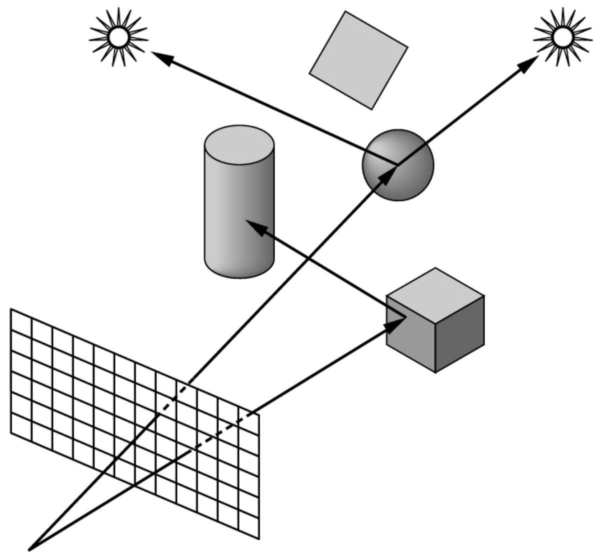
CSE 5542 - Real Time Rendering
Week 2

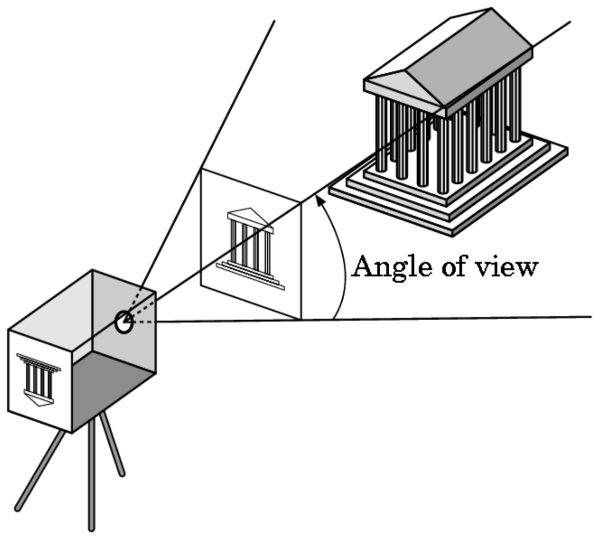
THE OHIO STATE UNIVERSITY
DEPARTMENT OF COMPUTER SCIENCE AND ENGINEERING

Graphics Processing

Physical Approaches



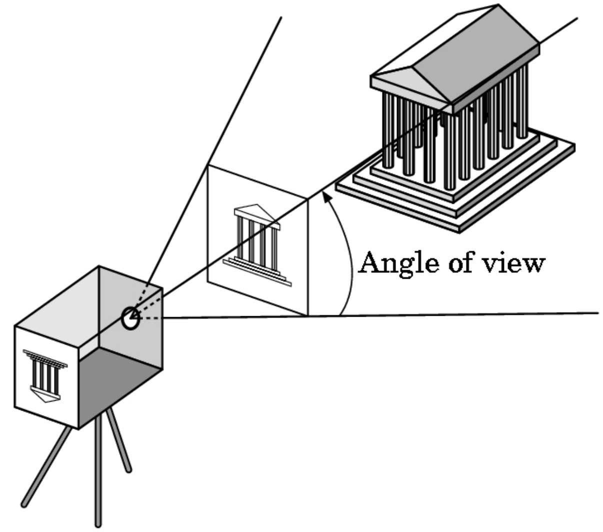
Projection-Based

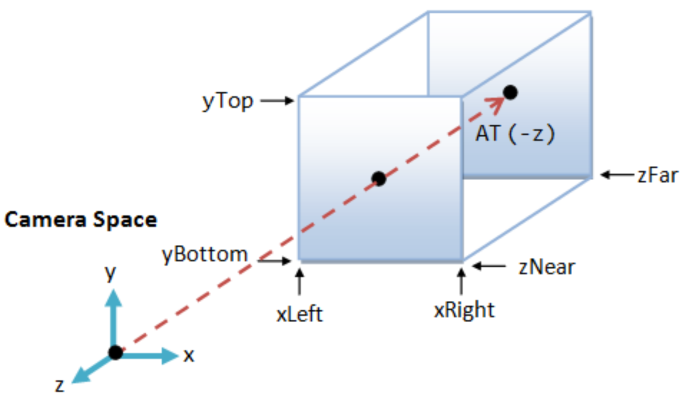


Projection

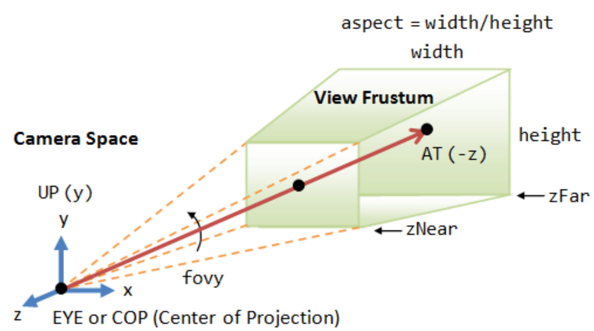
3D objects -> 2D image

- Perspective
- Parallel/Orthographic





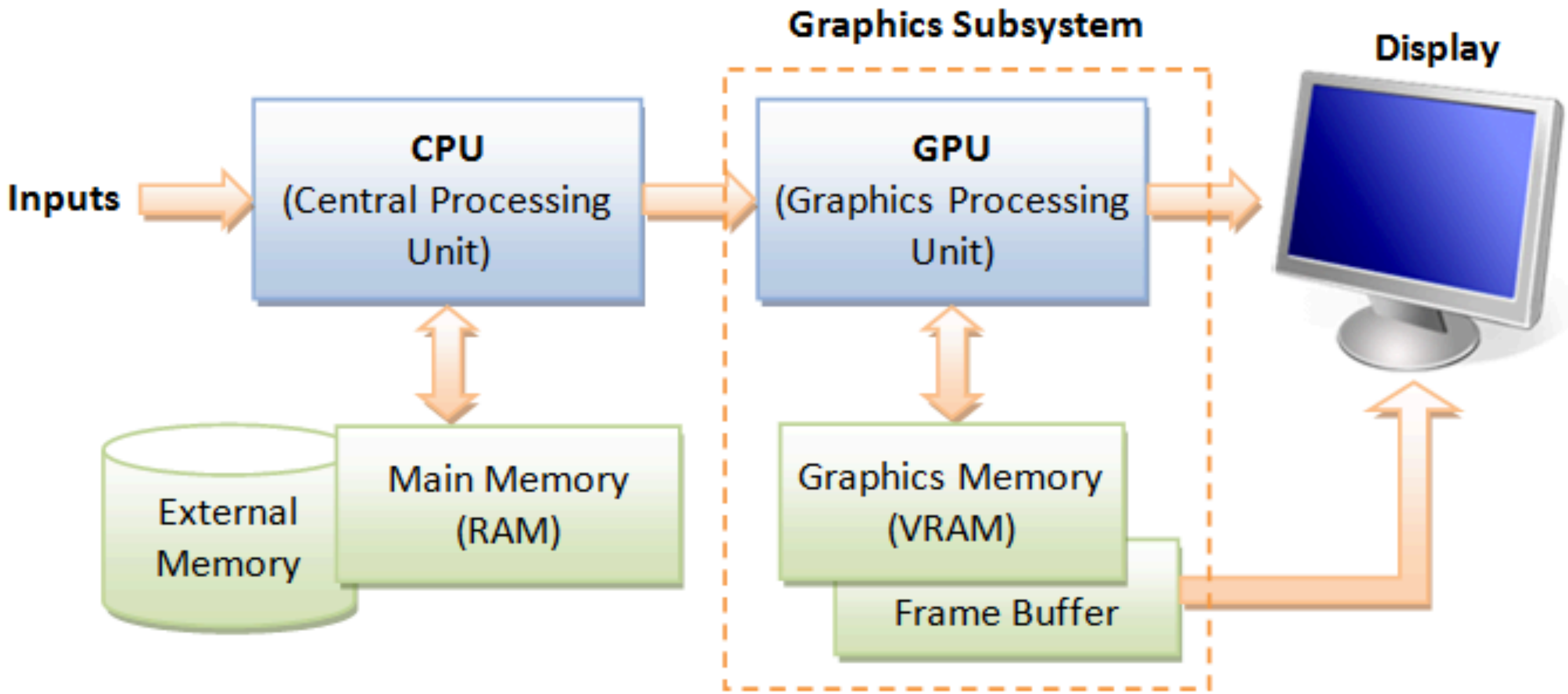
Orthographic Projection: Camera positioned infinitely far away at $z = \infty$



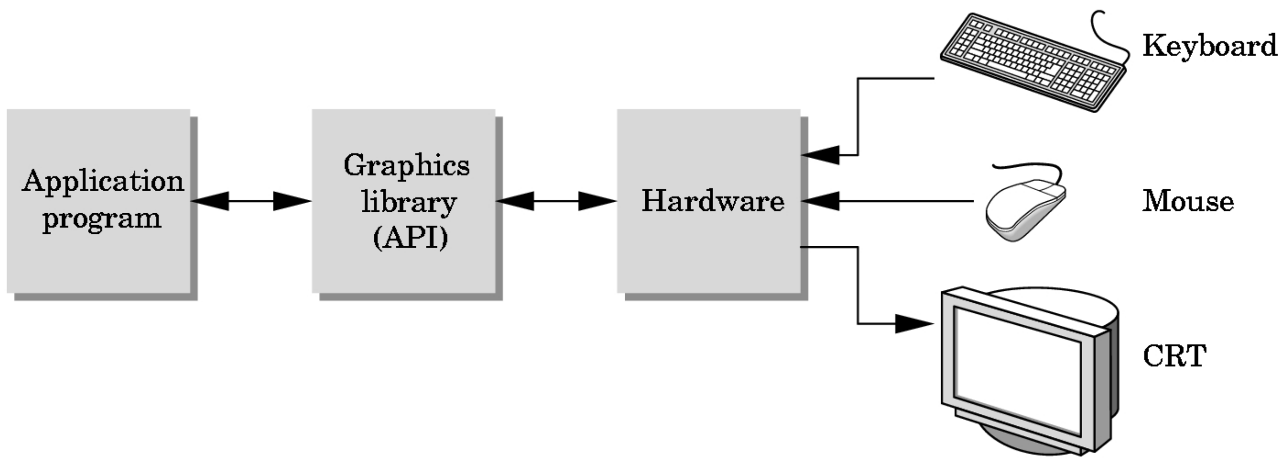
Perspective Projection: The camera's view frustum is specified via 4 view parameters: fovy, aspect, zNear and zFar.

