15-462 Computer Graphics: **Graphics Pipeline & HW**

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Quick Review…

- Graphics Pipeline
  1. Set State Variables
  2. Send Vertices
  3. Generate Image
- From the CPU -> GPU

Process of Abstraction

- Basis of Graphics
  - Set Transforms
  - Set Vertices
    - Floating Points multiplied and added to each other
- Rules applied on top of this
  - Transforms multiply to each other
  - Vertices & Vectors multiply to a Transform
- Sets of 3 Vertices create a triangle
  - Each Vertex has a corresponding set of more floats
    - Normal Vector
    - Color [Amb, Dif, Spc, Em, …]
    - Texture

Graphics – Computer Parallel

[Level of Abstraction]

COMPUTER

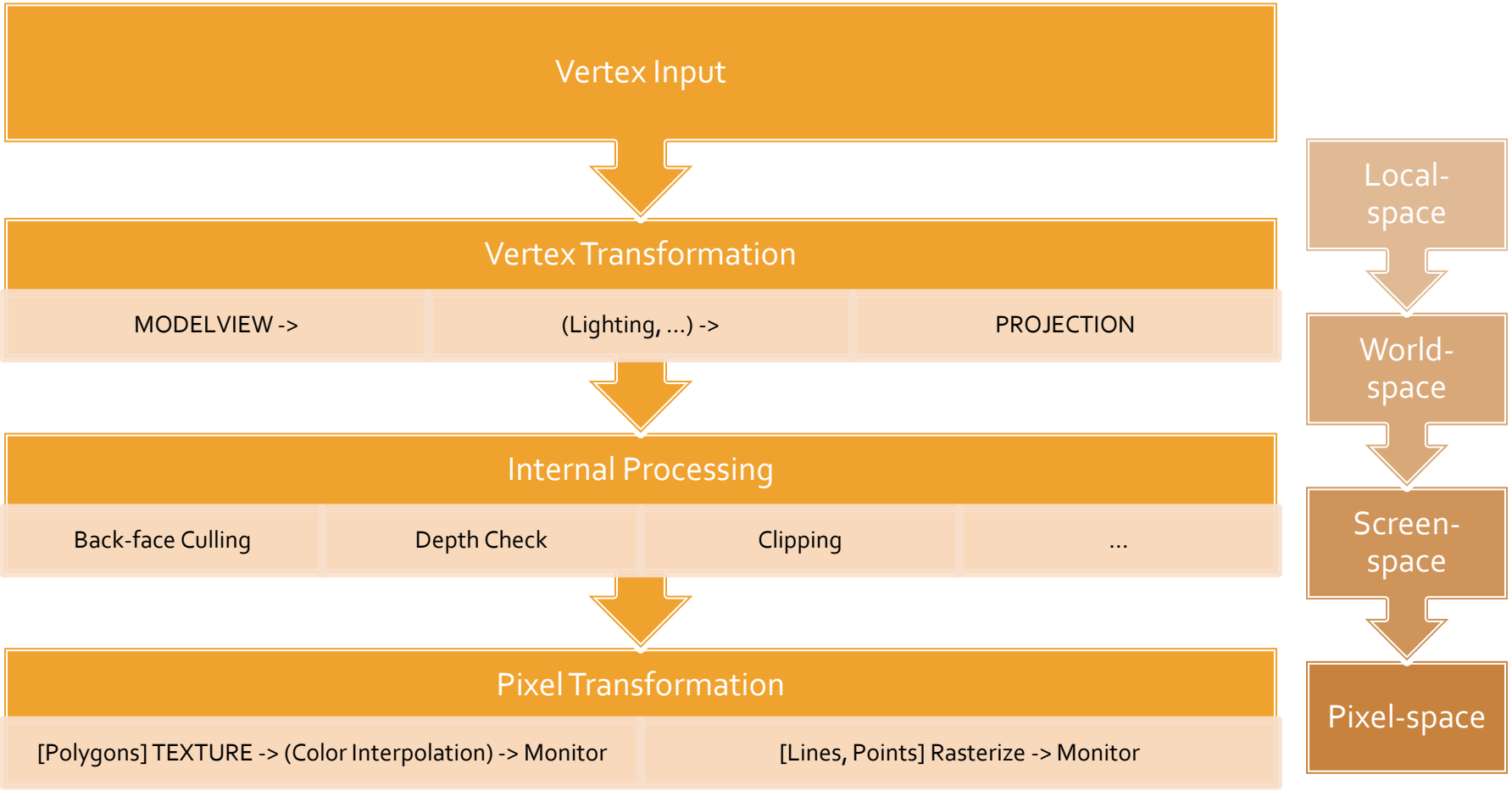
- **Assembly**
  - Direct Translation of Machine Code
  - (Add, Subtract, Multiply Divide)
- **Functions**
  - Input-output operation (variable -> value)
- **Data Structures**
  - Sets of Variables
- **Object-Orientation**
  - Sets of data w/ set of functions
- **Application Programming Interface (API)**

