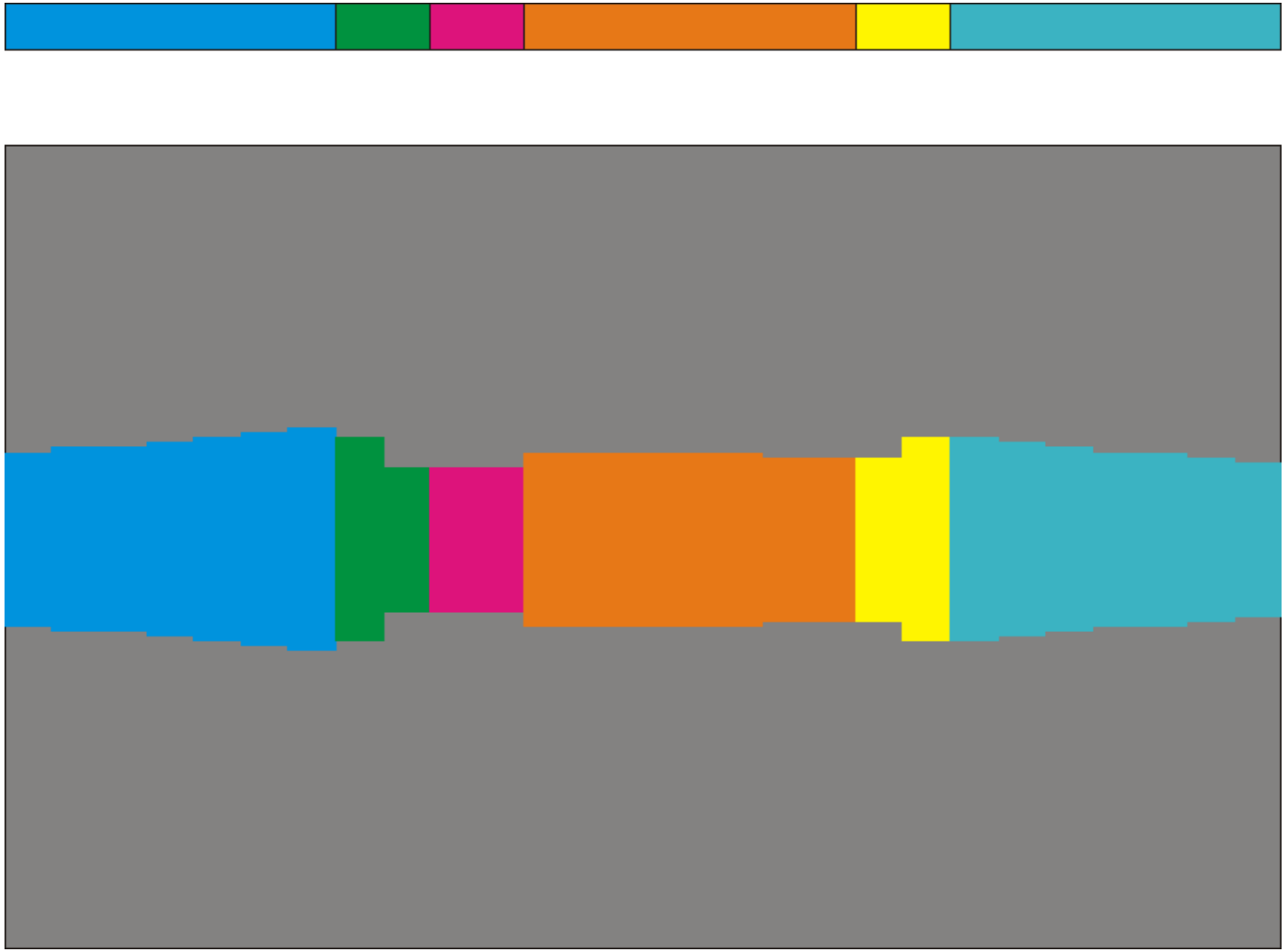
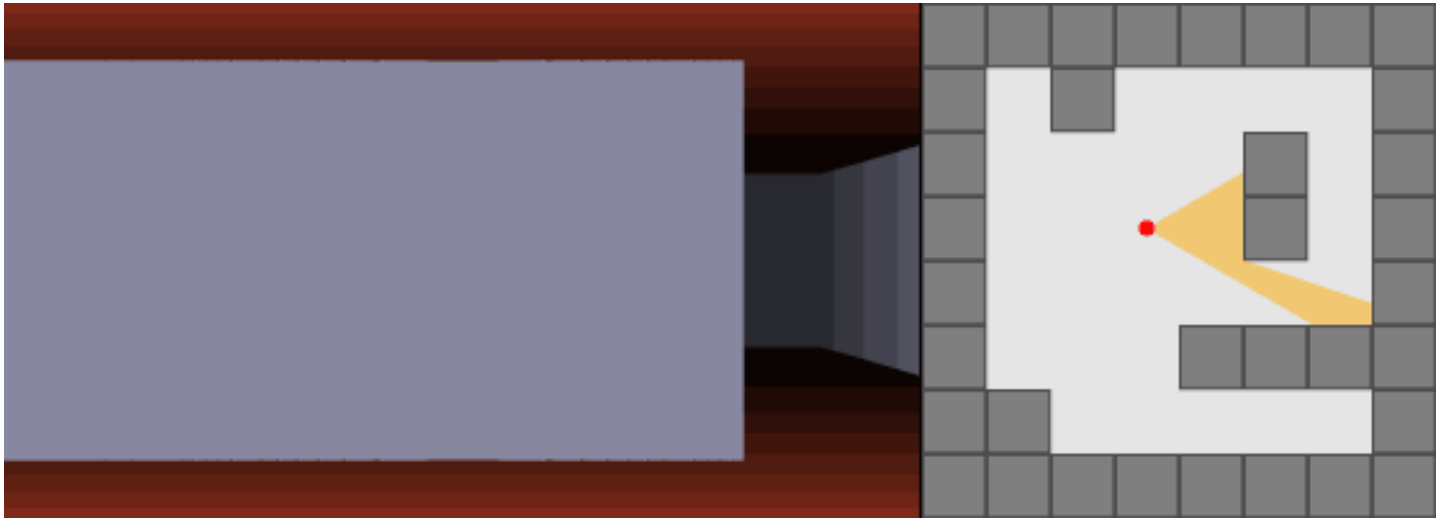
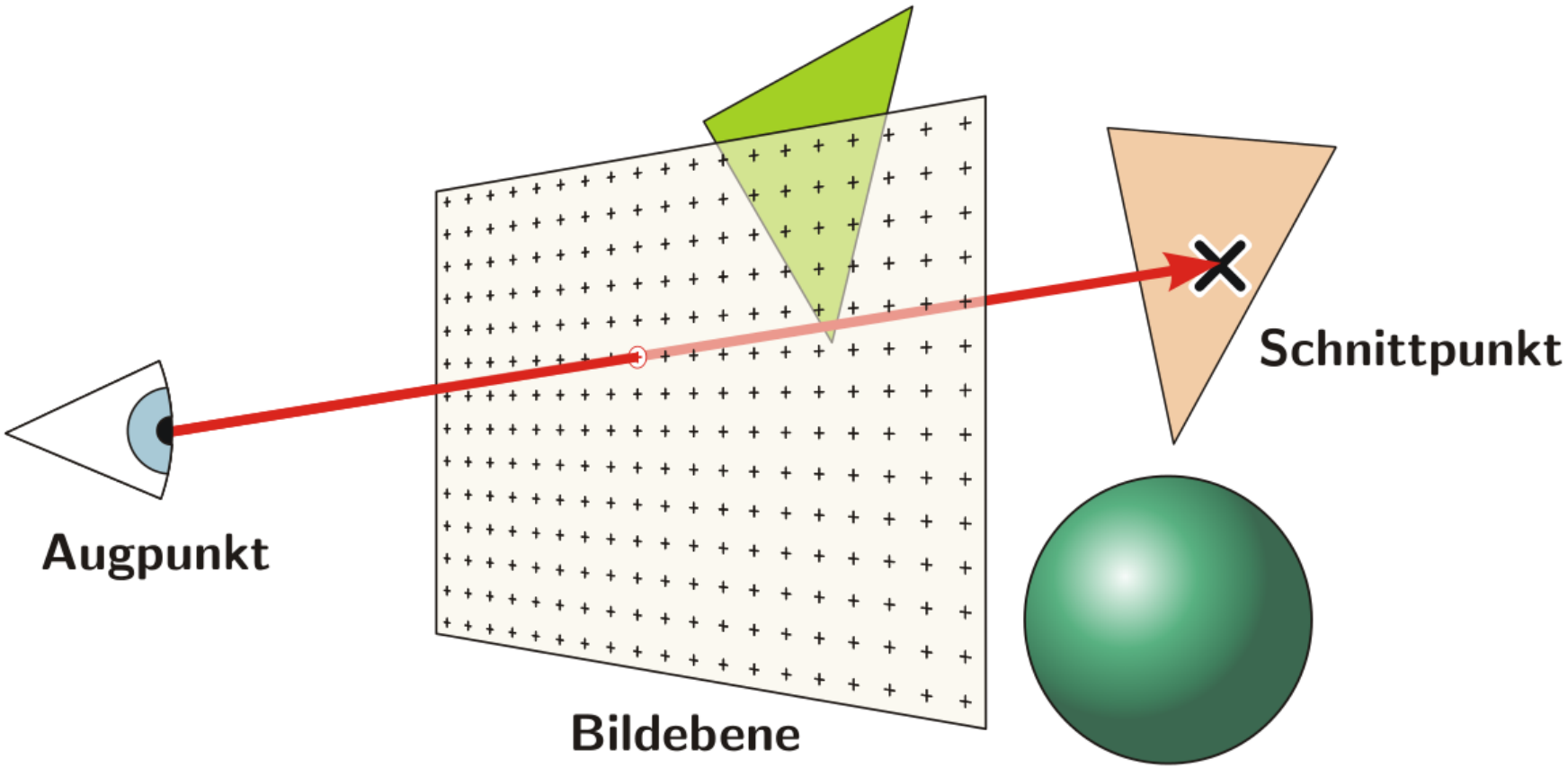