THE OHIO STATE UNIVERSITY
DEPARTMENT OF COMPUTER SCIENCE AND ENGINEERING

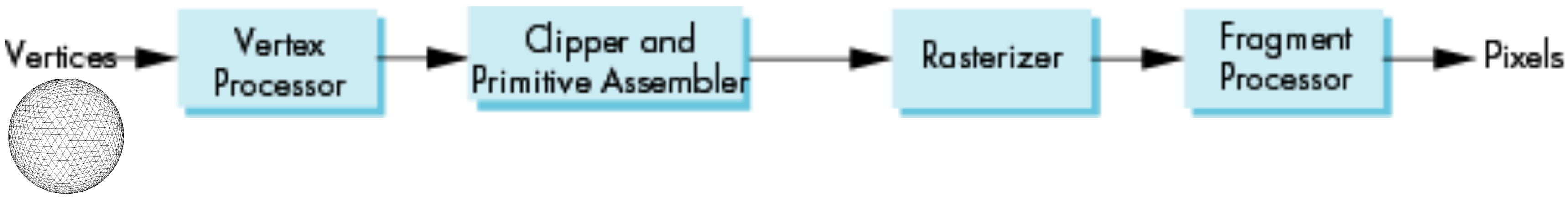
The Hardware

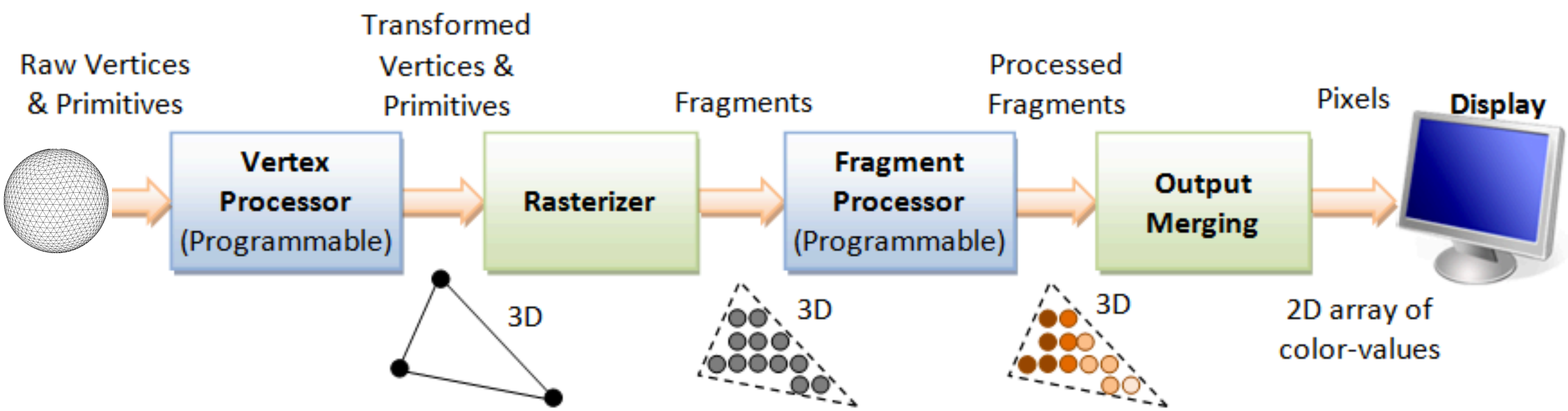


The API/System

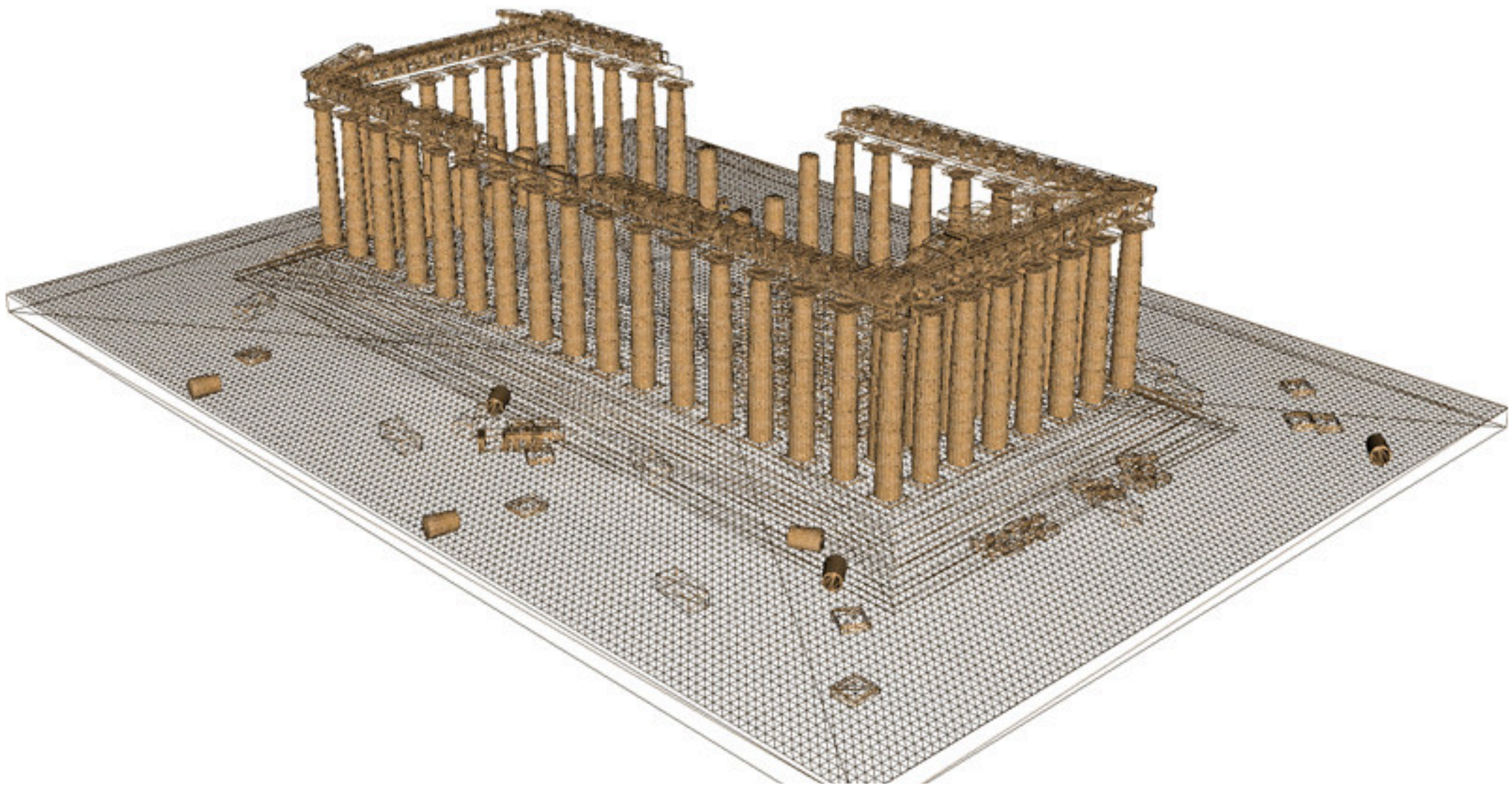


The Graphics Pipeline





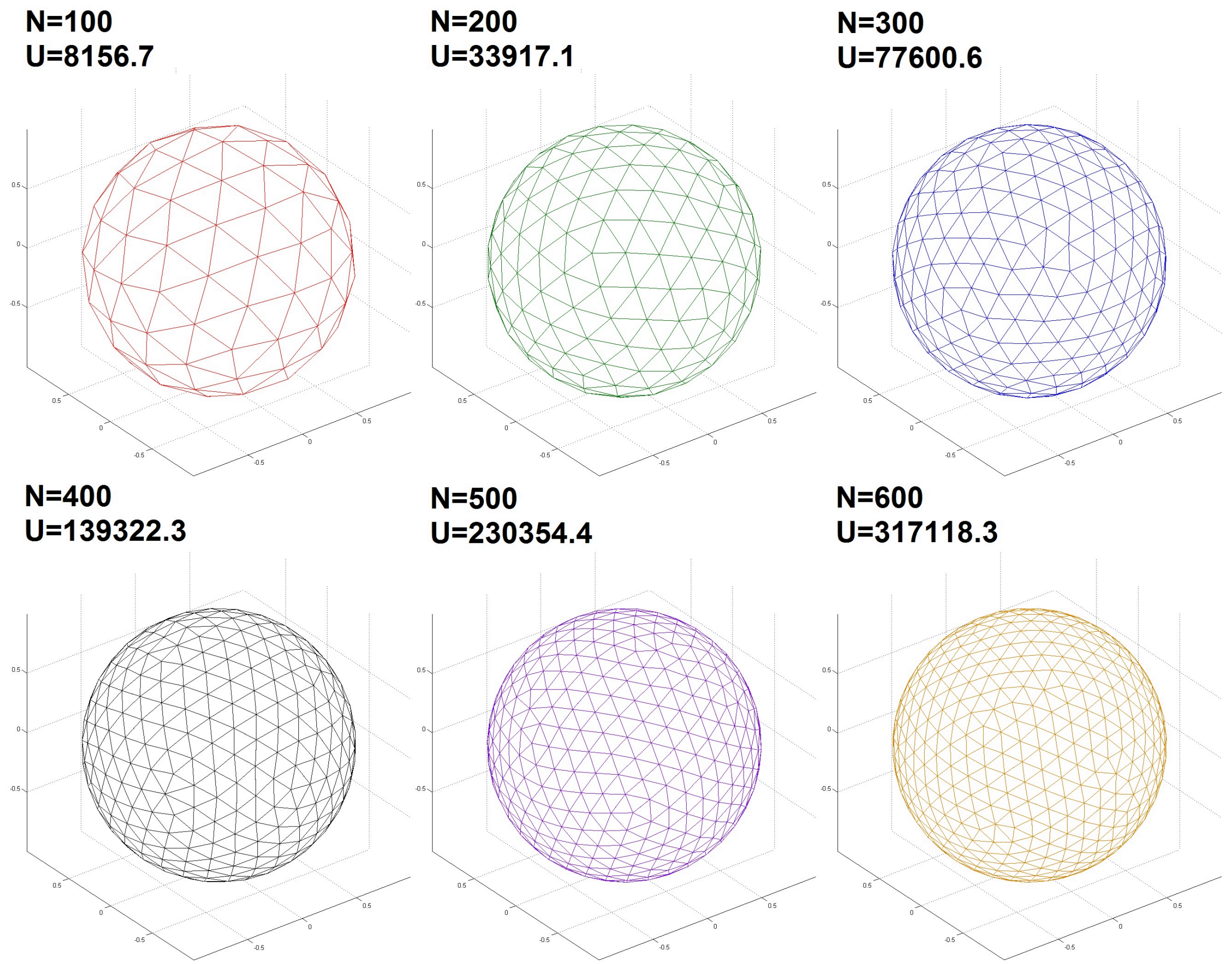
Object & Primitive & Vertex



http://www.3dcadbrowser.com/download.aspx?3dmodel=27814

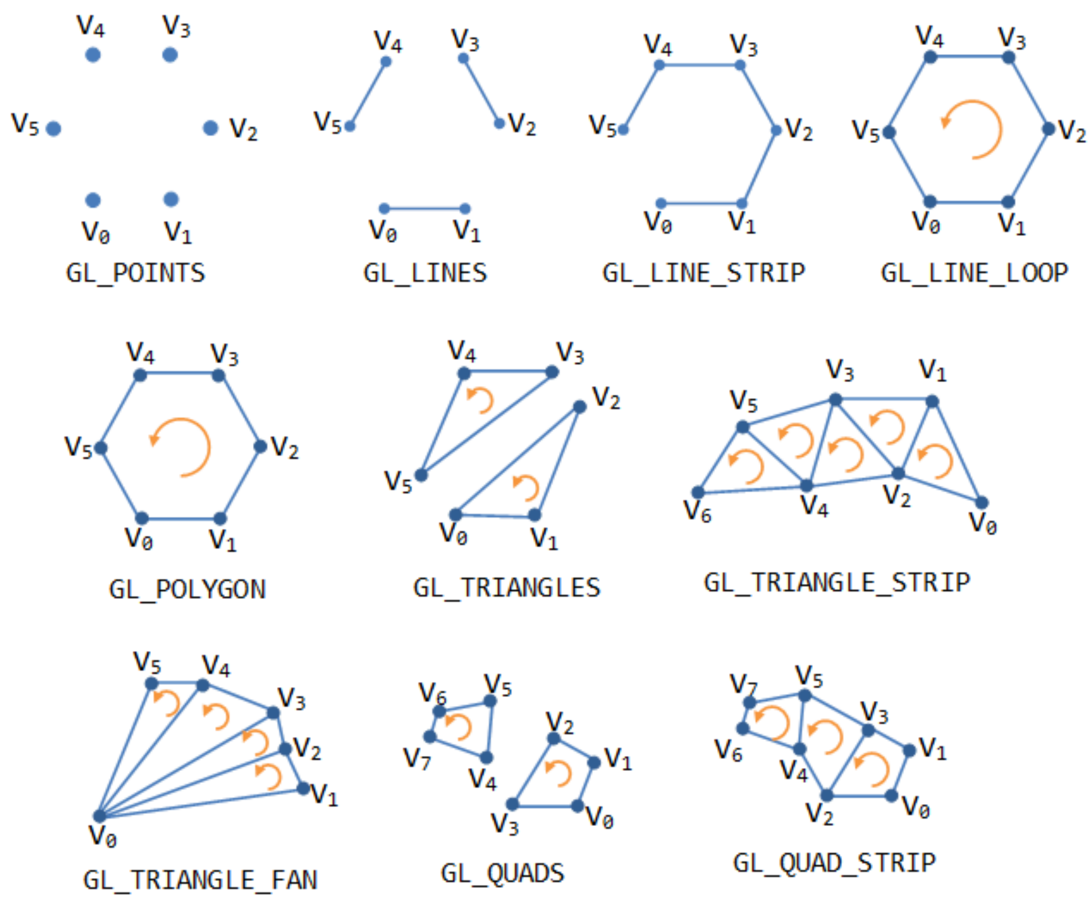
THE OHIO STATE UNIVERSITY
DEPARTMENT OF COMPUTER SCIENCE AND ENGINEERING

Object & Triangles & Vertices



http://www.mathworks.com/matlabcentral/fileexchange/37004-uniform-sampling-of-a-sphere

Primitives



OpenGL Primitives

Example (old style)

type of object

location of vertex

```
glBegin(GL_POLYGON)
   glVertex3f(0.0, 0.0, 0.0);
   glVertex3f(0.0, 1.0, 0.0);
   glVertex3f(0.0, 0.0, 1.0);
glEnd( );
```

end of object definition

Example (GPU based)

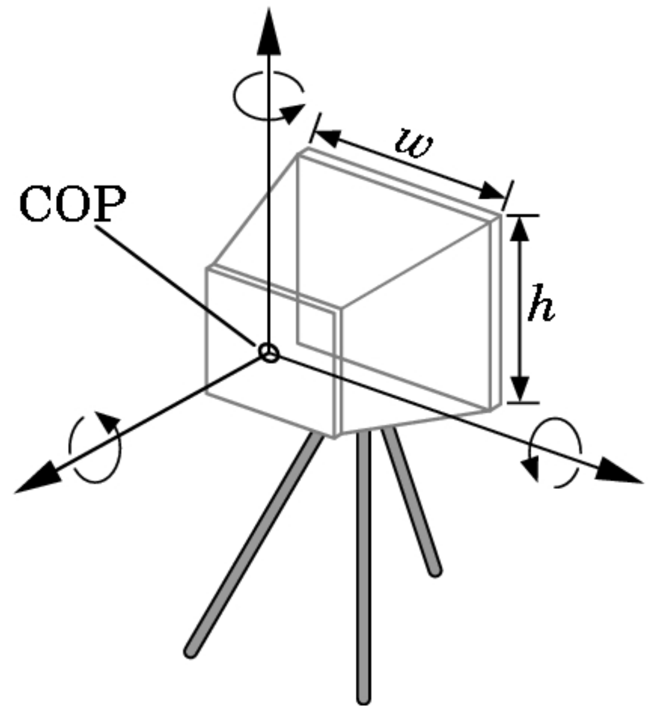
- Put geometric data in an array

```
vec3 points[3];
points[0] = vec3(0.0, 0.0, 0.0);
points[1] = vec3(0.0, 1.0, 0.0);
points[2] = vec3(0.0, 0.0, 1.0);
```

- Send array to GPU
- Tell GPU to render as triangle

Camera Specification

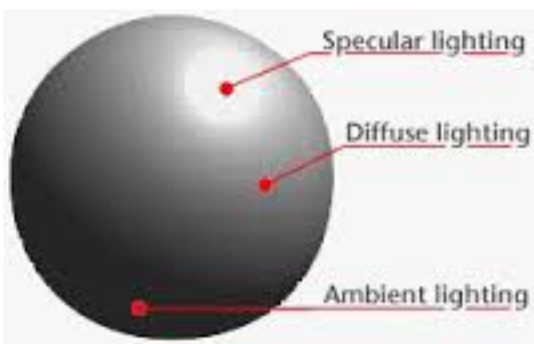
- Six degrees of freedom
  - Position of center of lens
  - Orientation
- Lens
- Film size
- Orientation of film plane



Materials

Optical properties

- Absorption/Reflection: color Scattering
  - Diffuse
  - Specular
  - Transparent
- Texture
- …

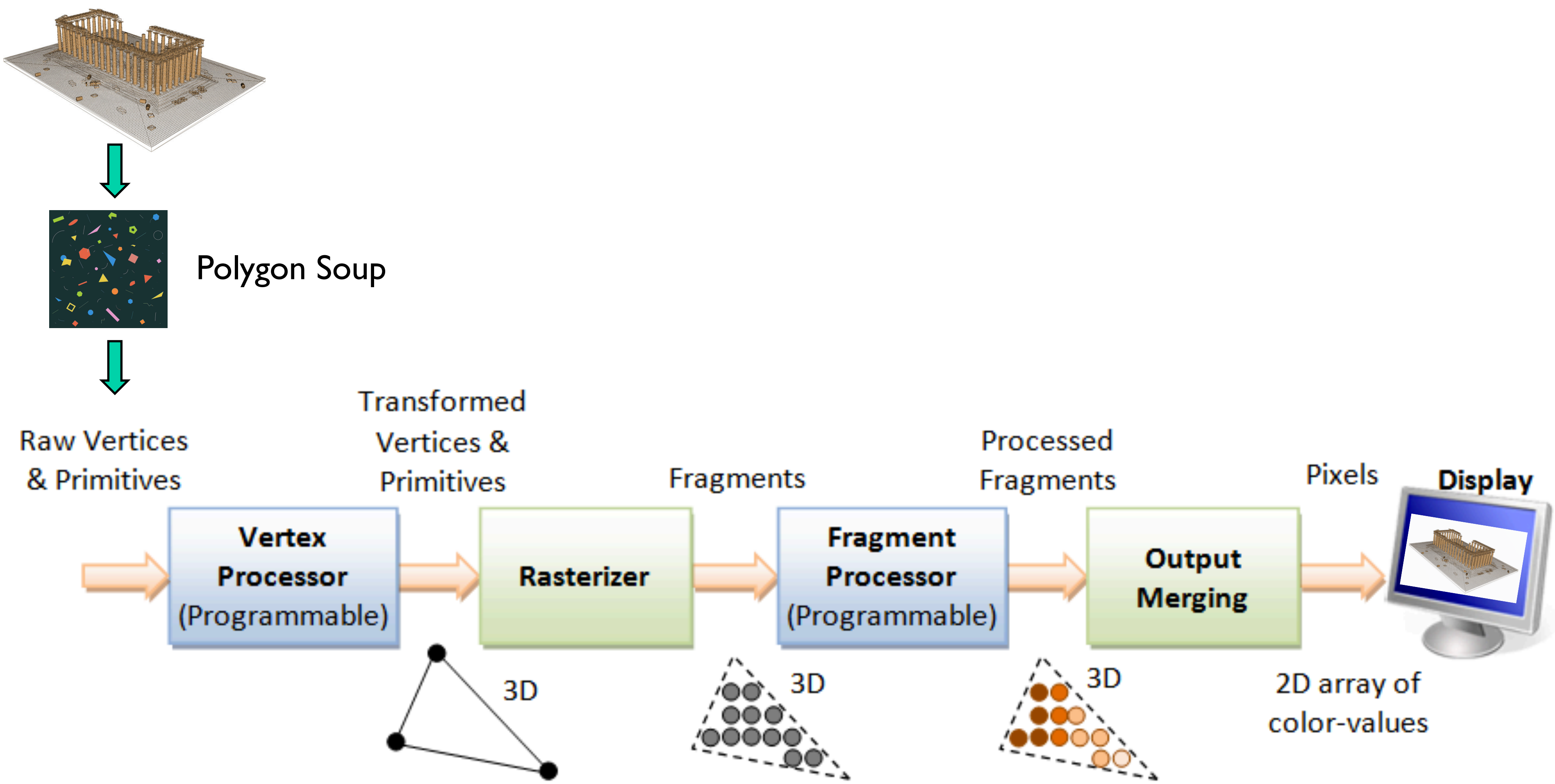


Lights

Types

- Point sources vs distributed sources
- Spot lights
- Near and far sources
- Color properties

Vertex Processing

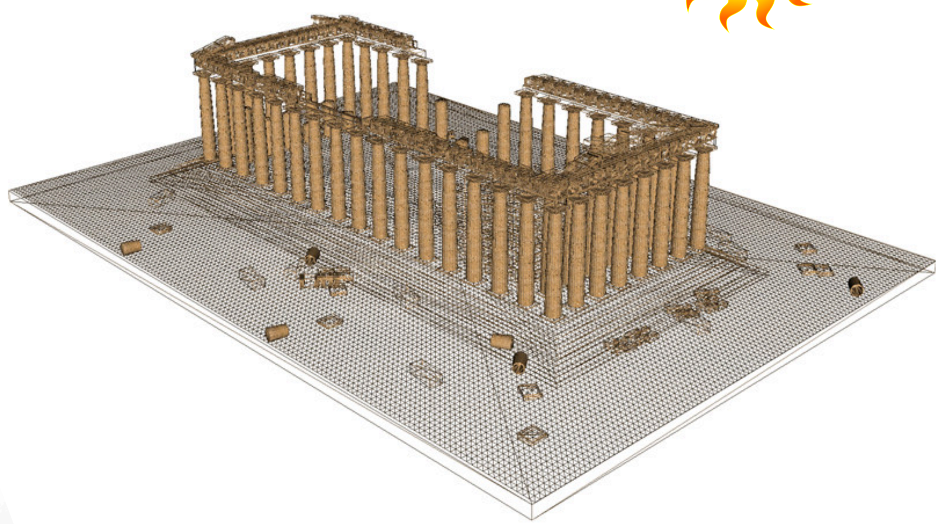


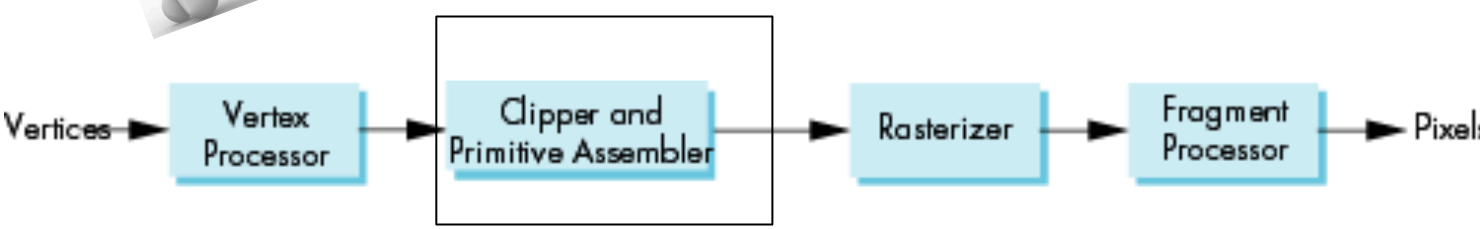
Vertex Processing

- Define object representations from one coordinate system to another
  - Object coordinates
  - World Coordinates
  - Camera (eye) coordinates
  - Screen coordinates
- Enter Linear algebra – Transformations
- Material properties