GRAPHICS

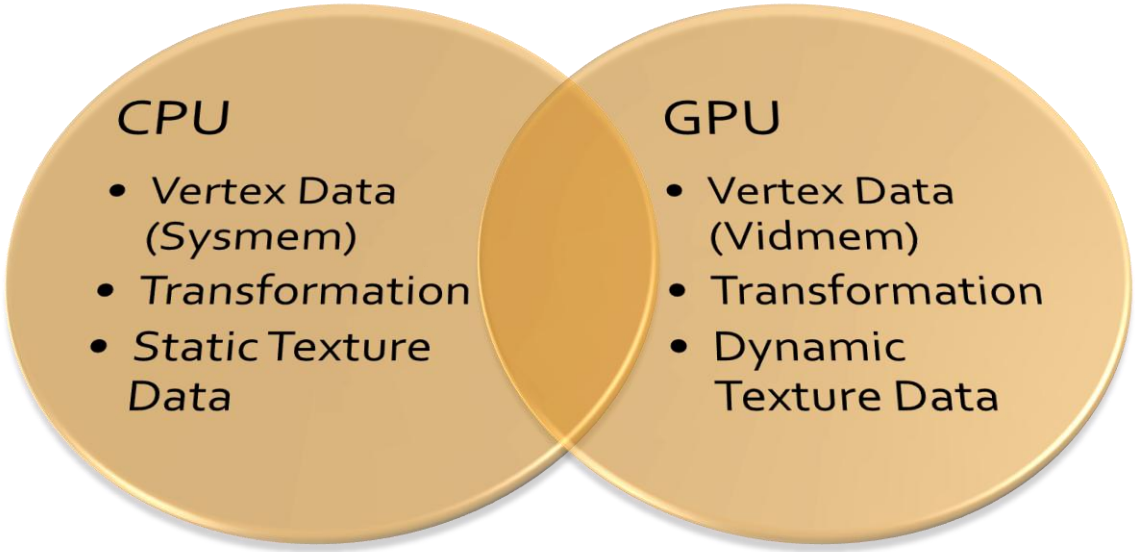
- **Floating point arithmetic**
  - Direct translation of graphics processing
  - (Add, Subtract, DotProd, CrossProd)
- **Transforms**
  - Input-output operation (floats -> color)
- **"Vectors"/"Vertices"**
  - Sets of Floats
- **Vertex -> Polygon**
  - Data
    - Position Vertex
    - Normal Vector
    - Color Vectors
    - Texture Coordinates
  - Functions
    - Vertex Transformation
    - Barycentric Color interpolation
    - Lighting Calculation
    - Depth Checking
    - …
- **Graphics Interface**
  - OpenGL, DirectX, …

Where to draw the line between CPU/GPU?

Beneath the hood, Graphics APIs do:



Where to draw the line between CPU/GPU? (Cont'd)



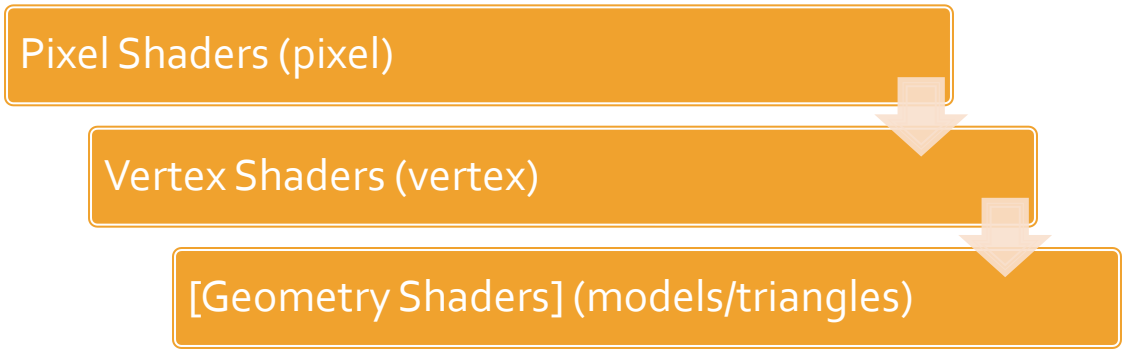
- Vertex Shaders (single-vertex input)
  - Vertex Transformation Replacement
  - Can be done in CPU/GPU
  - Replaces MODELVIEW, PROJECTION…
- Pixel Shaders (single-pixel input)
  - Pixel Transformation Replacement
  - Done in GPU
  - Replaces TEXTURE Coordinates, Pixel Color, Bump Mapping, …