„Raycasting“

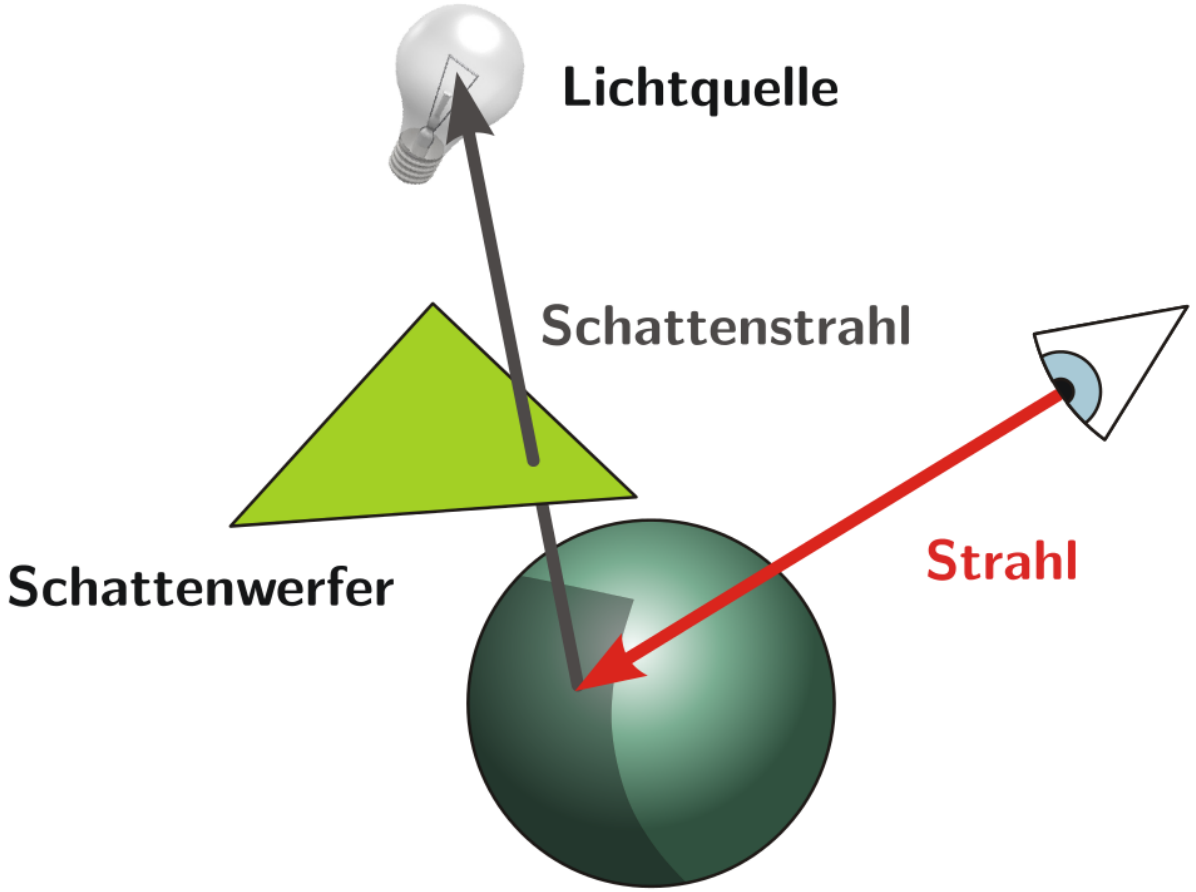


https://en.wikipedia.org/wiki/Wolfenstein_3D_engine

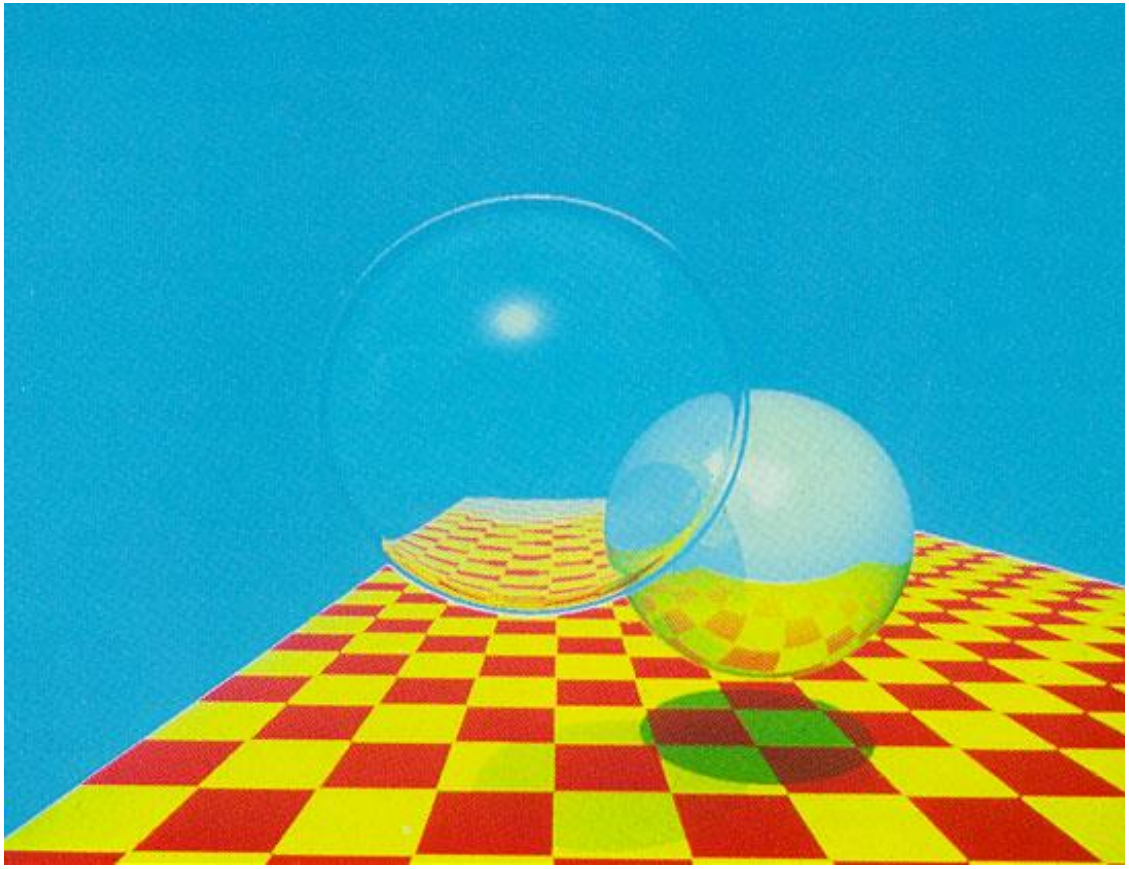
Raytracing



Raytracing

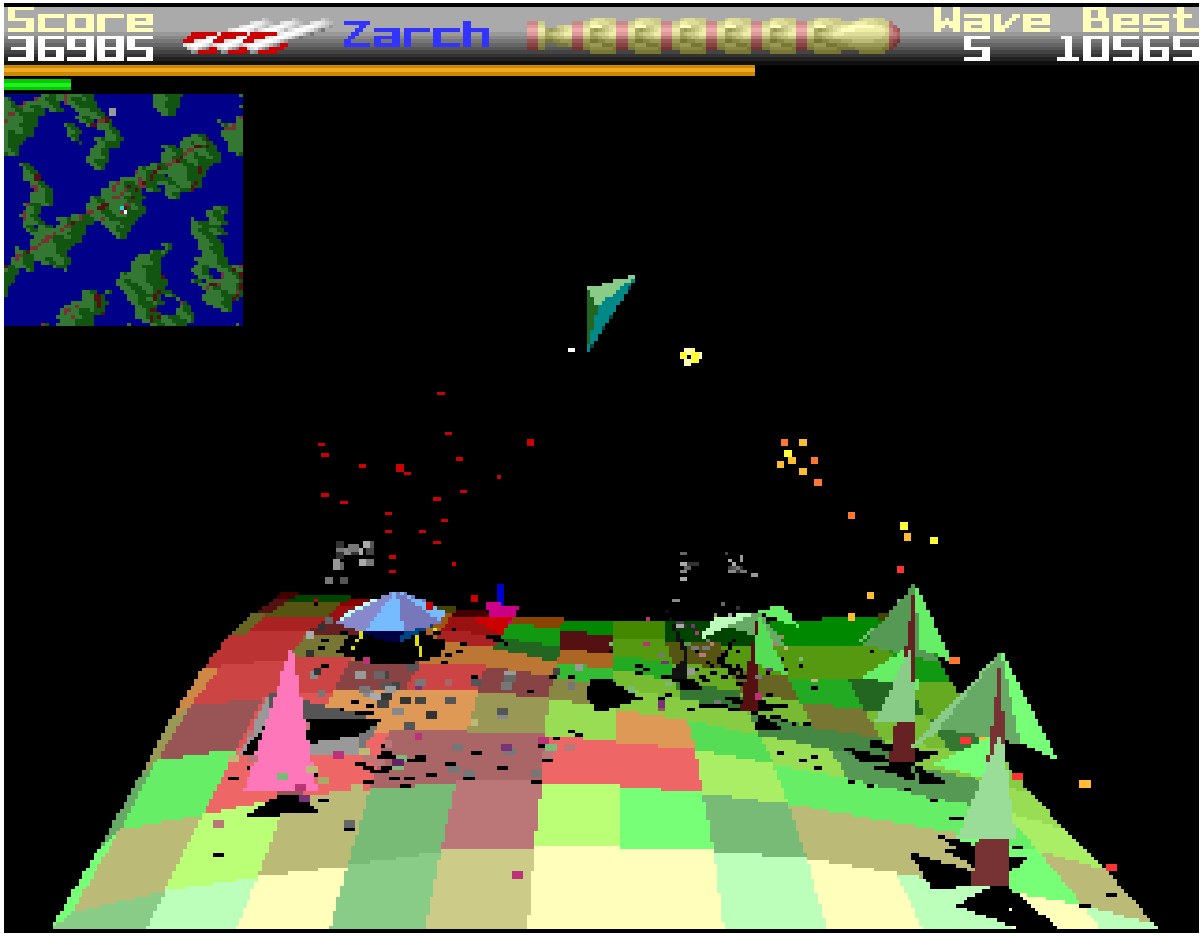


Raytracing



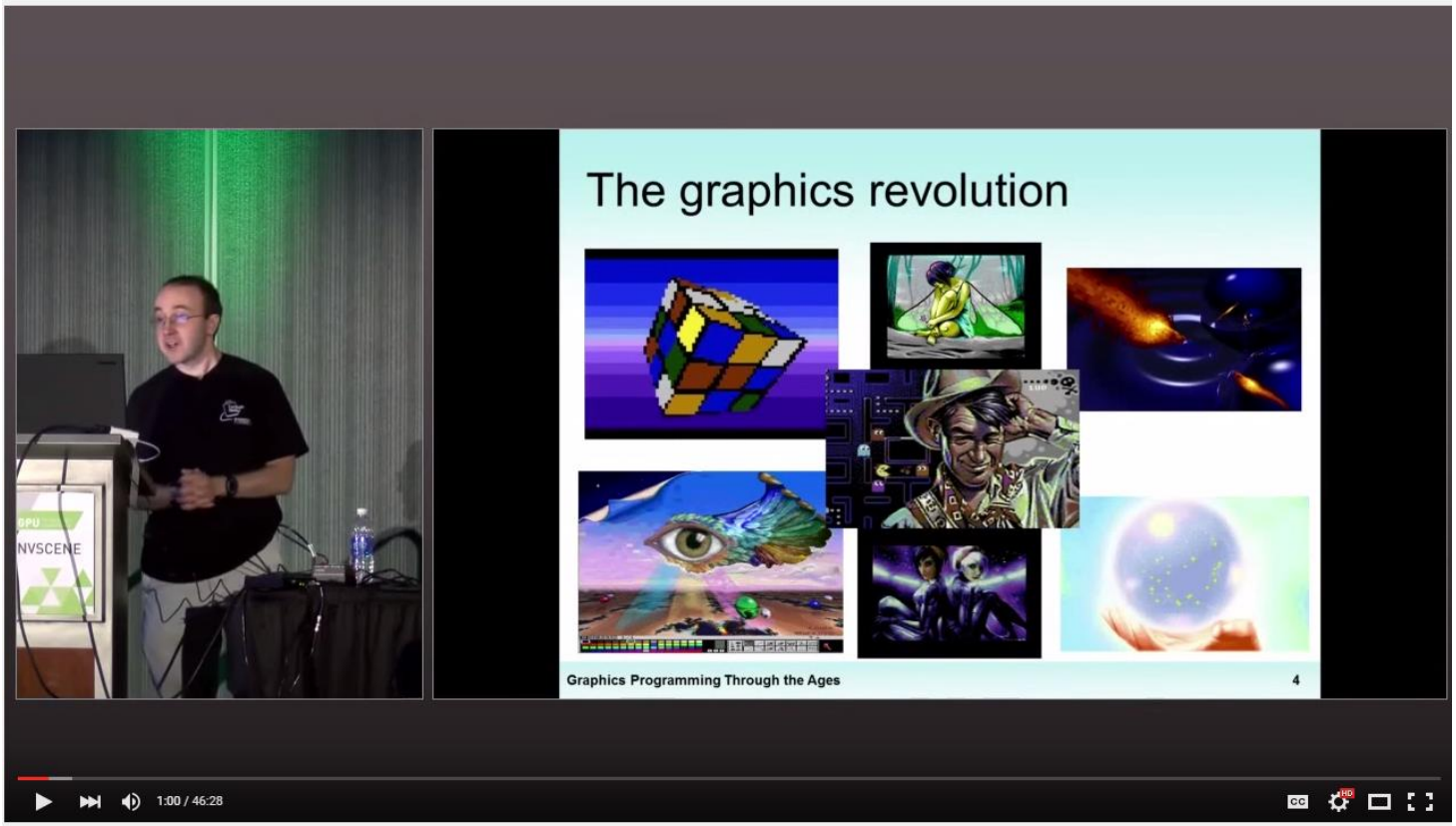
Turner Whitted: An Improved Illumination Model for Shaded Display. Communications of the ACM 23, 6 (June 1980): 343–349

Rasterisation



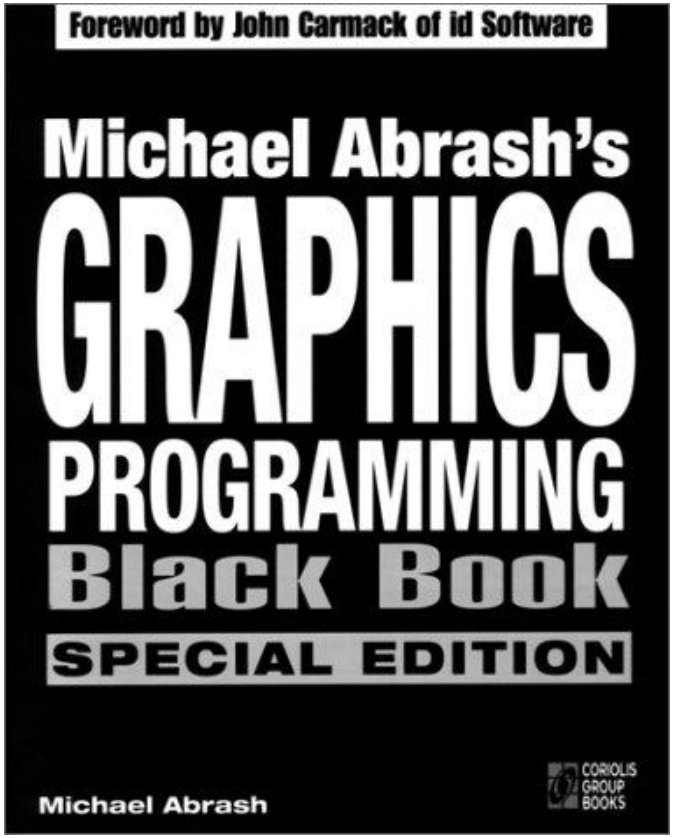
Zarch, 1987

Side note: If you find this interesting…



NVScene 2015 Session: Graphics Programming Through the Ages (Michael Dille, Keith Bare)
https://www.youtube.com/watch?v=D6DCEeJzZso