THE OHIO STATE UNIVERSITY
DEPARTMENT OF COMPUTER SCIENCE AND ENGINEERING

World

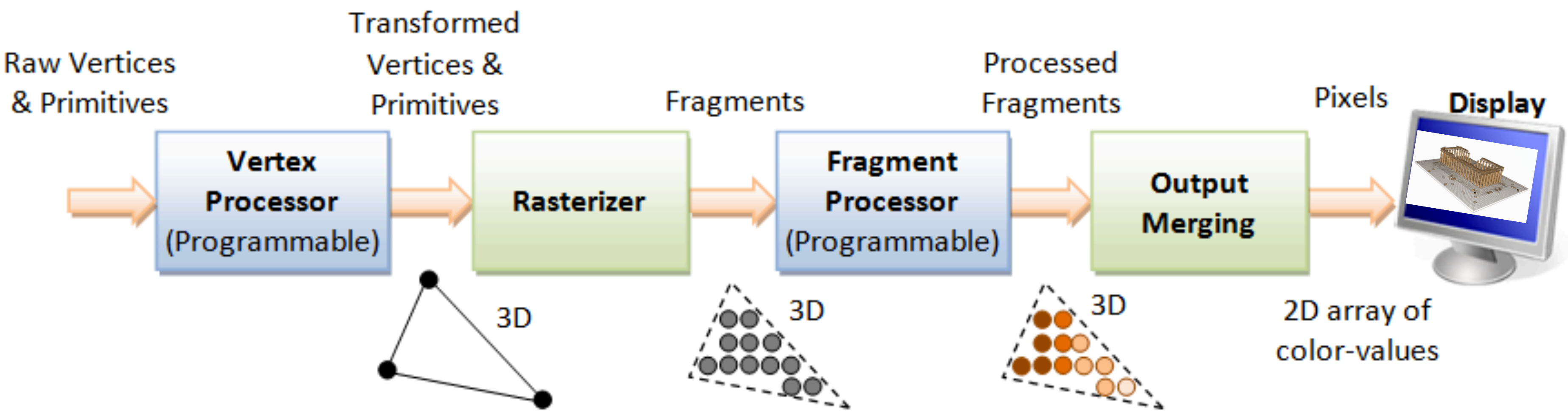



Vertices
Vertex Processor
Clipper and Primitive Assembler
Rasterizer
Fragment Processor
Pixels

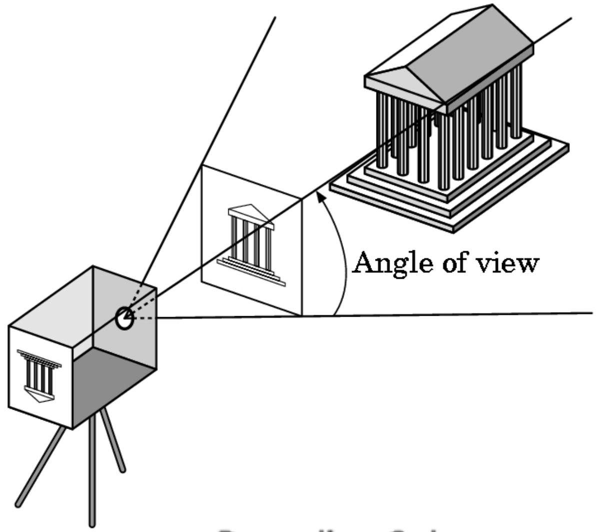
Primitive Assembly

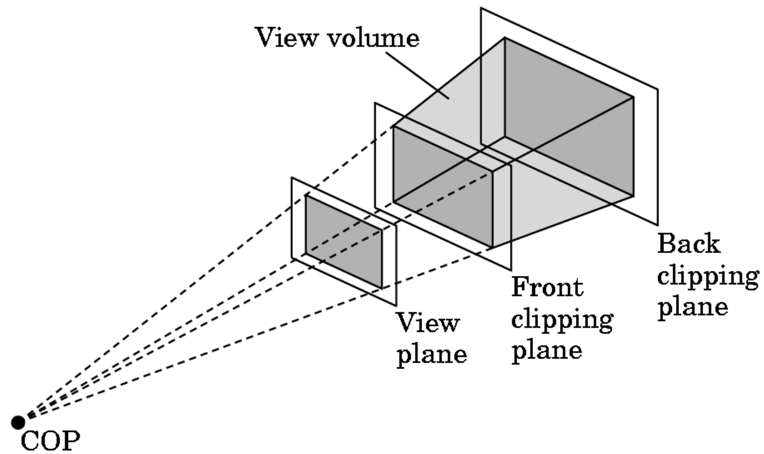
Vertices collected into geometric objects

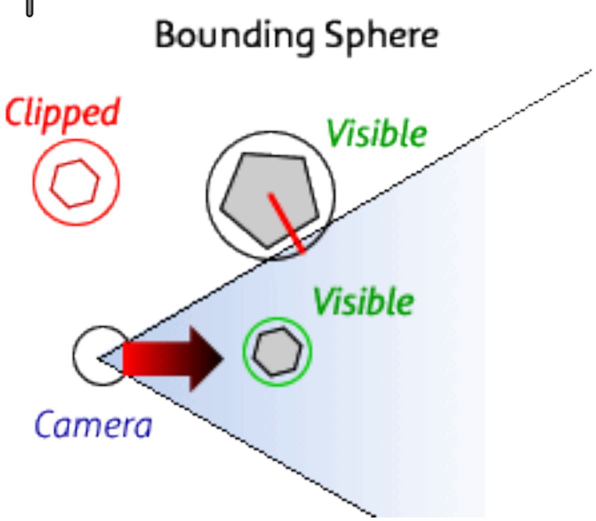
- Line segments
- Polygons
- Curves and surfaces

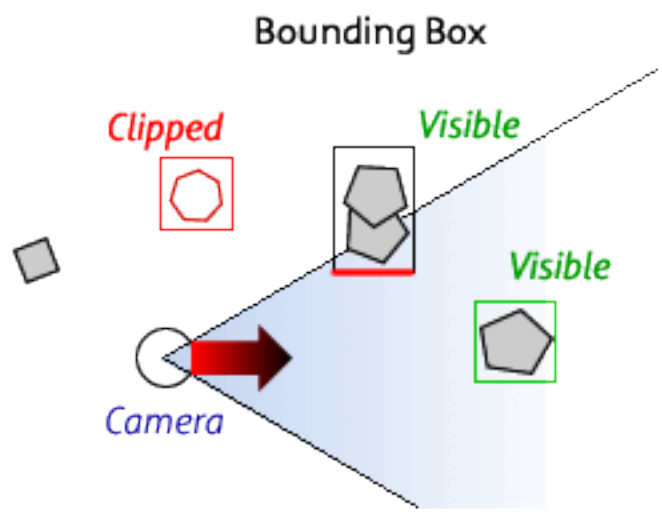


Clipping


Angle of view

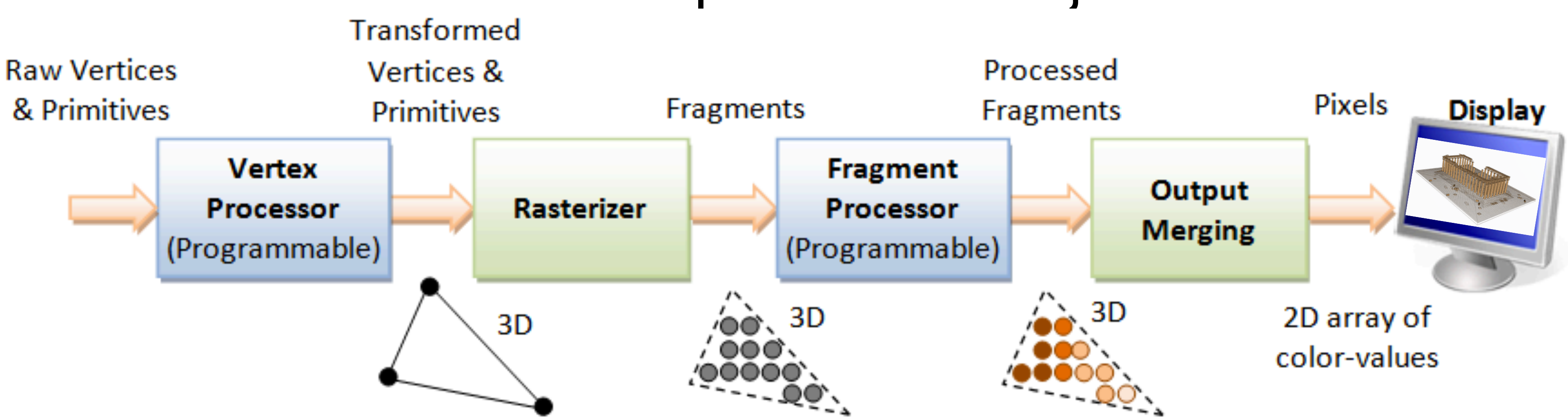

View volume
Back
clipping
plane
Front
clipping
plane
View
plane
COP


Bounding Sphere
Clipped
Visible
Visible
Camera

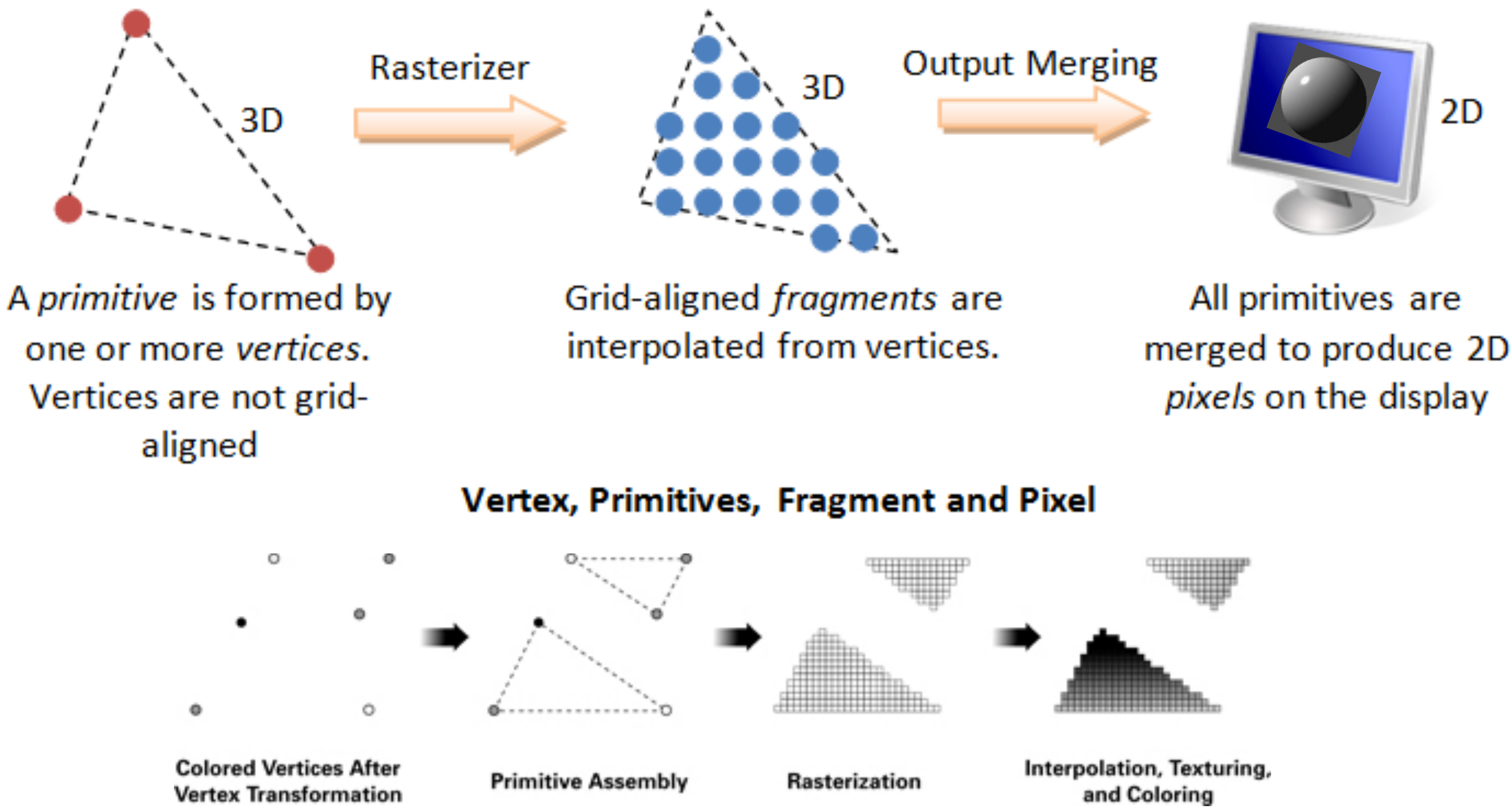

Bounding Box
Clipped
Visible
Visible
Camera

Rasterization

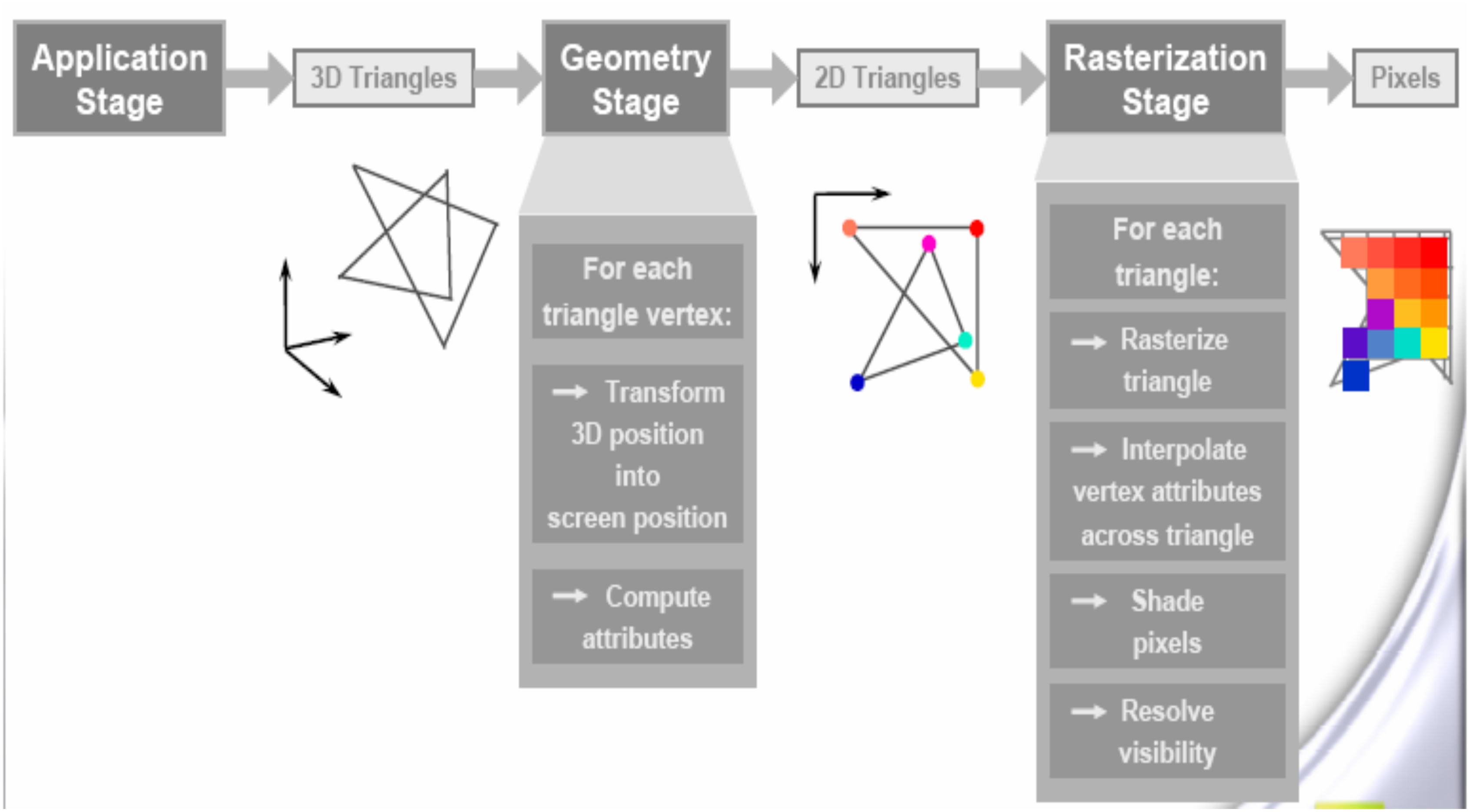
- Output are fragments
- Fragments == potential pixels
  - Location in frame buffer
  - Color and depth attributes at vertices
  - Hidden surface removal ?
- Vertex attributes are interpolated over objects



Fragment Processing



The Graphics Pipeline



What is Missing ?


Reflective environment Mapping Demo
NVIDIA

Not Quite ?

Next ?

My Desktop

My Desktop

Chipset Model: AMD Radeon HD 6770M
Type: GPU
Bus: PCIe
PCIe Lane Width: x16
VRAM (Total): 512 MB
Vendor: ATI (0x1002)
Device ID: 0x6740
Revision ID: 0x0000
ROM Revision: 113-C0170F-170
EFI Driver Version: 01.00.544
Displays:

iMac:

Display Type: LCD
Resolution: 2560 x 1440
Pixel Depth: 32-Bit Color (ARGB8888)
Main Display: Yes
Mirror: Off
Online: Yes
Built-In: Yes

Fancy Stuff !