Fixed-Function Pipeline Limitations

- Large, Clunky
  - Work with big buffers at a time
- Inflexible
- Made to simply chug out triangles
- No scene information, single raycast

Graphics HW Evolution

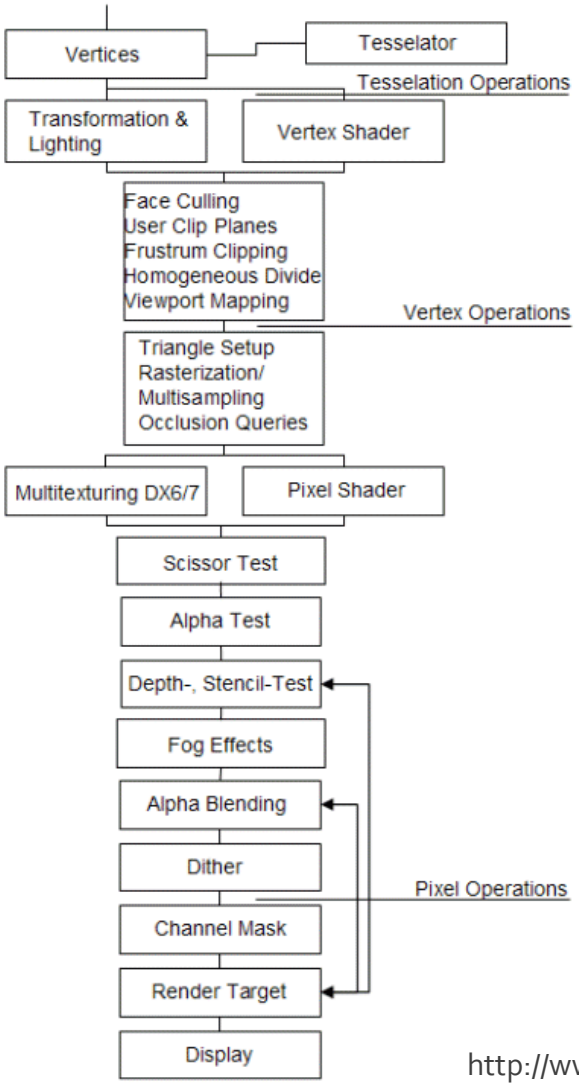
- As the GPU gains more processing power it can…
  - Work with separate triangles
  - Work with individual pixels
  - Start gaining scene information
- Replacing the pipeline



Graphics HW Evolution (Cont'd)

- Shader Flexibility – Biggest Advantage/Drawback
  - Interpret & manipulate vertex/matrices as non-coordinate data
  - Full understanding of graphics, lighting, etc. required
- Unable to create data
  - 1 Input -> 1 Output

HLSL Shader Example (DirectX)



$I = A_{intensity} * A_{color} + D_{intensity} * D_{color} * N.L + Specular$ (A = Ambient, D = Diffuse)
Ignoring Specular, just Ambient + Diffuse Per-Pixel Lighting

```
float4x4 matWorldViewProj;
float4x4 matWorld;
float4 vecLightDir;

struct VS_OUTPUT
{
   float4 Pos : POSITION;
   float3 Light : TEXCOORD0;
   float3 Norm : TEXCOORD1;
};

VS_OUTPUT VS(float4 Pos : POSITION, float3 Normal : NORMAL)
{
   VS_OUTPUT Out = (VS_OUTPUT)0;
   Out.Pos = mul(Pos, matWorldViewProj); // transform Position
   Out.Light = vecLightDir; // output light vector
   Out.Norm = normalize(mul(Normal, matWorld)); // transform Normal and normalize it
   return Out;
}

float4 PS(float3 Light: TEXCOORD0, float3 Norm : TEXCOORD1) : COLOR
{
   float4 diffuse = { 1.0f, 0.0f, 0.0f, 1.0f};
   float4 ambient = {0.1, 0.0, 0.0, 1.0};
   return ambient + diffuse * saturate(dot(Light, Norm));
}
```

http://www.gamasutra.com/features/20030418/engel_01.shtml

Future of Graphics Hardware

- Shaders -> Scene Data
  - Shared System/Video Memory (Xbox 360)
  - Geometry Shaders
  - 'Instancing'
- Multi-core Graphics Cards
  - Fast floating-point processing
  - Physics, AI, etc.

Questions?