Side note #2



Michael Abrash's Graphics Programming Black Book
http://www.jagregory.com/abrash-black-book/

Rasterisation

Ultima Underworld: The Stygian Abyss, 1992

Rasterisation & Raytracing

Sun Temple – UE4 demo, 2014

Rasterisation

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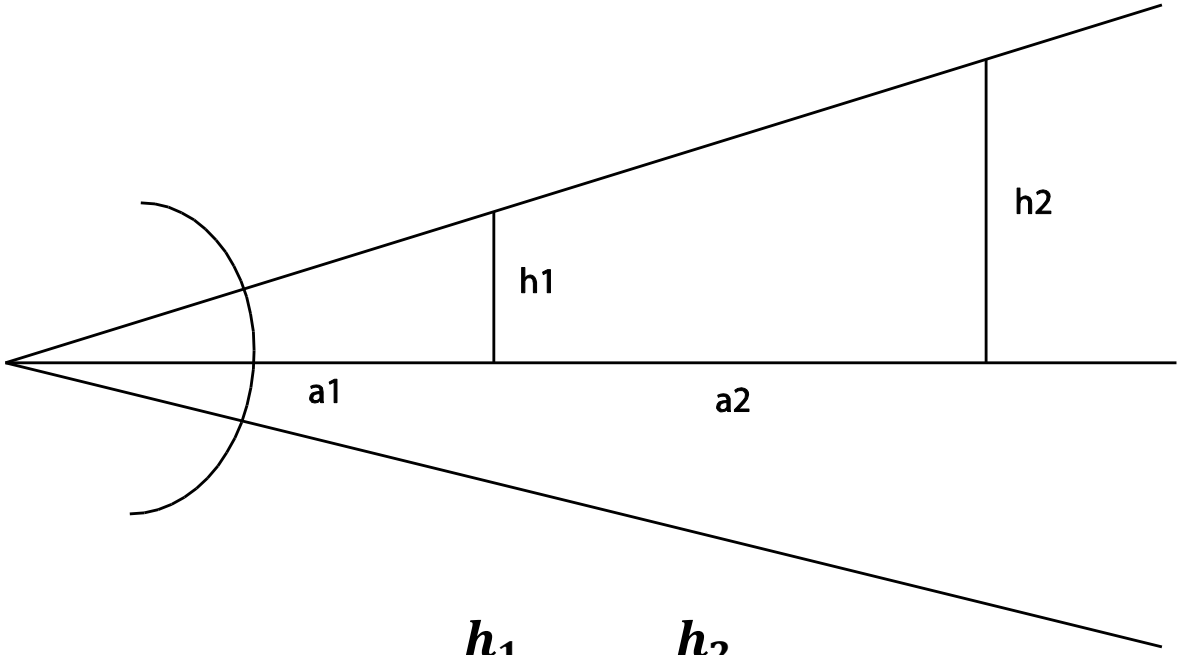
World defined by triangles

- Each triangle -> 3 3D points

```
foreach (tri in world) {
        Point p1 = transform(tri._1);
        Point p2 = transform(tri._2);
        Point p3 = transform(tri._3);
        drawTriangle(p1, p2, p3); // 2D operation
}
```

Perspective



$$\frac{h_1}{a_1} = \frac{h_2}{(a_1 + a_2)}$$

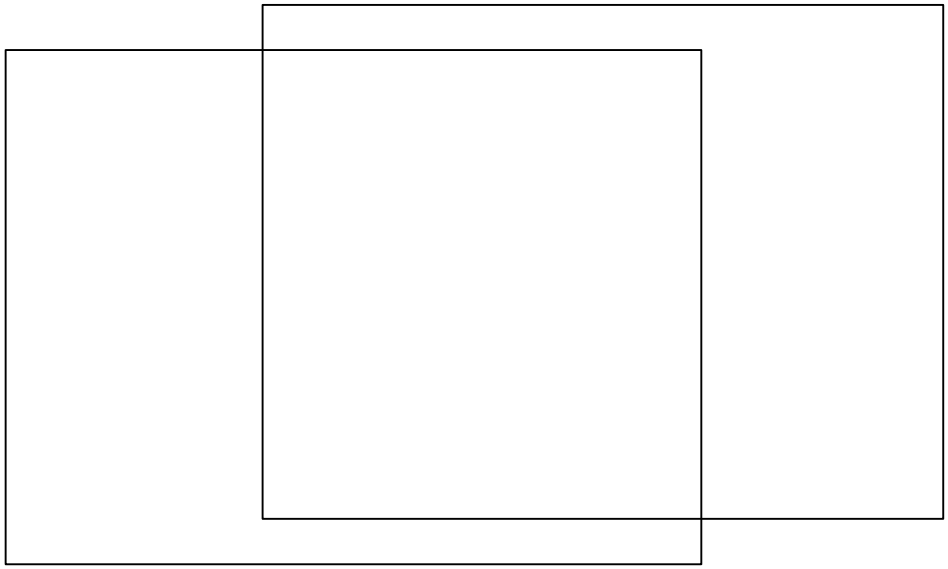
Doubled distance + doubled size → same projection