AMD RADEON™

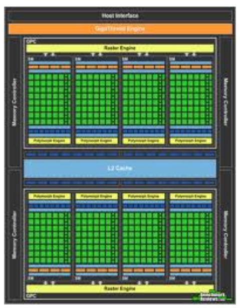
HD 6770 GPU
ENGINE CLOCK Up to 850MHz
MEMORY 512MB or 1GB DDR3 or GDDR5
MEMORY CLOCK 1200MHz
MEMORY BANDWIDTH 76.8 GB/s (maximum)
SINGLE PRECISION COMPUTE POWER 1.36 TFLOPs
TERASCALE 2 UNIFIED PROCESSING ARCHITECTURE
800 Stream Processors
40 Texture Units
64 Z/Stencil ROP Units
16 Color ROP Units
BUS INTERFACE PCI Express 2.1 x16
OPENGL 4.1 SUPPORT Yes
IMAGE QUALITY ENHANCEMENT TECHNOLOGY
Up to 24x multi-sample and super-sample anti-aliasing modes
Adaptive anti-aliasing
16x angle independent anisotropic texture filtering
128-bit floating point HDR rendering
CUTTING-EDGE INTEGRATED DISPLAY SUPPORT
Integrated DisplayPort Output
Max resolution: 2560x1600 per display
HDMI® (With 3D, Deep Color and x.v.Color™)
Max resolution: 1920x1200
Integrated Dual-link DVI with HDCP
Max resolution: 2560x1600
Integrated VGA
Max resolution: 2048x1536

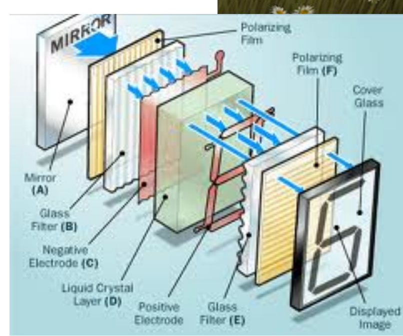
INTEGRATED HD AUDIO CONTROLLER
Output protected high bit rate 7.1 channel surround sound over HDMI or DisplayPort with no additional cables required
Supports AC-3, AAC, Dolby TrueHD and DTS Master Audio formats
AMD TECHNOLOGIES
AMD Eyefinity multidisplay technology2
Native support for up to 5 simultaneous displays
Independent resolutions, refresh rates, color controls and video overlays
Display grouping
Combine multiple displays to behave like a single large display
AMD App Acceleration3
OpenCL 1.1 Support
DirectCompute 11
Accelerated video encoding, transcoding and upscaling
UVD 2 dedicated video playback accelerator
H.264
VC-1
MPEG-2
H.264 MVC (Blu-ray 3D)5
Adobe Flash
Enhanced Video Quality features
Advanced post-processing and scaling
Dynamic contrast enhancement and color correction
Brighter whites processing (Blue Stretch)
Independent video gamma control
Dynamic video range control
Dual-stream HD (1080p) playback support
DXVA 1.0 & 2.0 support

AMD HD3D technology5
Stereoscopic 3D display/glasses support
Blu-ray 3D support
Stereoscopic 3D gaming
3rd party Stereoscopic 3D middleware software support
AMD CrossFire™ multi-GPU technology6
Dual GPU scaling
AMD PowerPlay™ power management technology4
Dynamic power management with low power idle state
Ultra-low power state support for multi-GPU configurations

AMD Catalyst™ software and HD video configuration software
Unified graphics display drivers
Certified for Windows 7, Windows Vista, and Windows XP
AMD CatalystTM Control Center
Software application and user interface for setup, configuration and accessing special features of AMD Radeon products.

Computer Graphics Hardware: An Overview



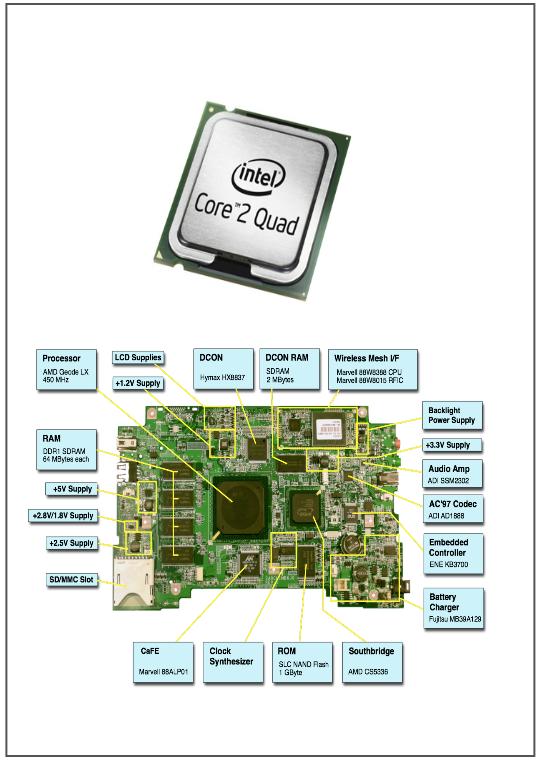


THE OHIO STATE UNIVERSITY DEPARTMENT OF COMPUTER SCIENCE AND ENGINEERING

Many Thanks to Prof. Han-wei Shen, CSE, OSU

Graphics System

Input devices

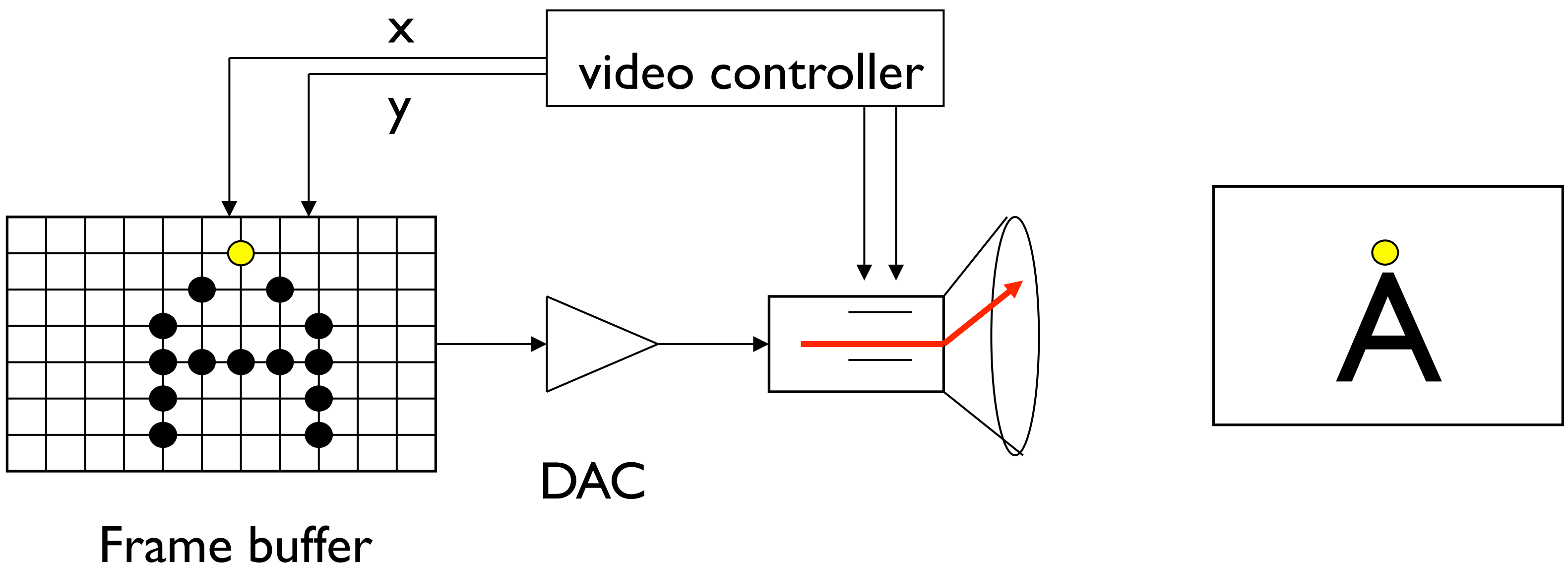


CPU/Memory

GPU

Monitor

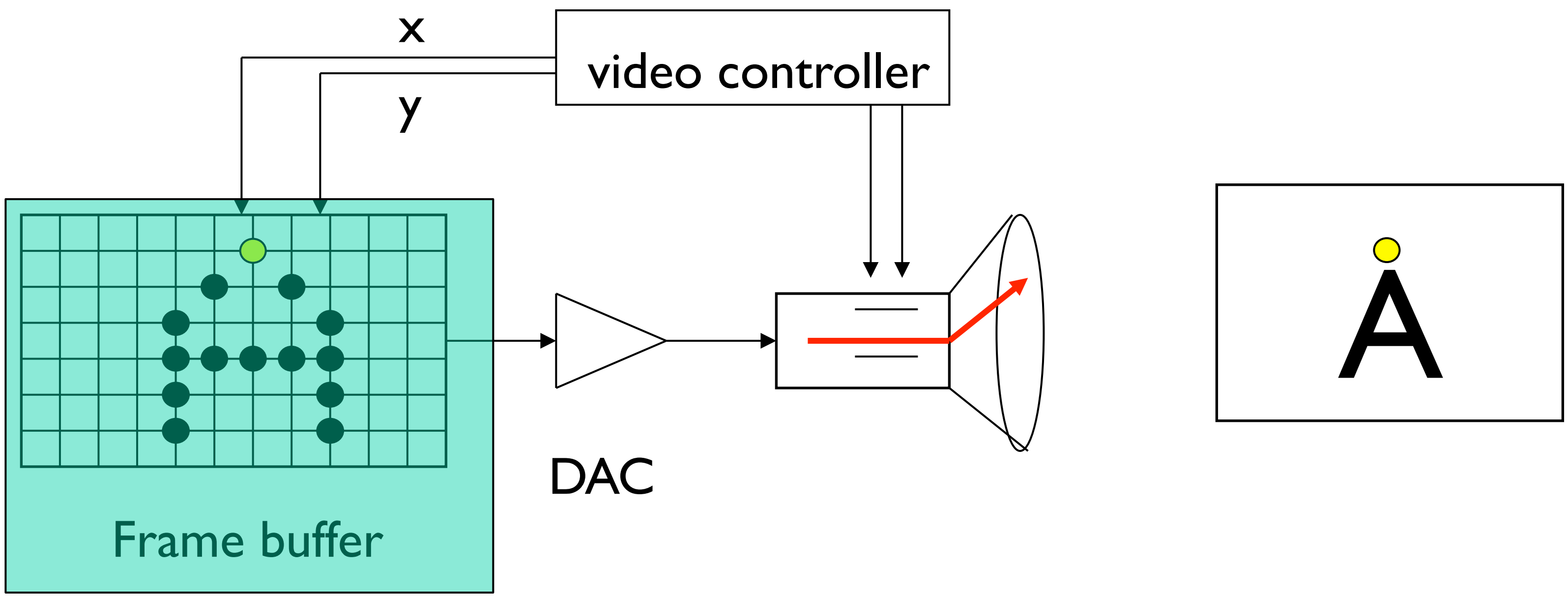
Raster Graphics System



To Note

- ✓ Raster: An array of picture elements
- ✓ Based on raster-scan TV technology
- ✓ The screen & rendering consists of discrete pixels
- ✓ Each pixel has a small display area

The Frame Buffer



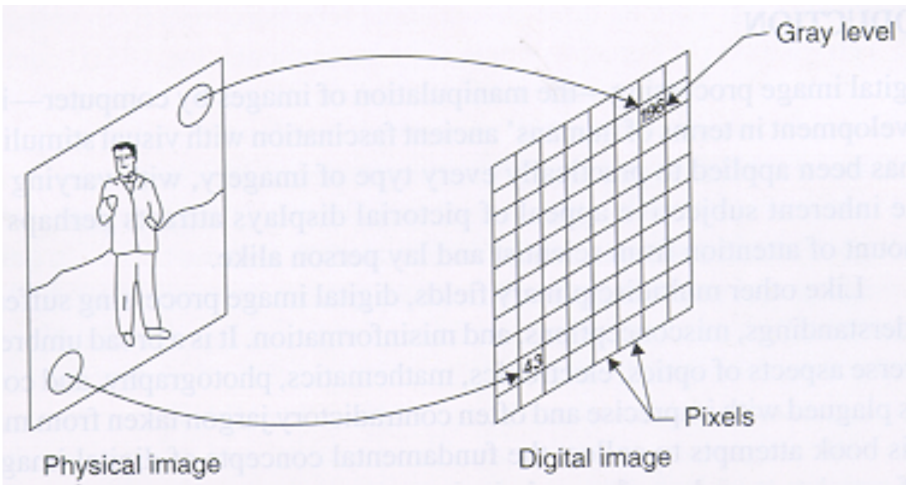
Frame Buffer

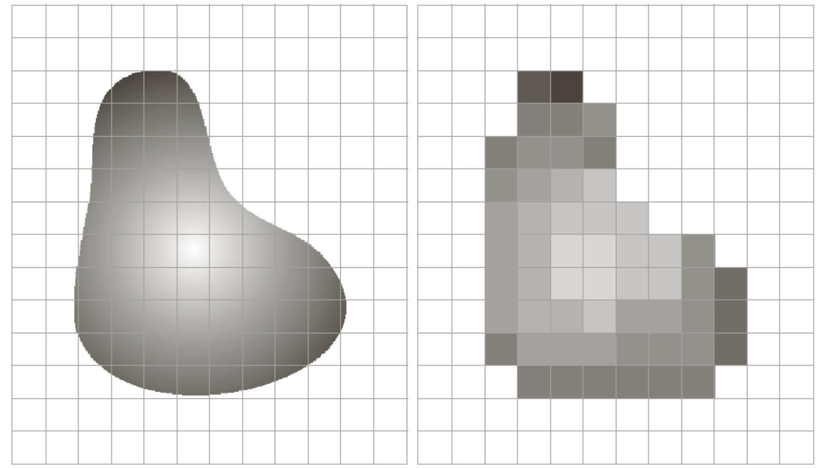
- Low-latency memory to hold pixel attributes
  - color, alpha, depth, stencil mask, who-knows-what
- Performance depends on
  - Size: screen resolution
  - Depth: color level
  - Speed: refresh speed

Depth

- bit/pixel: black and white
- 8 bits/pixel: 256 levels of gray or color pallet index
- 24 bits/pixel: 16 million colors