$$X_{proj} = \frac{z_{min}}{\text{distance}} X$$

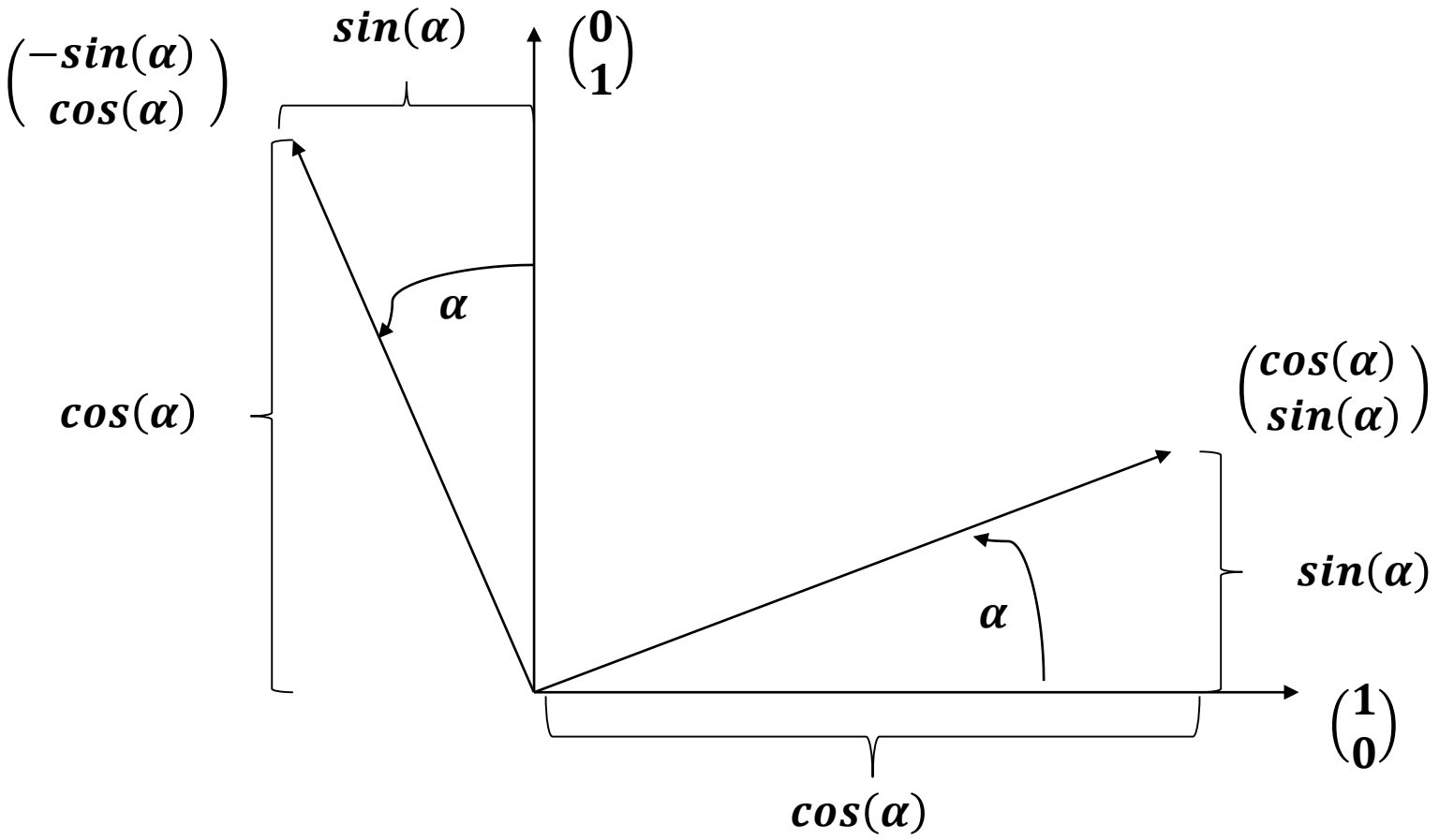
Offset from camera

$$X_{proj} = \frac{z_{min}}{\text{distance}}(X - x_{camera}) + \frac{screenWidth}{2}$$

$$Y_p = \ldots$$



Camera Rotations



Camera Rotations

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Old Point

$$\begin{pmatrix} x \\ y \end{pmatrix} = x \begin{pmatrix} 1 \\ 0 \end{pmatrix} + y \begin{pmatrix} 0 \\ 1 \end{pmatrix}$$

New Point

$$R\left(\begin{pmatrix} x \\ y \end{pmatrix}, \alpha\right) = x \begin{pmatrix} cos(\alpha) \\ sin(\alpha) \end{pmatrix} + y \begin{pmatrix} -sin(\alpha) \\ cos(\alpha) \end{pmatrix}$$

$$R\left(\begin{pmatrix} x \\ y \end{pmatrix}, \alpha\right) = \begin{pmatrix} x \cdot cos(\alpha) \\ x \cdot sin(\alpha) \end{pmatrix} + \begin{pmatrix} -y \cdot sin(\alpha) \\ y \cdot cos(\alpha) \end{pmatrix}$$

$$R\left(\begin{pmatrix} x \\ y \end{pmatrix}, \alpha\right) = \begin{pmatrix} x \cdot cos(\alpha) - y \cdot sin(\alpha) \\ x \cdot sin(\alpha) + y \cdot cos(\alpha) \end{pmatrix}$$

Camera Rotations

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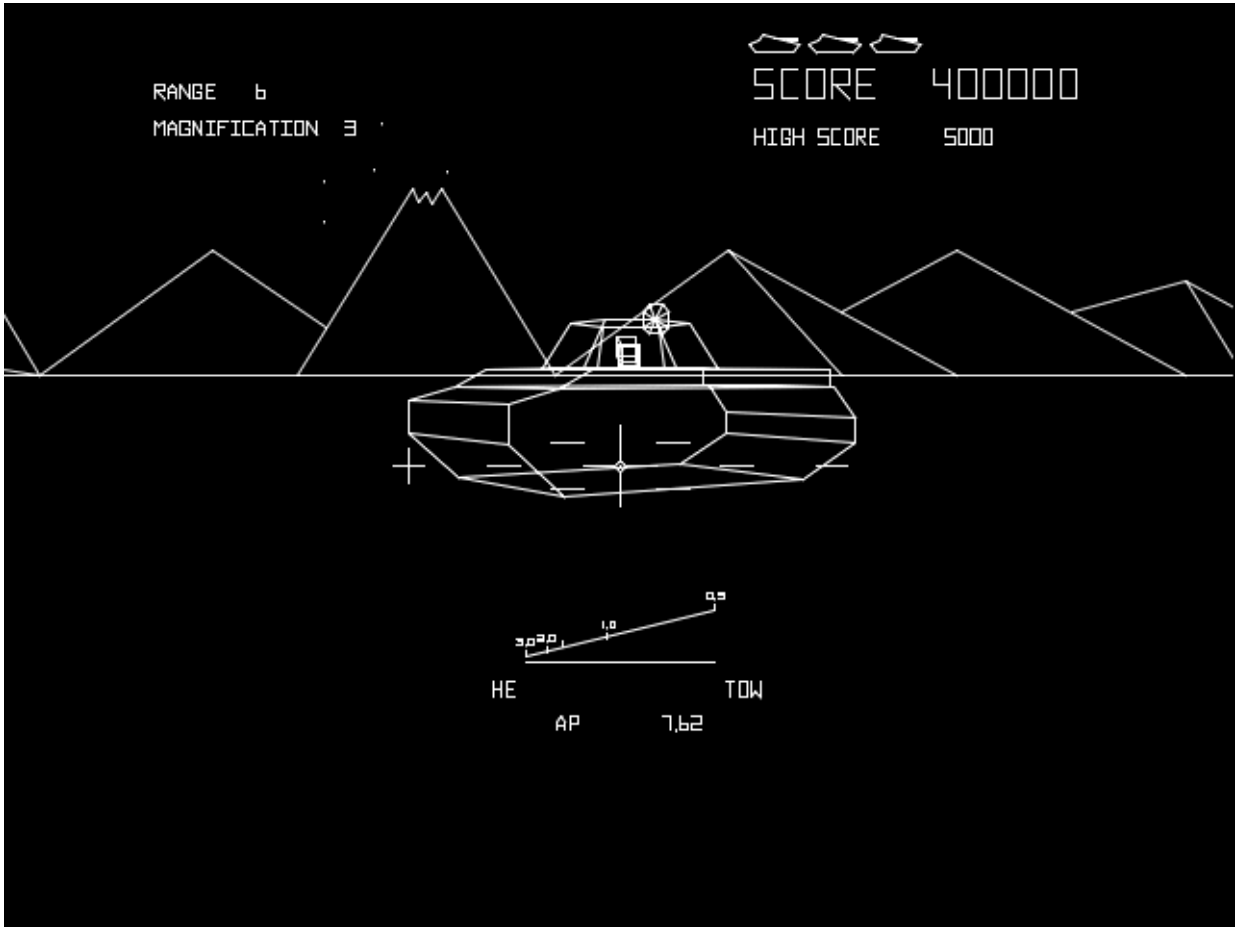
```
float dx = X - camera.x;
float dy = Y - camera.y;
float dz = Z - camera.z;
float d1x = cos(camera.ry) * dx + sin(camera.ry) * dz;
float d1y = dy;
float d1z = cos(camera.ry) * dz - sin(camera.ry) * dx;
float d2x = d1x;
float d2y = cos(camera.rx) * d1y - sin(camera.rx) * d1z;
float d2z = cos(camera.rx) * d1z + sin(camera.rx) * d1y;
float d3x = cos(camera.rz) * d2x + sin(camera.rz) * d2y;
float d3y = cos(camera.rz) * d2y - sin(camera.rz) * d2x;
float d3z = d2z;
Xp = (zmin / d3z) * d3x + screenWidth / 2;
Yp = …
```

Lines



Battlezone, 1980

Digital differential analyzer

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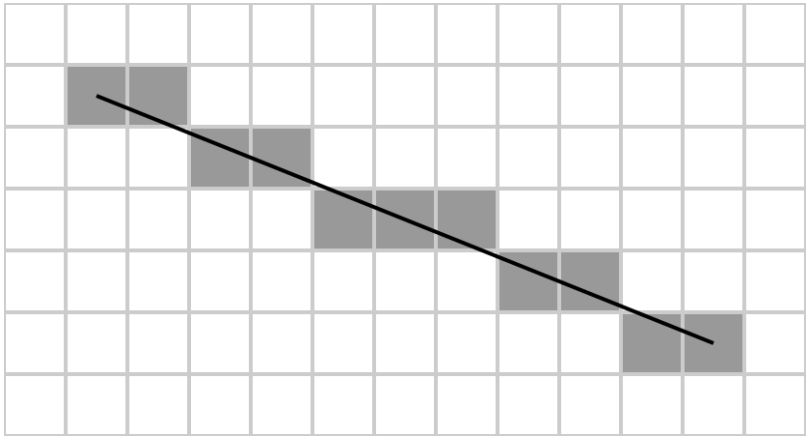
```
dx = x2 - x1
dy = y2 - y1
for x from x1 to x2 {
    y = y1 + dy * (x - x1)
    plot(x, y)
}
```

Bresenham

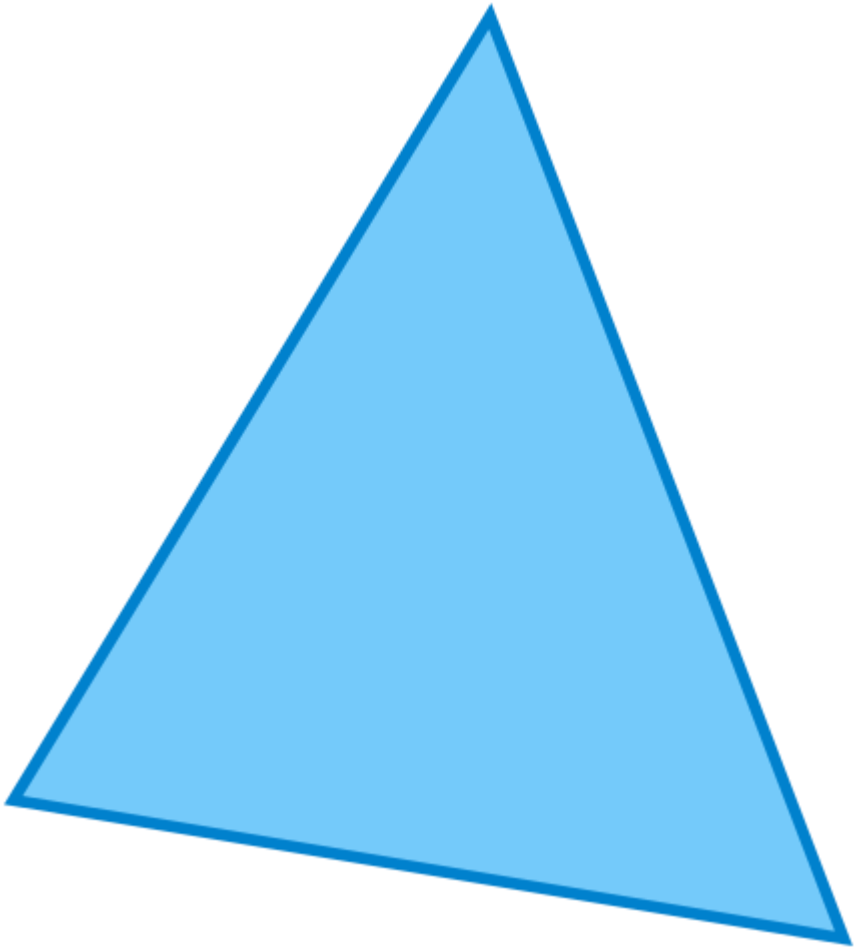
```
plotLine(x0,y0, x1,y1)
  dx=x1-x0
  dy=y1-y0

  D = 2*dy - dx
  plot(x0,y0)
  y=y0

  for x from x0+1 to x1
    D = D + (2*dy)
    if D > 0
      y = y+1
      D = D - (2*dx)
    plot(x,y)
```



Triangles



Triangle Rasterisation

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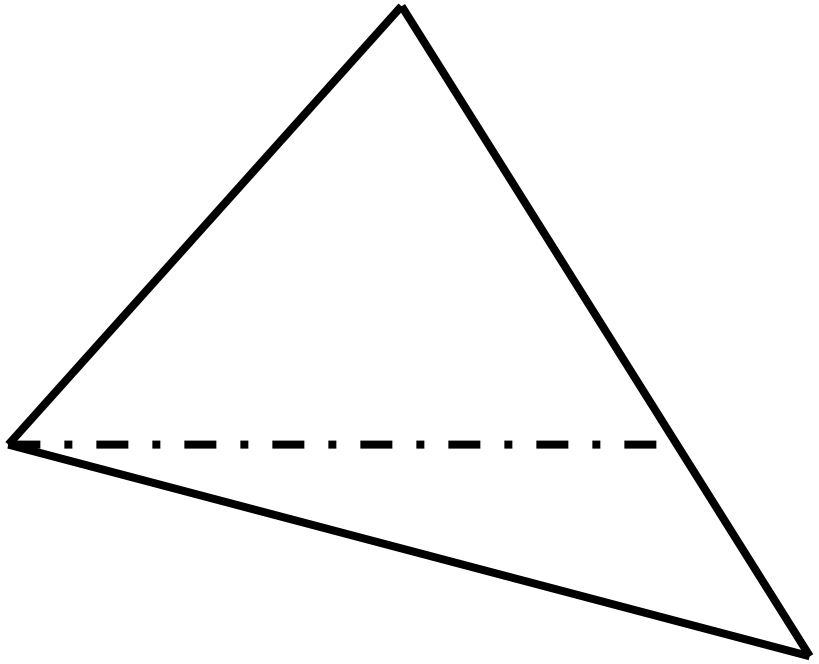
- **Find edge longest with biggest ydif**
- **Fill lines between long edge and other edge 1**
- **Fill lines between long edge and other edge 2**