Image Digitization - Recap

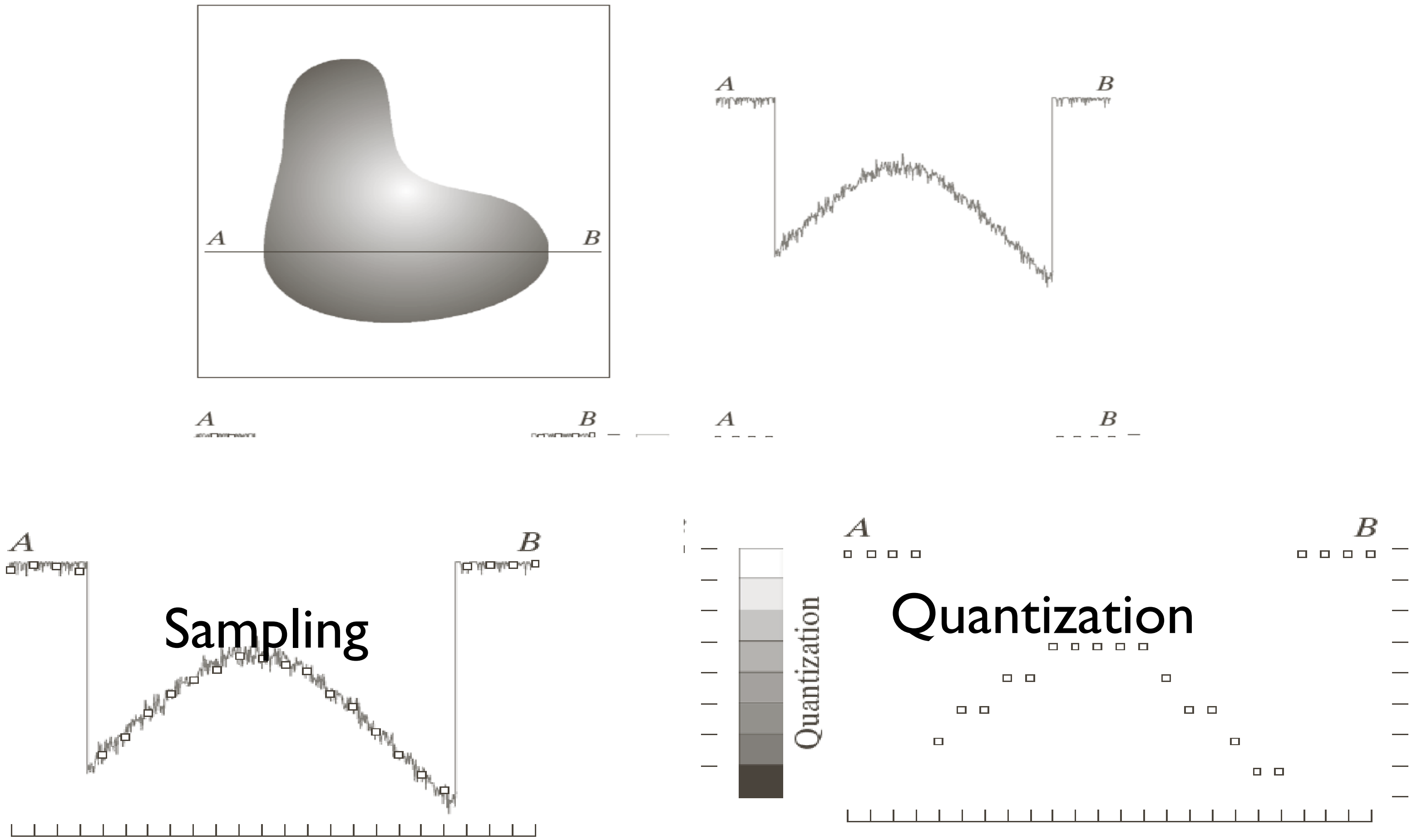




Sampling: Resolution

Quantization: Measured Value

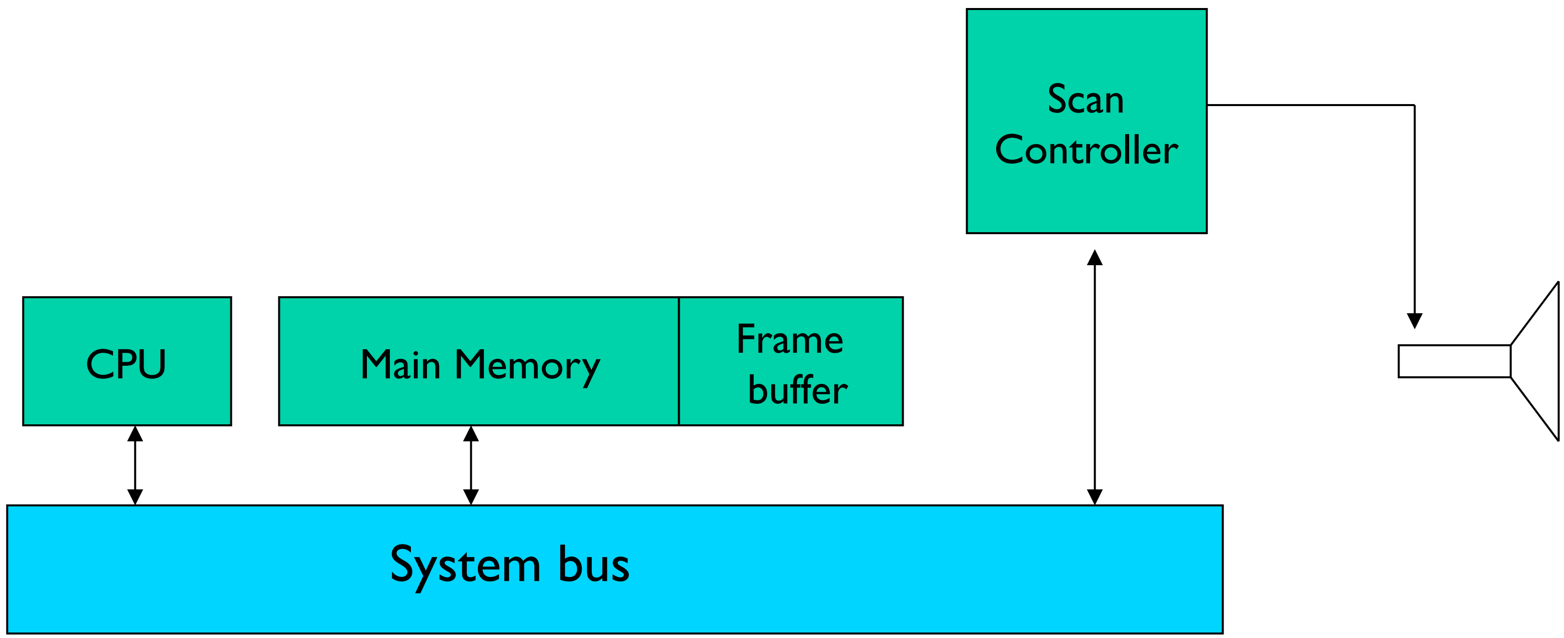
Image Digitization-Recap



The Architecture

(A way too) Simple Graphik System

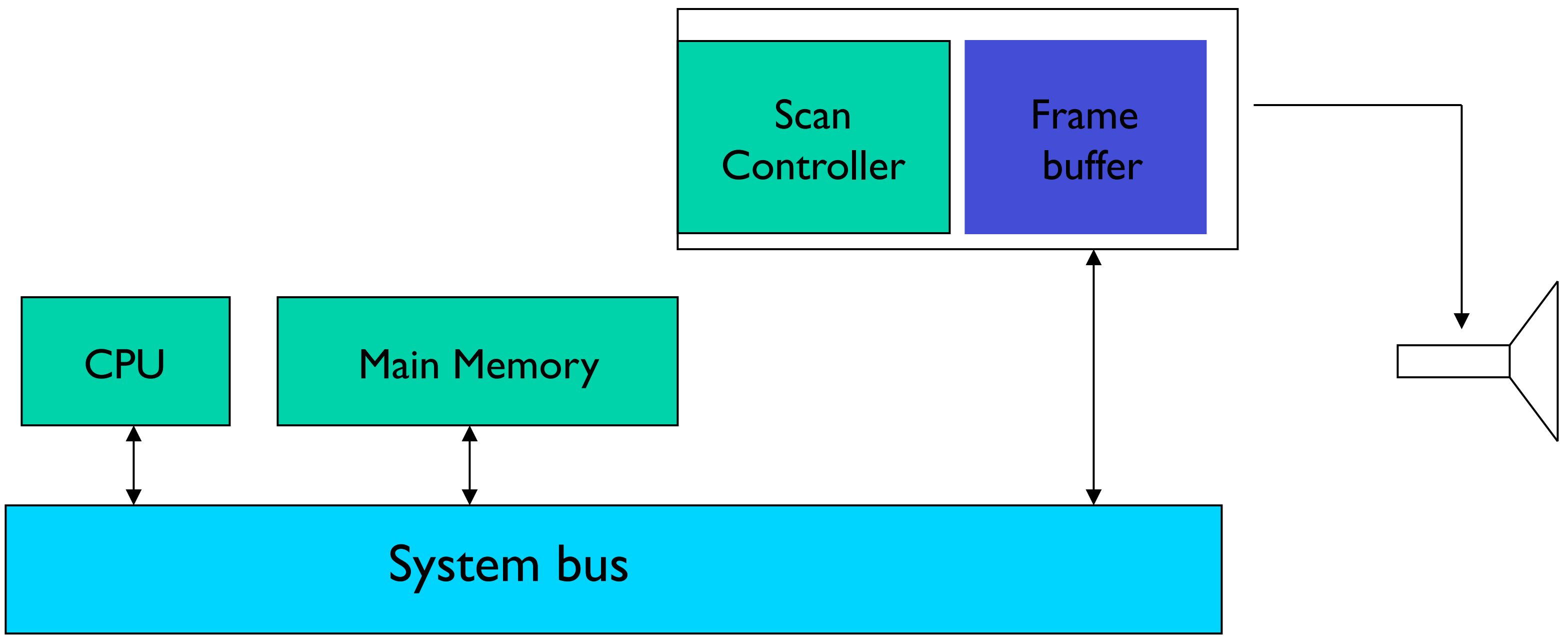
Frame buffer is part of main memory



Problem?

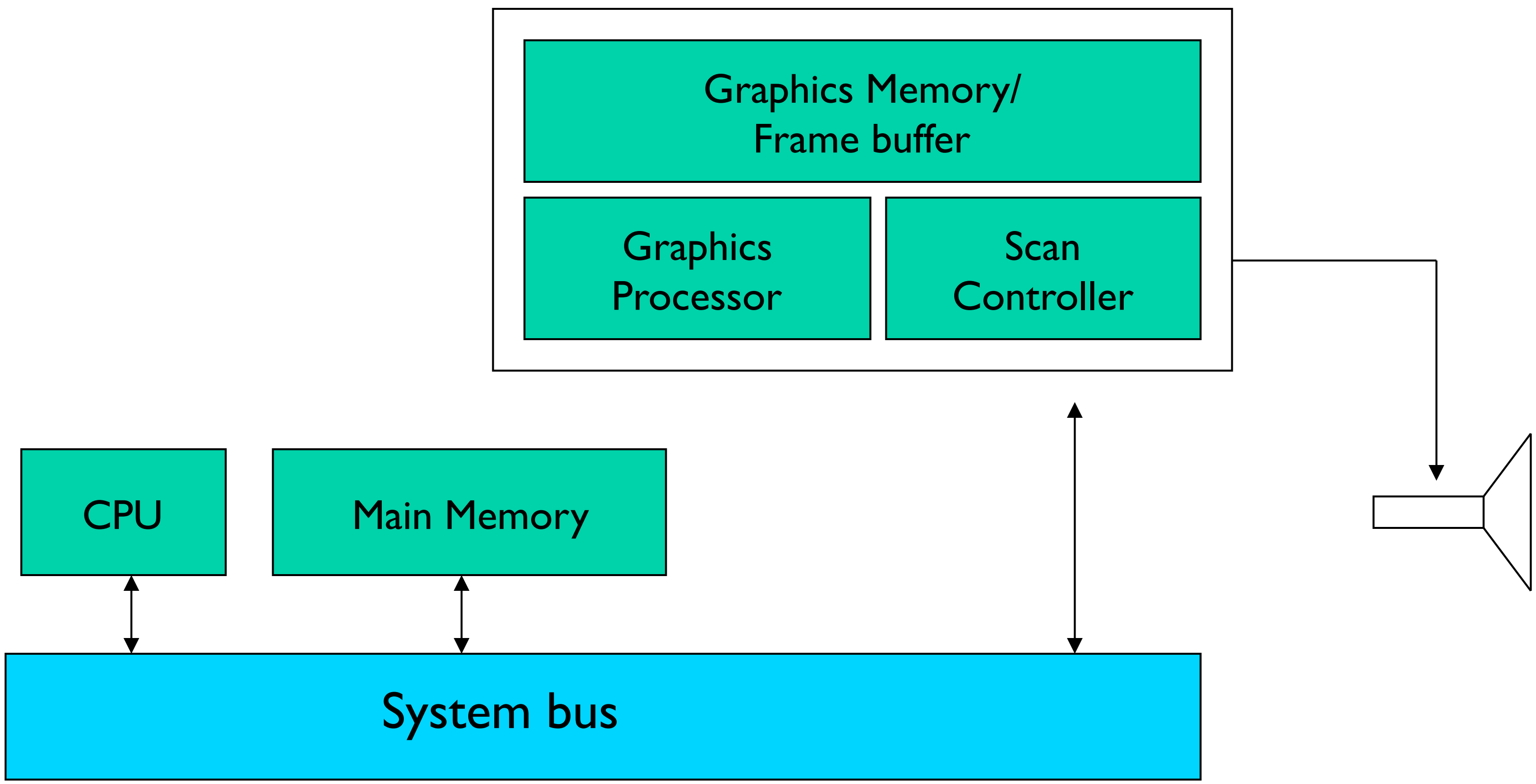
Dedicated memory

Video memory: On-board frame buffer: much faster to access



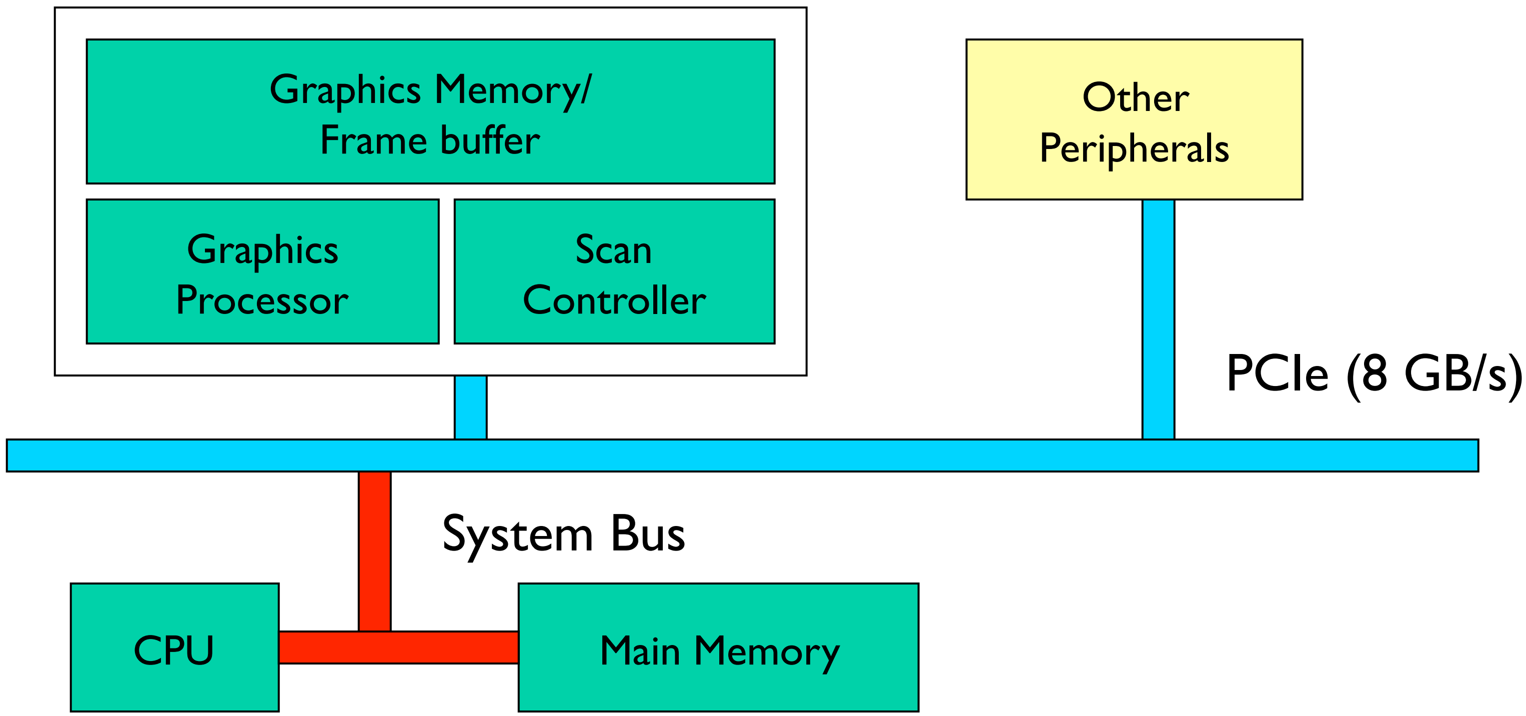
Graphics Accelerator

A dedicated processor for graphics processing



Graphics Bus Interface

PCI based technology

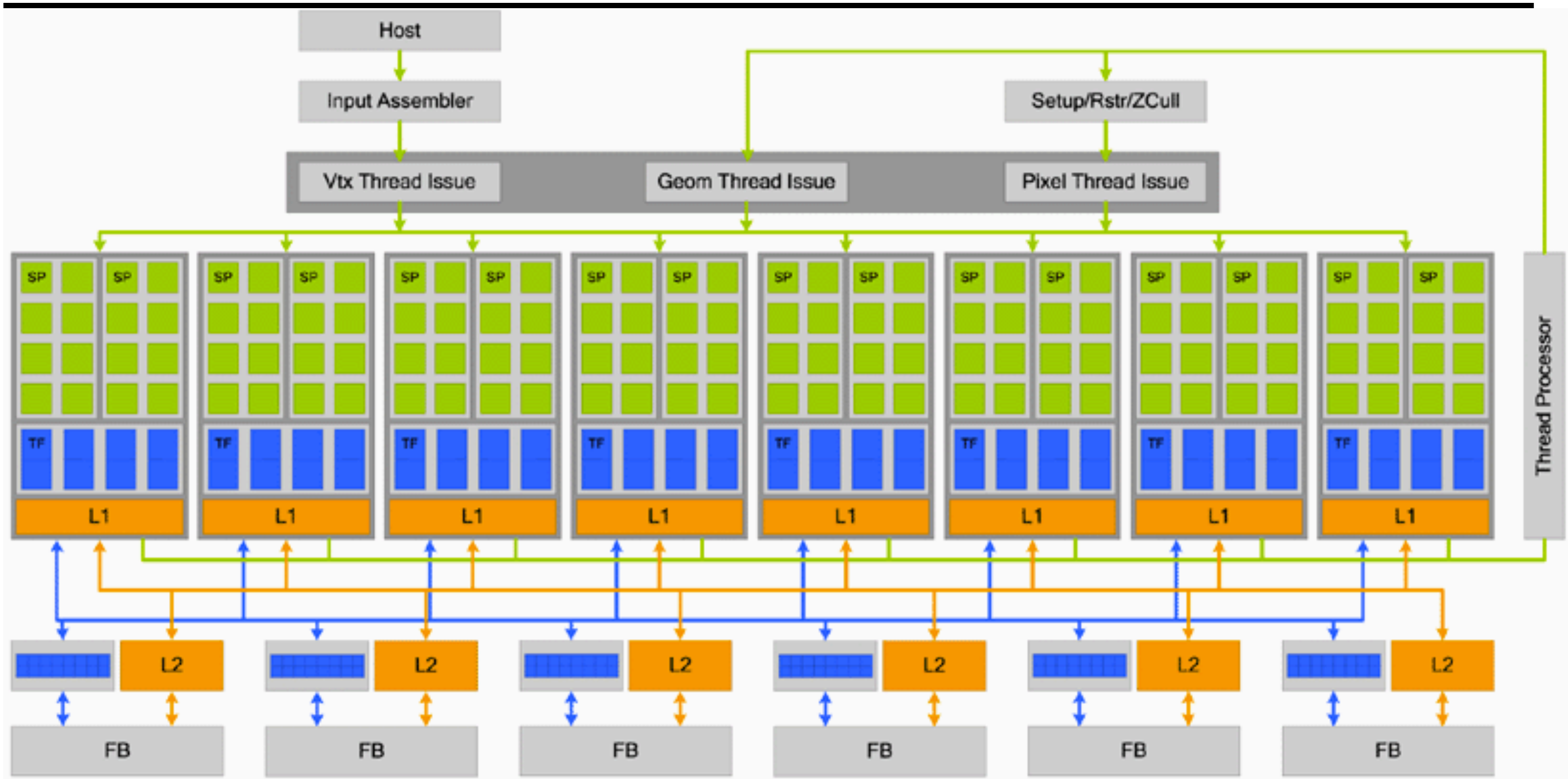


ATI TECHNOLOGIES INC.