Mesh structure

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Array of 3D positions

- Often additional data

Array of indices

- Three indices -> triangle

Example from Exercise‘s „SimpleGraphics“

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```
VertexStructure structure;
structure.add("pos", Float3VertexData);
structure.add("tex", Float2VertexData);
vb = new VertexBuffer(4, structure, 0);
float* v = vb->lock();
{
  int i = 0;
  v[i++] = -1; v[i++] = 1; v[i++] = 0.5; v[i++] = 0; v[i++] = 0;
  v[i++] = 1; v[i++] = 1; v[i++] = 0.5; v[i++] = xAspect; v[i++] = 0;
  v[i++] = 1; v[i++] = -1; v[i++] = 0.5; v[i++] = xAspect; v[i++] = yAspect;
  v[i++] = -1; v[i++] = -1; v[i++] = 0.5; v[i++] = 0; v[i++] = yAspect;
}
vb->unlock();
ib = new IndexBuffer(6);
int* ii = ib->lock();
{
  int i = 0;
  ii[i++] = 0; ii[i++] = 1; ii[i++] = 3; ii[i++] = 1; ii[i++] = 2; ii[i++] = 3;
} ib->unlock();
```

Backface Culling

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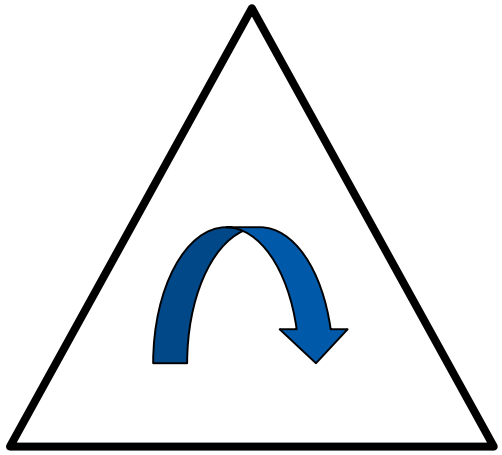
Remove tris showing away from camera

Use tri winding

cross(b - a, c - a)



Dot product, Cross product

$$v_1 = (x_1, y_1, z_1), v_2 = (x_2, y_2, z_2)$$

Dot Product

$$v_1 \cdot v_2 = x_1 x_2 + y_1 y_2 + z_1 z_2$$

$$v_1 \cdot v_2 = |v_1| \cos(\alpha)$$

Cross Product

$$v_1 \times v_2 = (y_1 z_2 - z_1 y_2, z_1 x_2 - x_1 z_2, x_1 y_2 - y_1 x_2)$$

$$v_1 \times v_2 = |v_1||v_2| sin(\alpha) n$$

Geometric interpretations

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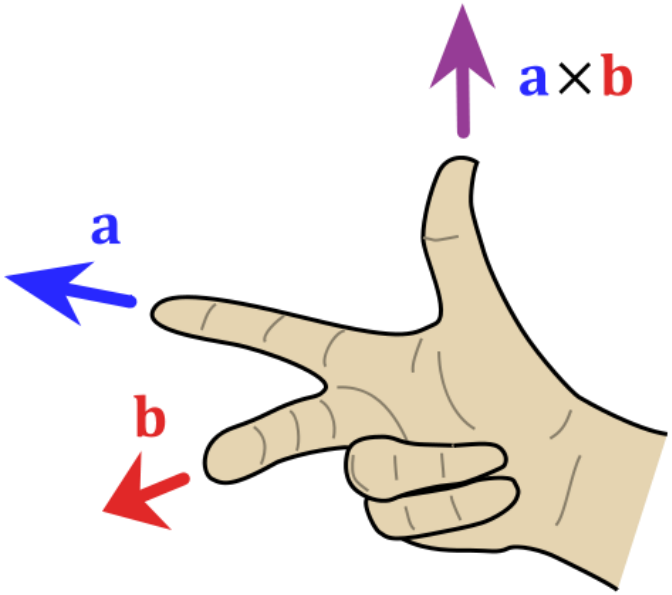
Cross product

- Gives us the direction the normal is facing

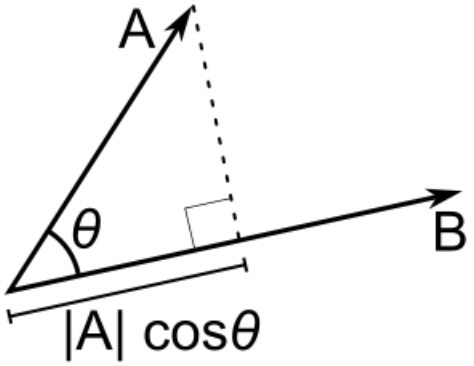


Scalar product

- Projection of one vector onto the other

Special case of normals

- Can use to calculate angles



Textures

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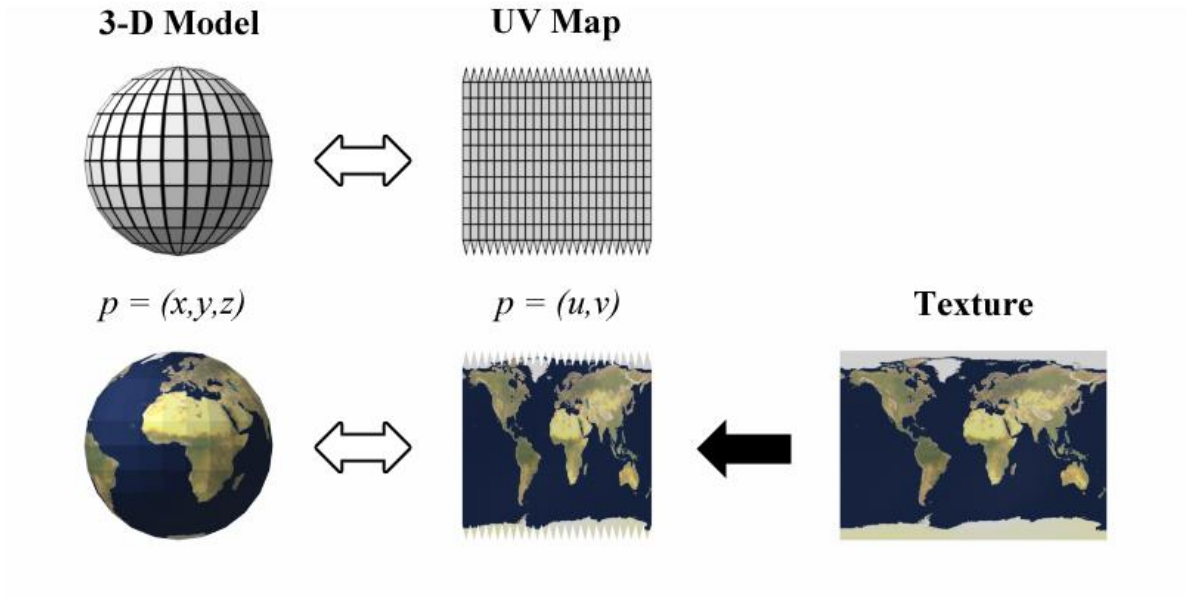
Add texture coordinates (uv) to mesh positions

Interpolate coordinates during rasterisation

Sample texture at interpolated coordinates



Depth Sorting

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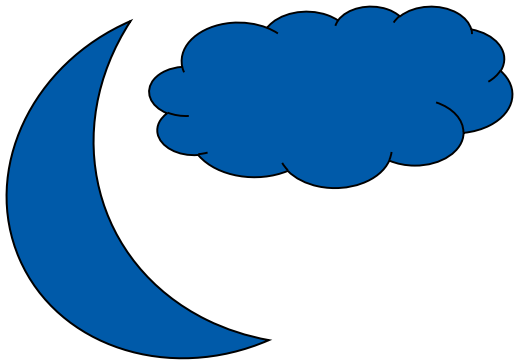
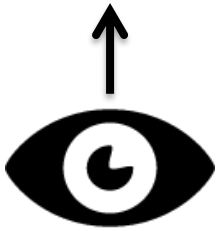
Sort only complete meshes

- For performance reasons

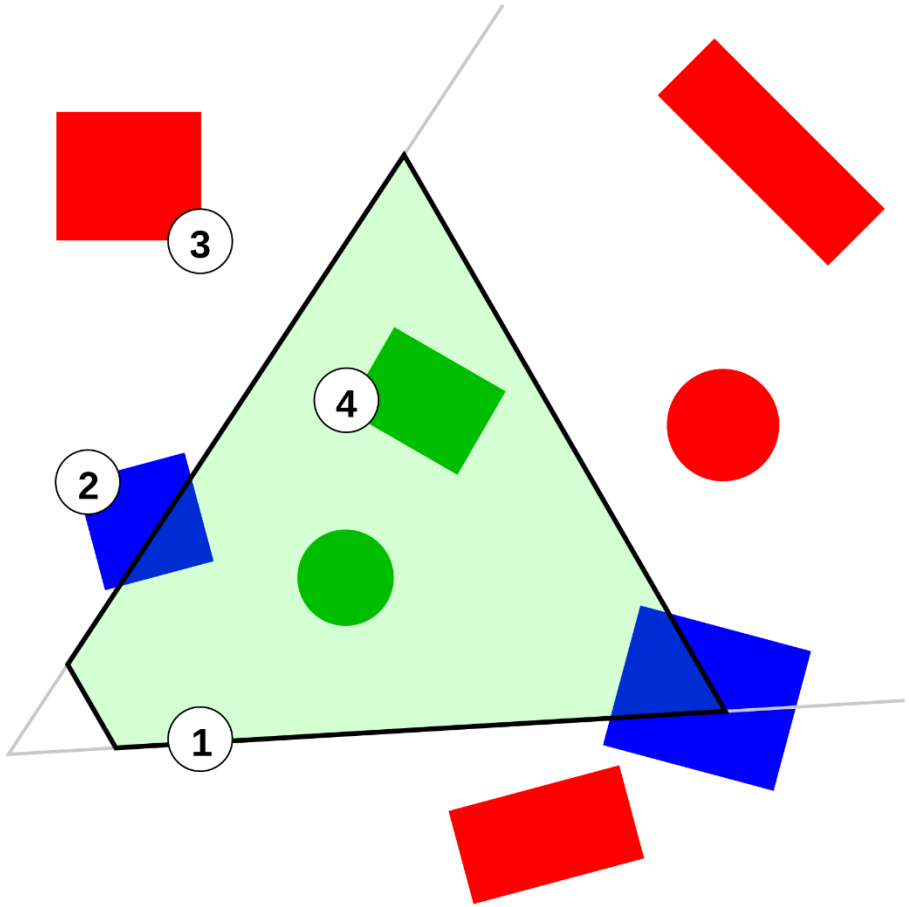
Sort by distance from camera to object

Draw nearest objects last





Frustum Culling



Hierarchical Scenes

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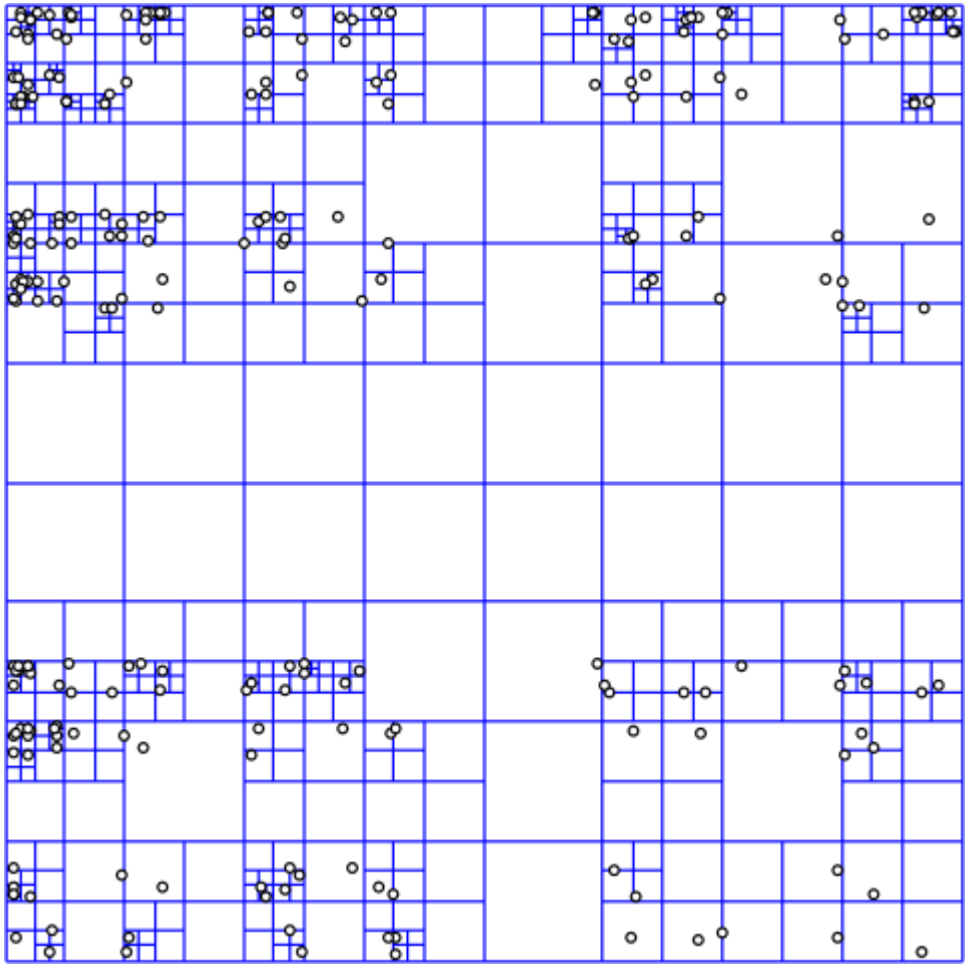
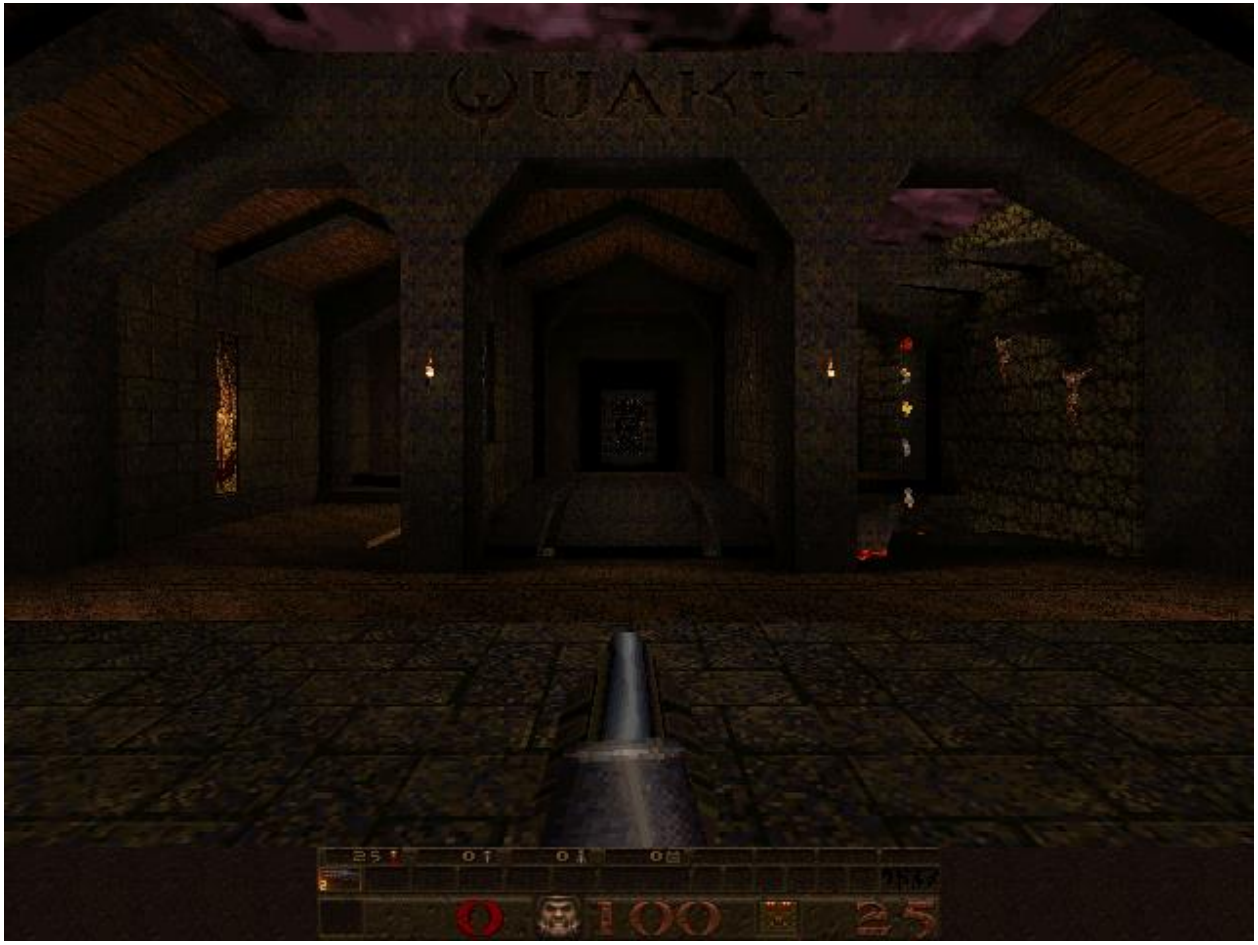


Quake



Quake, 1996

Optimization

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```
foreach (object in world) {
  if (infrustum(object)){
       render(object);
  }
}
```