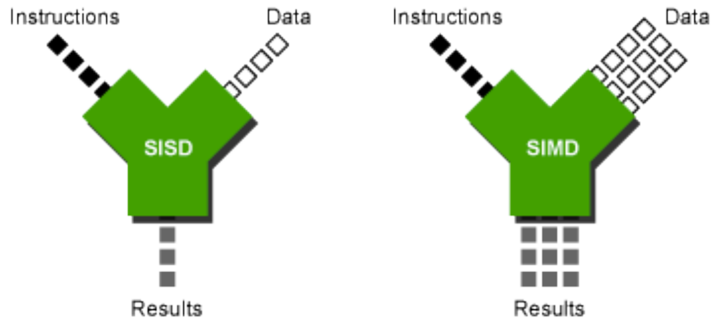
NVIDIA.
PersonalCinema

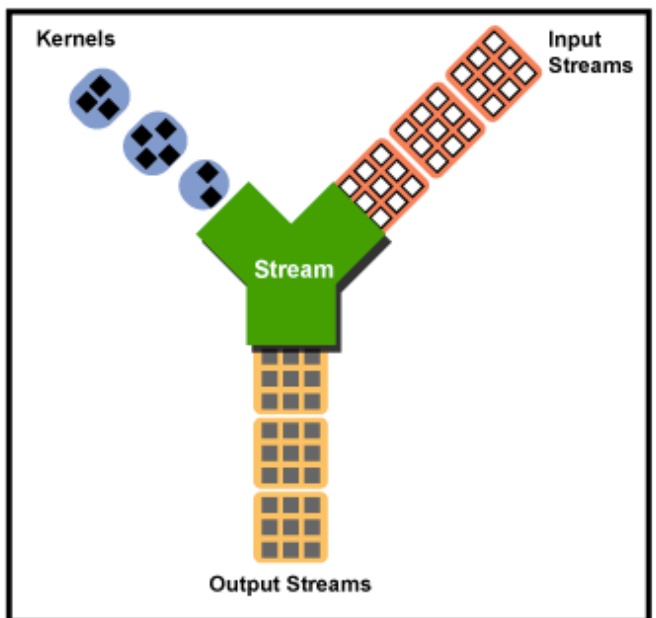
Graphics Accelerators

(Massively) Parallel Processors

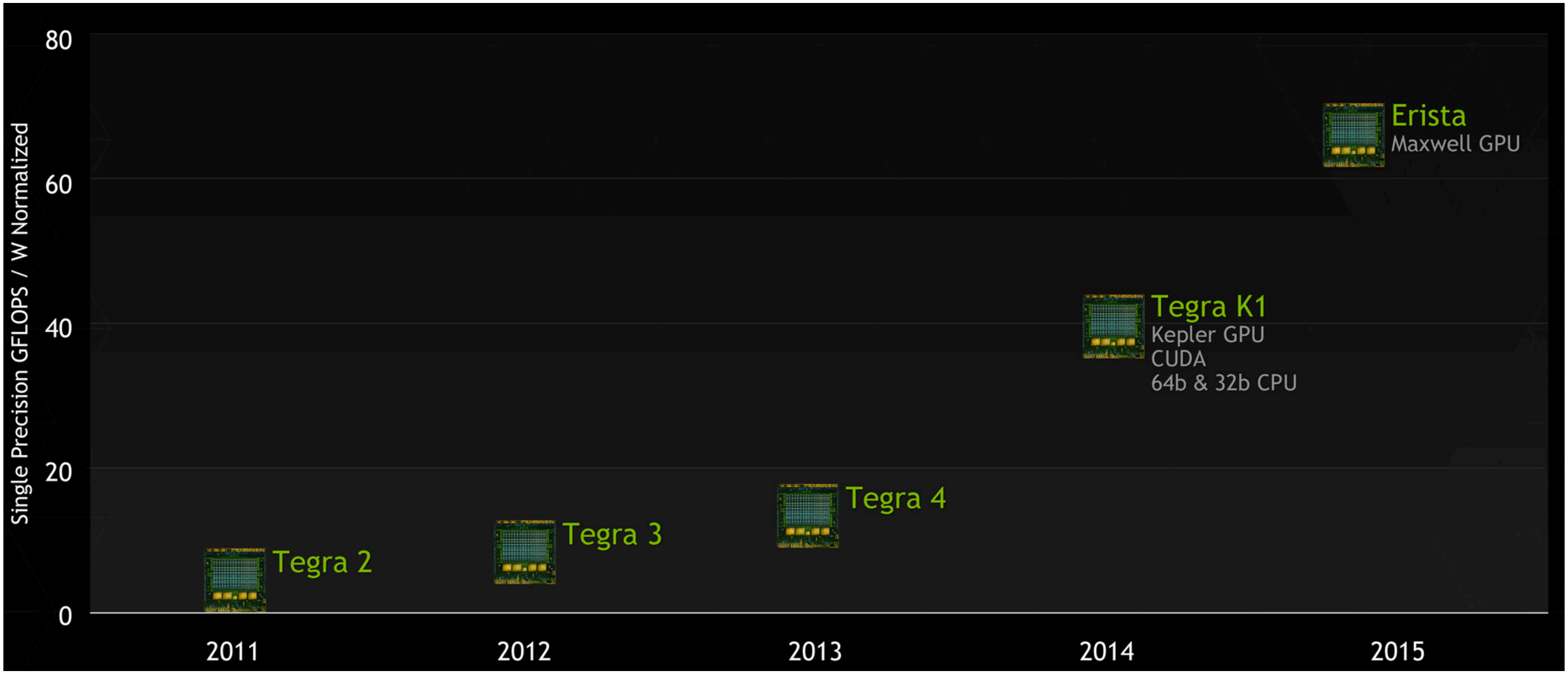


Stream Processing





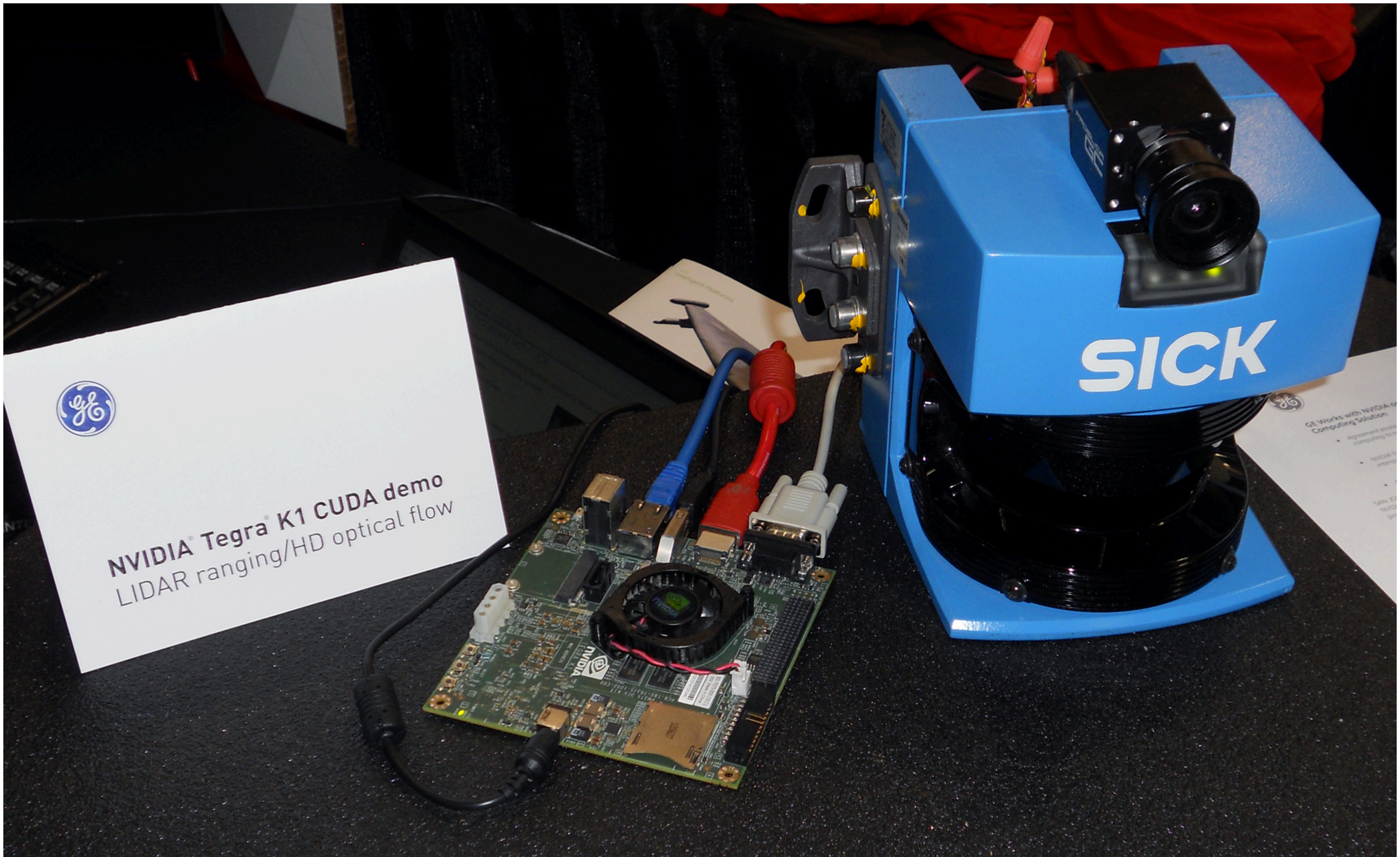
A Roadmap



Single Precision GFLOPS / W Normalized
80
60
40
20
0
2011
2012
2013
2014
2015
Tegra 2
Tegra 3
Tegra 4
Tegra K1
Kepler GPU
CUDA
64b & 32b CPU
Erista
Maxwell GPU

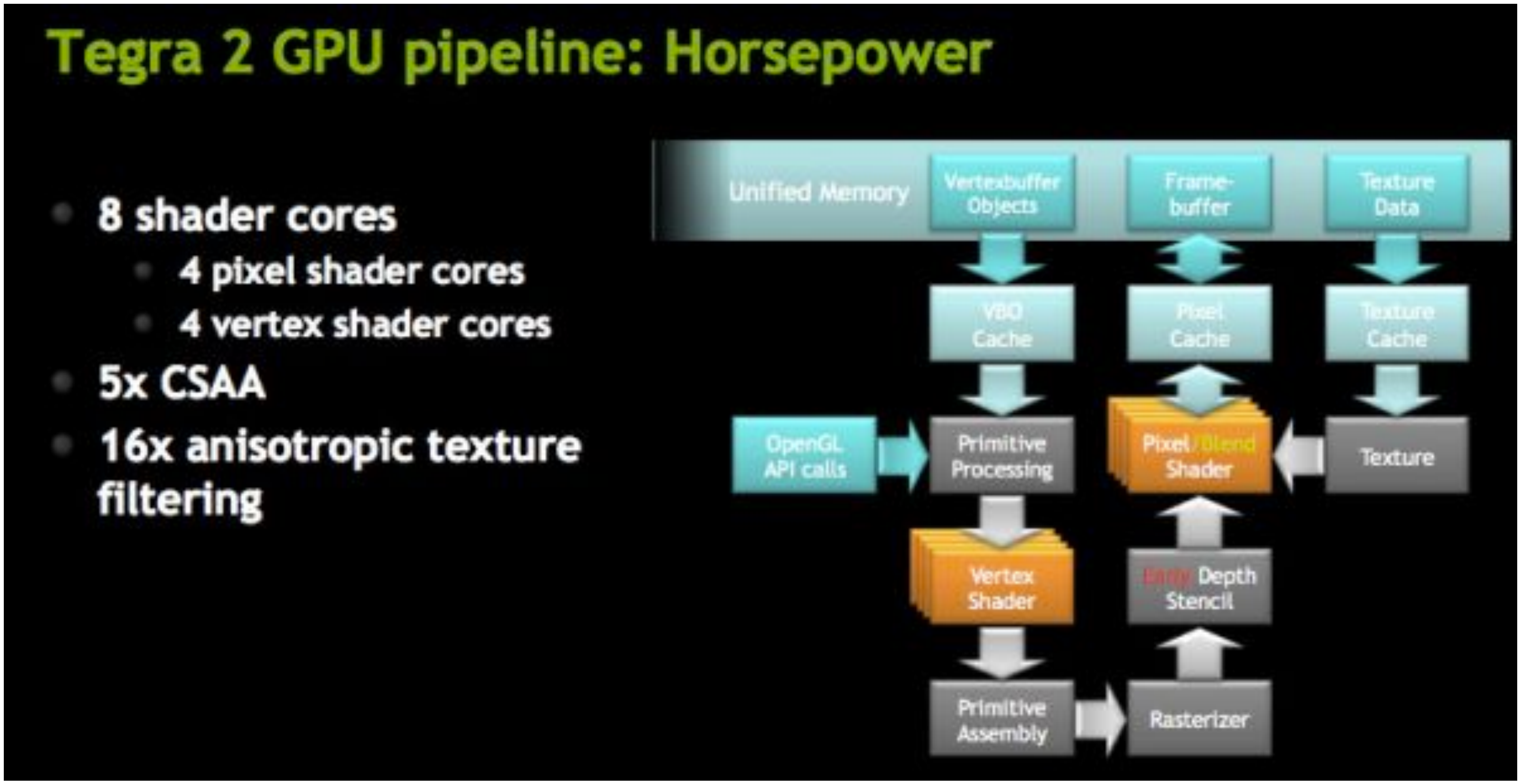
The Main Drivers

GPU = General Purpose Units !



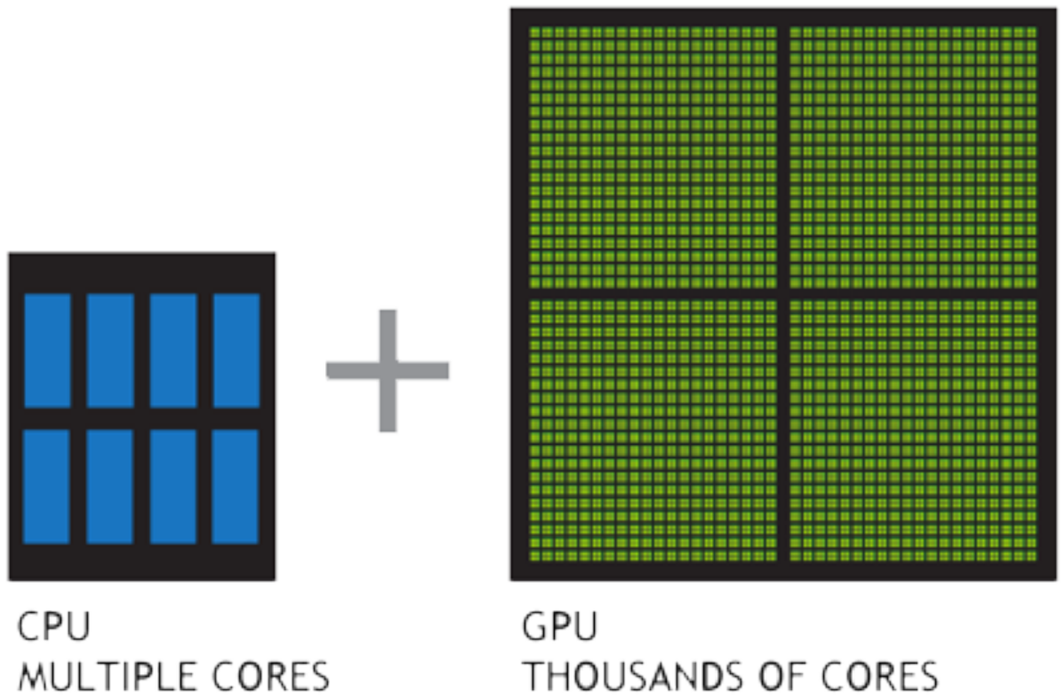
My Own nVidia

The Existentialist GPU

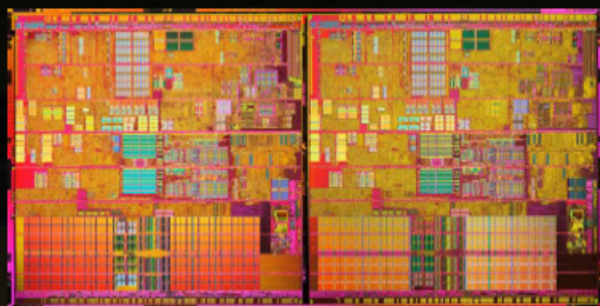


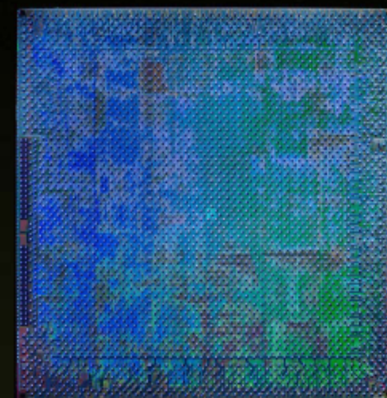
http://www.anandtech.com/show/4225/the-ipad-2-review/5