Hierarchical structures slow on modern CPUs

- Cache misses

Occlusion Culling

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Computations can be expensive

Precompute

- Unity

Rasterize in low resolution

- Software Occlusion Culling from intel

Occlusion Query

- Hardware feature

Deferred Rendering

- Hardware feature

Remember: Games need steady performance

C++

Optimization

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Example from last year‘s exercise „Hypertheoretical Exercise“

Measure the performance of DDA vs. Bresenham

Results (Performance of Bresenham compared to DDA):

0,8002
0,6784
0,5681
1,1101
0,5681
1,9810
0,9933
0,1765
0,4671
1,2757
1,0612
0,9655
0,6000
1,0194

Optimization: Example

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```
sum = 0;
for (row = 0; row < rowCount; row++)
{
 for (column = 0; column < columnCount; column++)
 {
      sum = sum + matrix[row][column];
 }
}
```

2D array access entails a multiplication

Optimization: Example

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```
sum = 0;
elementPointer = matrix;
lastElementPointer = matrix[rowCount - 1][columnCount - 1] + 1;
while (elementPointer < lastElementPointer)
{
  sum = sum + *elementPointer;
}
```

Use the fact that 2D array is arranged linearly in memory

Improvement:

- None
- The compiler‘s optimizer already did this optimization…

Operator overloading

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```
class Number {
  …
};

Number operator+(Number a, Number b) {
  return …
}

Number a;
Number b;
Number c = a + b;
```

Operator overloading

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```
class Number {
 Number& operator++(); // ++num;
 Number operator++(int); // num++;
};

for (Number i = 0; i < 10; i++) { }

// maybe faster when ++ is overloaded
for (Number i = 0; i < 10; ++i) { }
```

Pre-increment: ++i

- Result is the value after incrementation

Post-increment: i++

- Result is the value before incrementation

References

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New name for existing variable

Same syntax for access

```
int a = 3;
int& b = a;
b = 4;        // a == 4
```

References

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```
void reference_test(int& b) {
 b = 4;
}

int a = 3;
reference_test(a);        // a == 4
```

References

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In theory just an unchangeable reference

- Not a hardware level concept
- Can often be removed by the optimizer

In practice works like restricted pointers

Added to support map implementations

```
class Map {
 int& operator[](int index);
};
```

Constness

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```
const int a = 3;

a = 4 ;
```

Constness

TECHNISCHE UNIVERSITÄT DARMSTADT

```
void bla(const int a) {
  a = 4;
}
```

Constness

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```
const char* bla1 = "bla";

char* const bla2 = "bla"";

bla1 = "blub"";

bla2[0] = 'g';
```

Constness

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```
void bla(const int& a) {
  …
}
```

Hint for the compiler: Do what you want

- Copying a value can be faster than using a pointer

Constness

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```
class A {
 void method1() const {
      a = 3;
 }

 void method2() const {
      b = 3;
 }

 int a;
 mutable int b;
};
```

Constness

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```
class A {
 void method1() const;
 void method1();
};

A a;
a.method1();

const A b;
b.method1();
```

Templates

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```
template<class T> class A {
  void method1() {

  }

  void method2();
};

A<int> a;
```

Templates

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```
template<int i> void bla() { … }

bla<3>();
```

static

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```
// functions.h

void func1() { }

static void func2() { }

inline void func3() { }

namespace {
  void func4() { }
}
```