Multi-Core Galore



Largest Chip on Mother Board





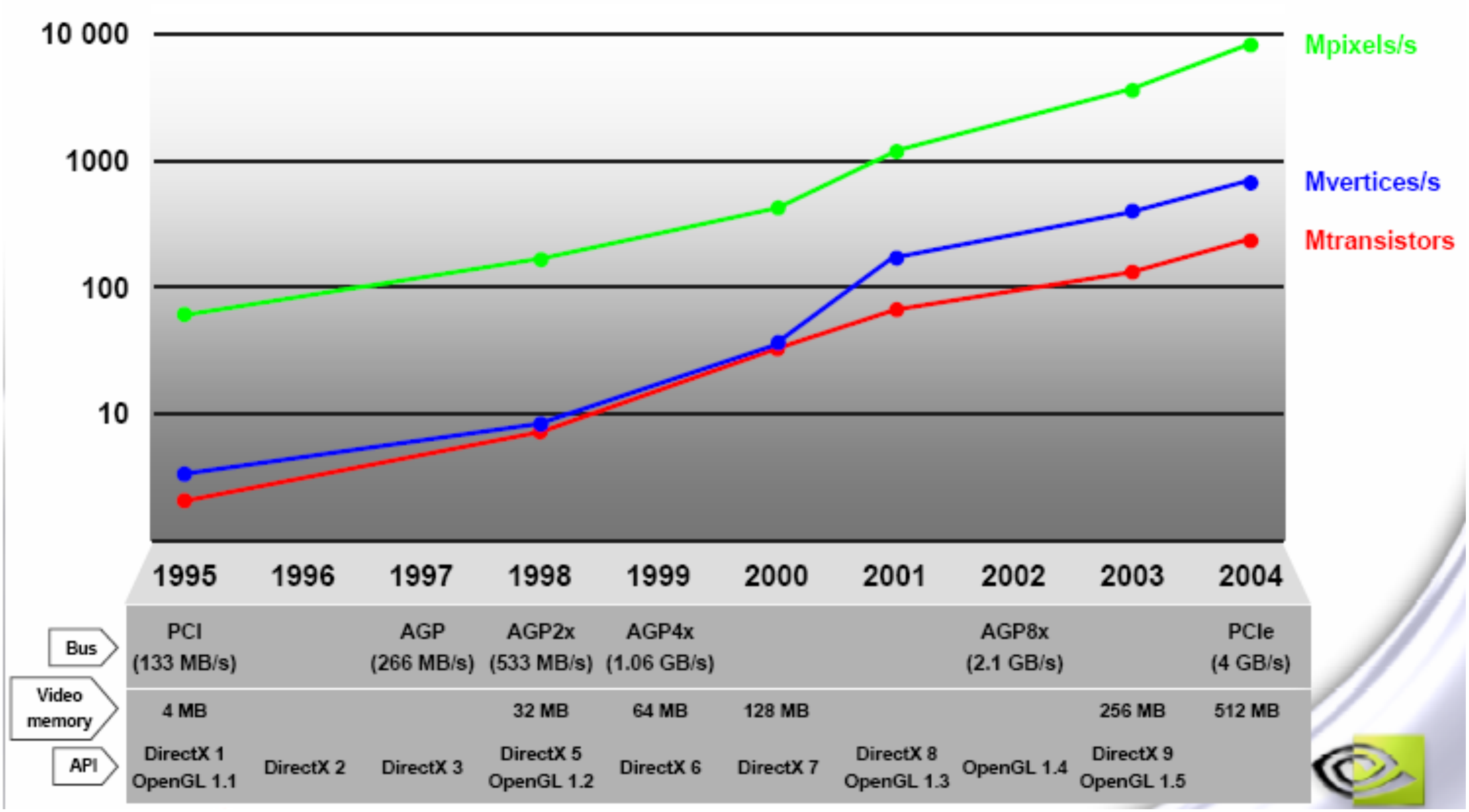
Pentium Extreme Edition 840

- 3.2 GHz Dual Core
- 230M Transistors
- 90nm process
- 206 mm^2
- 2 x 1MB Cache
- 25.6 GFlops

GeForce 7800 GTX

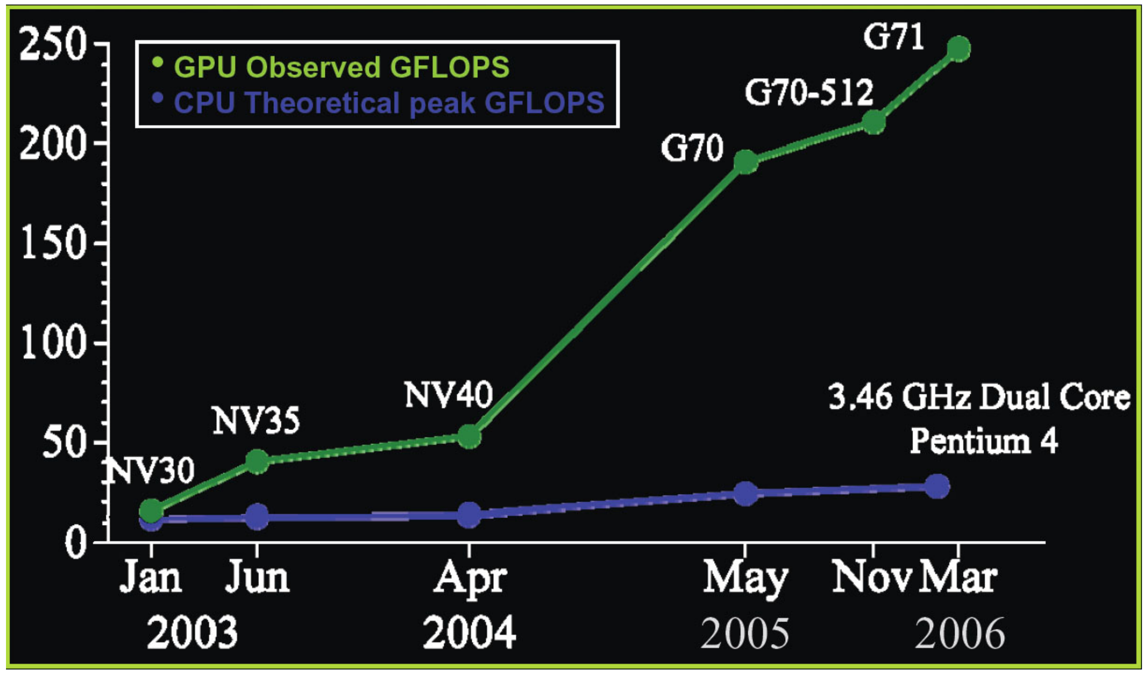
- 430 MHz
- 302M Transistors
- 110nm process
- 326 mm^2
- 313 GFlops (shader)
- 1.3 TFlops (total)

Evolution of Performance

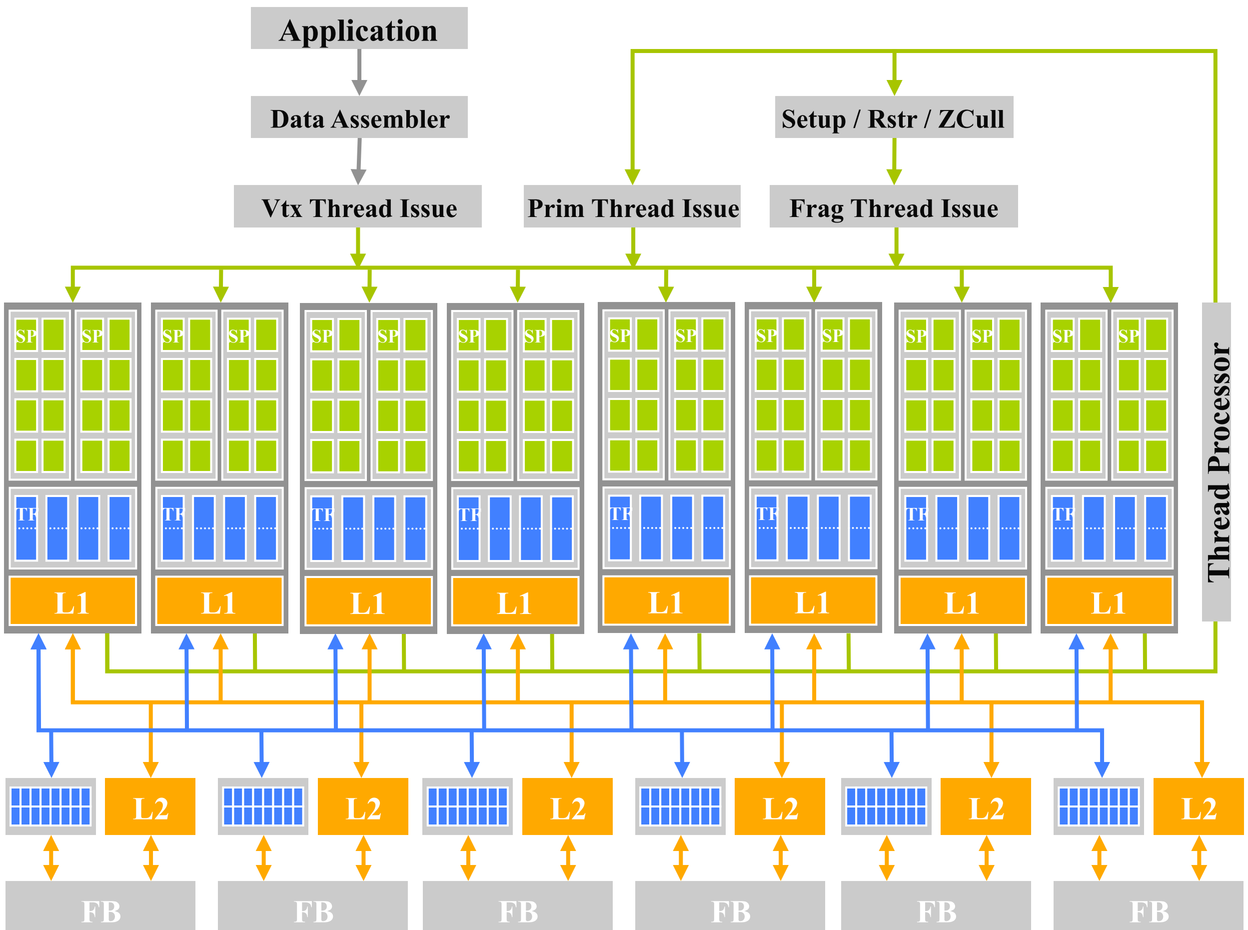


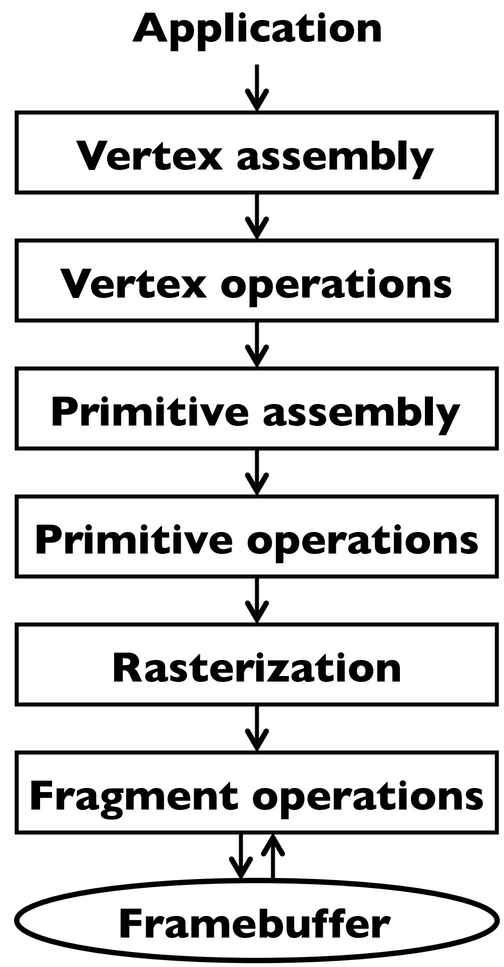
nVidia G80 GPU (2006)

- 128 streaming floating point processors @1.5Ghz
- 1.5 Gb Shared RAM with 86Gb/s bandwidth
- 500 Gflop on one chip (single precision)

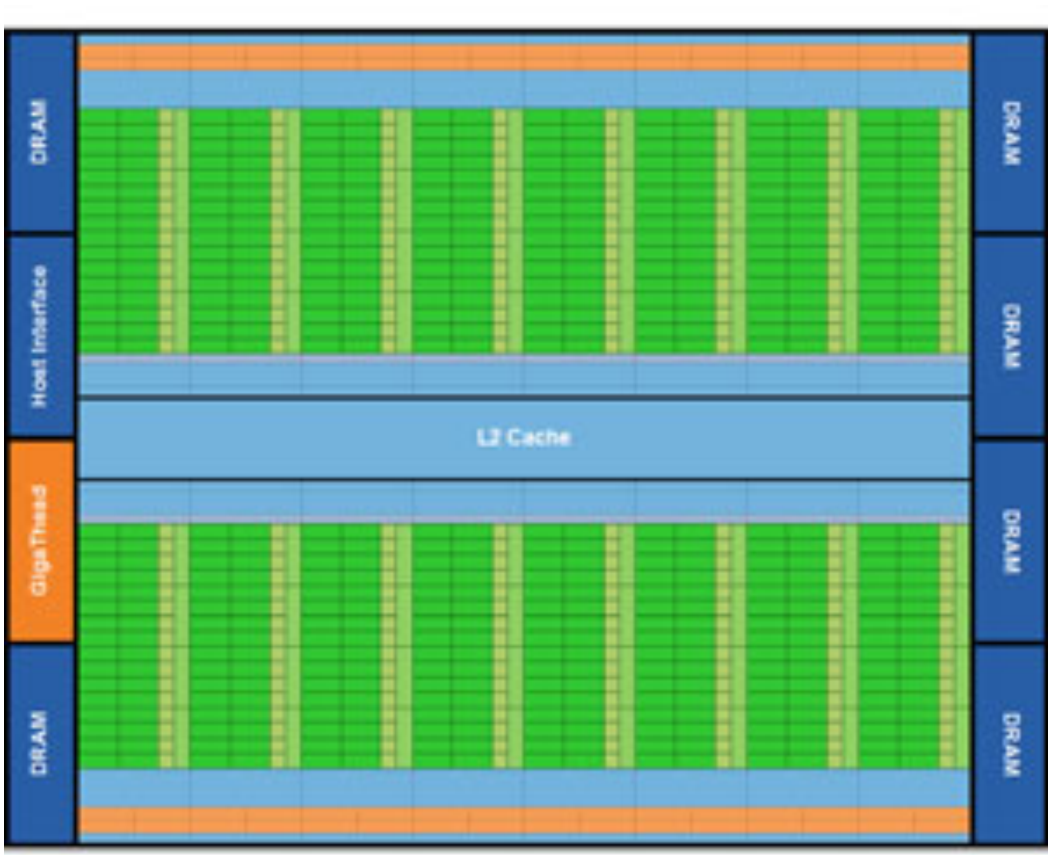


nVidia G80 GPU





nVidia Fermi GPU (2009)



nVidia Fermi GPU (2009)

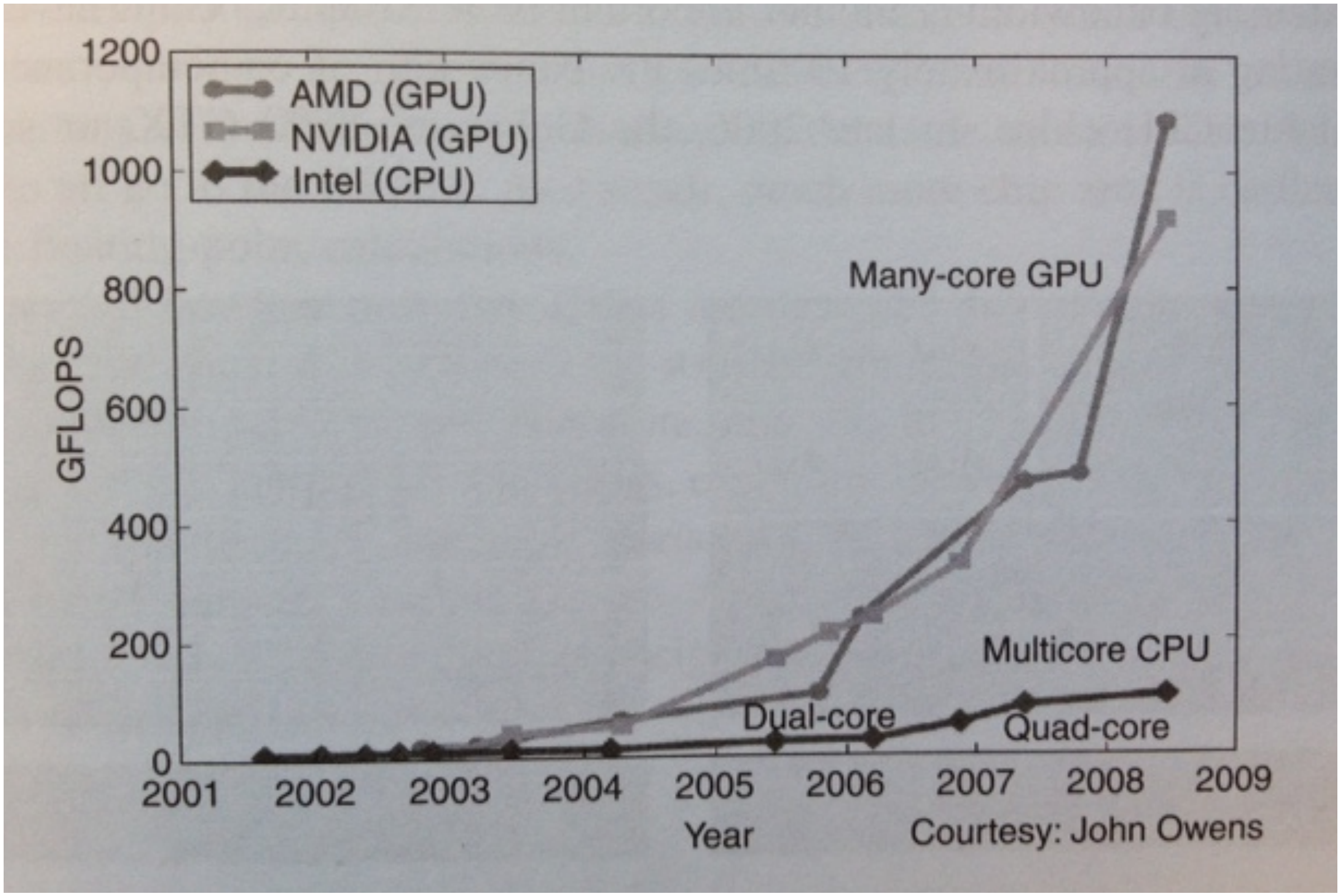
GPU	G80	GT200	Fermi
Transistors	681 million	1.4 billion	3.0 billion
CUDA Cores	128	240	512
Double Precision Floating Point Capability	None	30 FMA ops / clock	256 FMA ops /clock
Single Precision Floating Point Capability	128 MAD ops/clock	240 MAD ops / clock	512 FMA ops /clock
Special Function Units (SFUs) / SM	2	2	4
Warp schedulers (per SM)	1	1	2
Shared Memory (per SM)	16 KB	16 KB	Configurable 48 KB or 16 KB
L1 Cache (per SM)	None	None	Configurable 16 KB or 48 KB
L2 Cache	None	None	768 KB
ECC Memory Support	No	No	Yes
Concurrent Kernels	No	No	Up to 16
Load/Store Address Width	32-bit	32-bit	64-bit

nVidia Kepler GK110 (2012)

Architecture

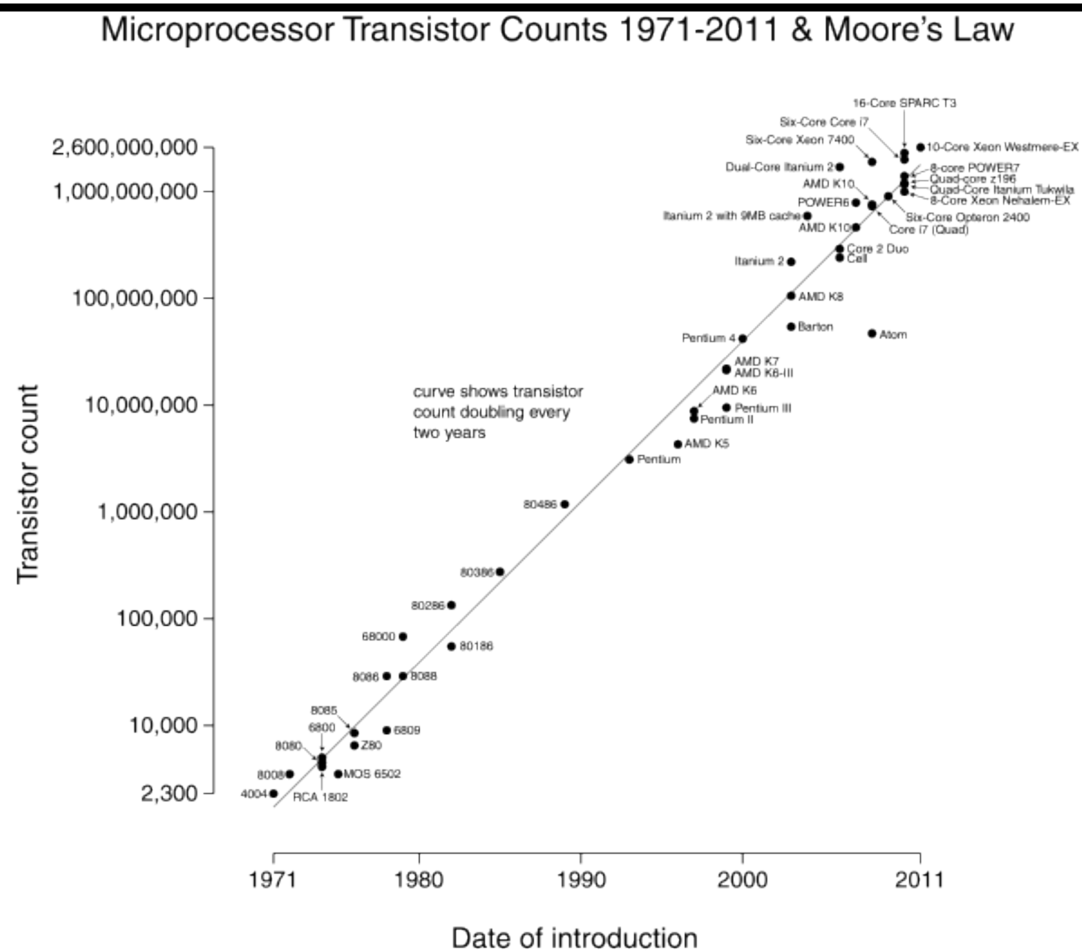
- 7.1B Transistors
- 15 SMX units
- > 1 TFLOP FP64
- 1.5 MB L2 Cache
- 384-bit GDDR5
- PCI Express Gen3

CPU/GPU Performance Gap



Why are GPUs Fast ?

Moore's Law ++


Microprocessor Transistor Counts 1971-2011 & Moore's Law
Transistor count
2,600,000,000
1,000,000,000
100,000,000
10,000,000
1,000,000
100,000
10,000
2,300
Date of introduction
1971
1980
1990
2000
2011
curve shows transistor count doubling every two years
16-Core SPARC T3
Six-Core Core i7
Six-Core Xeon 7400
10-Core Xeon Westmere-EX
Dual-Core Itanium 2
AMD K10
POWER6
8-core POWER7
Quad-core z196
Quad-Core Itanium Tukwila
8-Core Xeon Nehalem-EX
Itanium 2 with 9MB cache
AMD K10
Six-Core Opteron 2400
Core i7 (Quad)
Core 2 Duo
Cell
Itanium 2
AMD K8
Barton
Atom
Pentium 4
AMD K7
AMD K6-III
AMD K6
Pentium III
Pentium II
AMD K5
Pentium
80486
80386
80286
68000
80186
8086
8088
8085
6800
6809
8080
Z80
8008
MOS 6502
4004
RCA 1802

Modern GPU has more ALU's

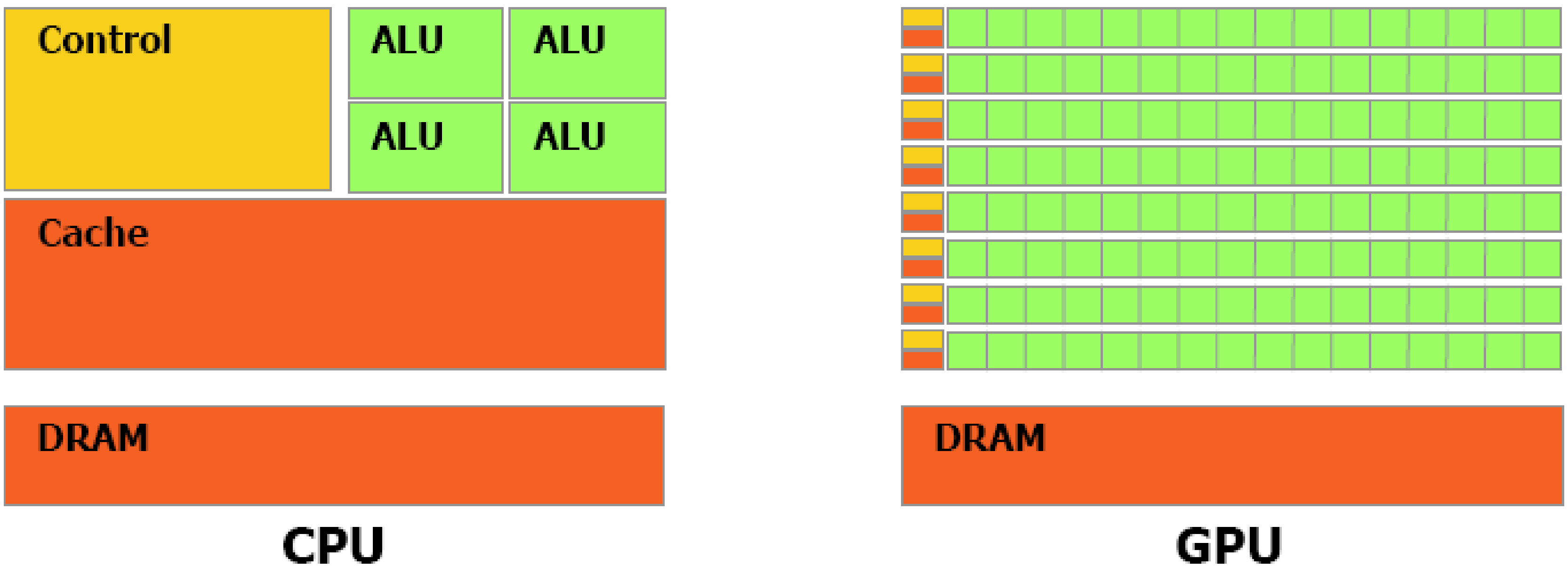
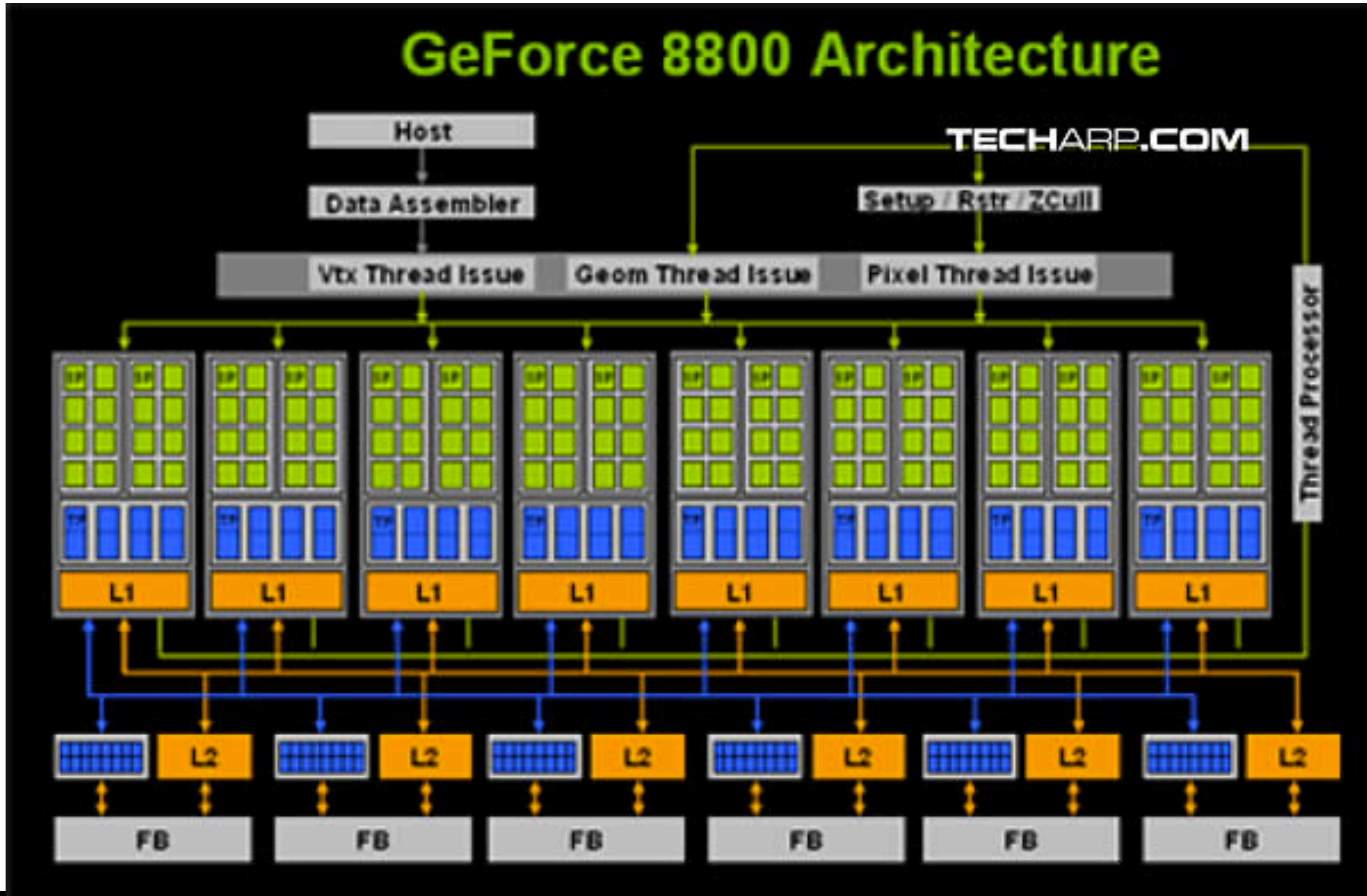
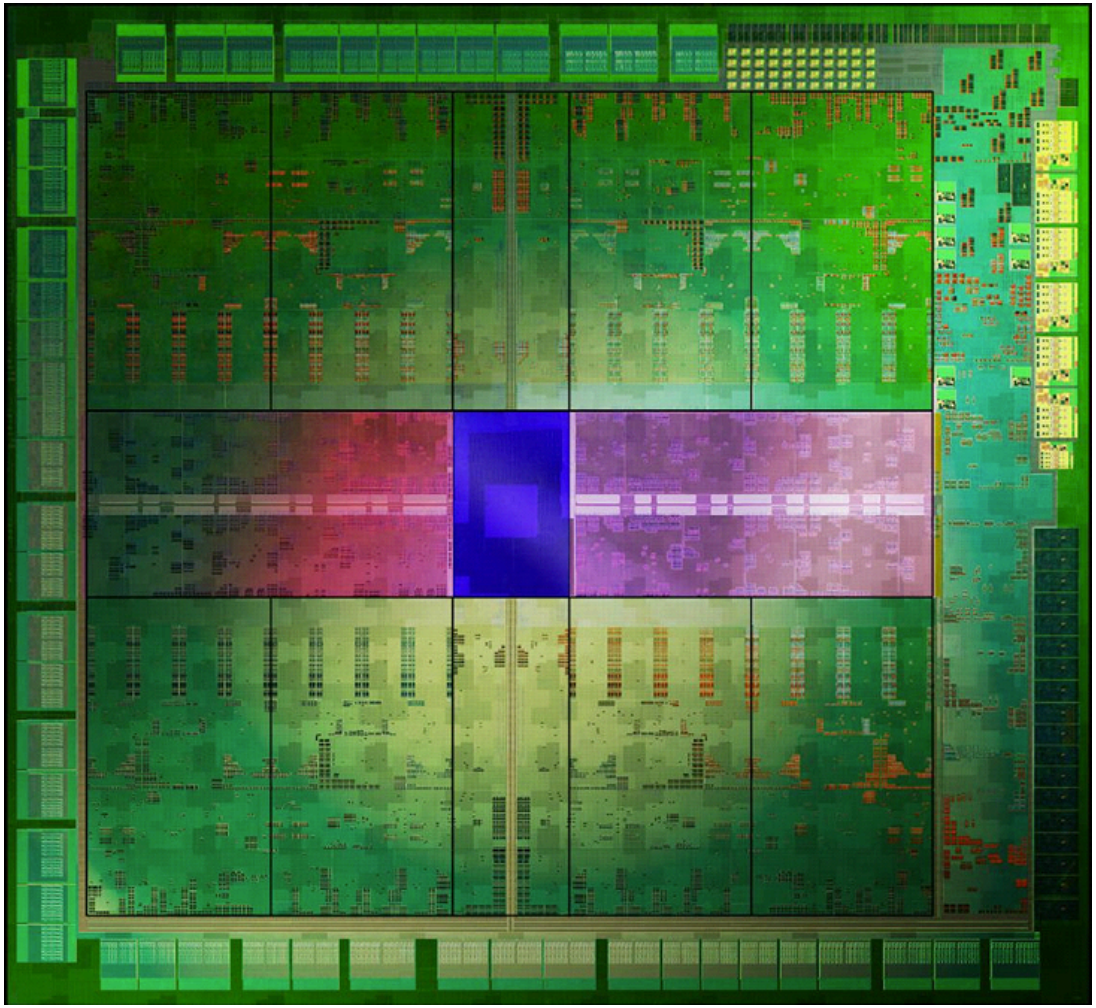


Figure 1-2. The GPU Devotes More Transistors to Data Processing

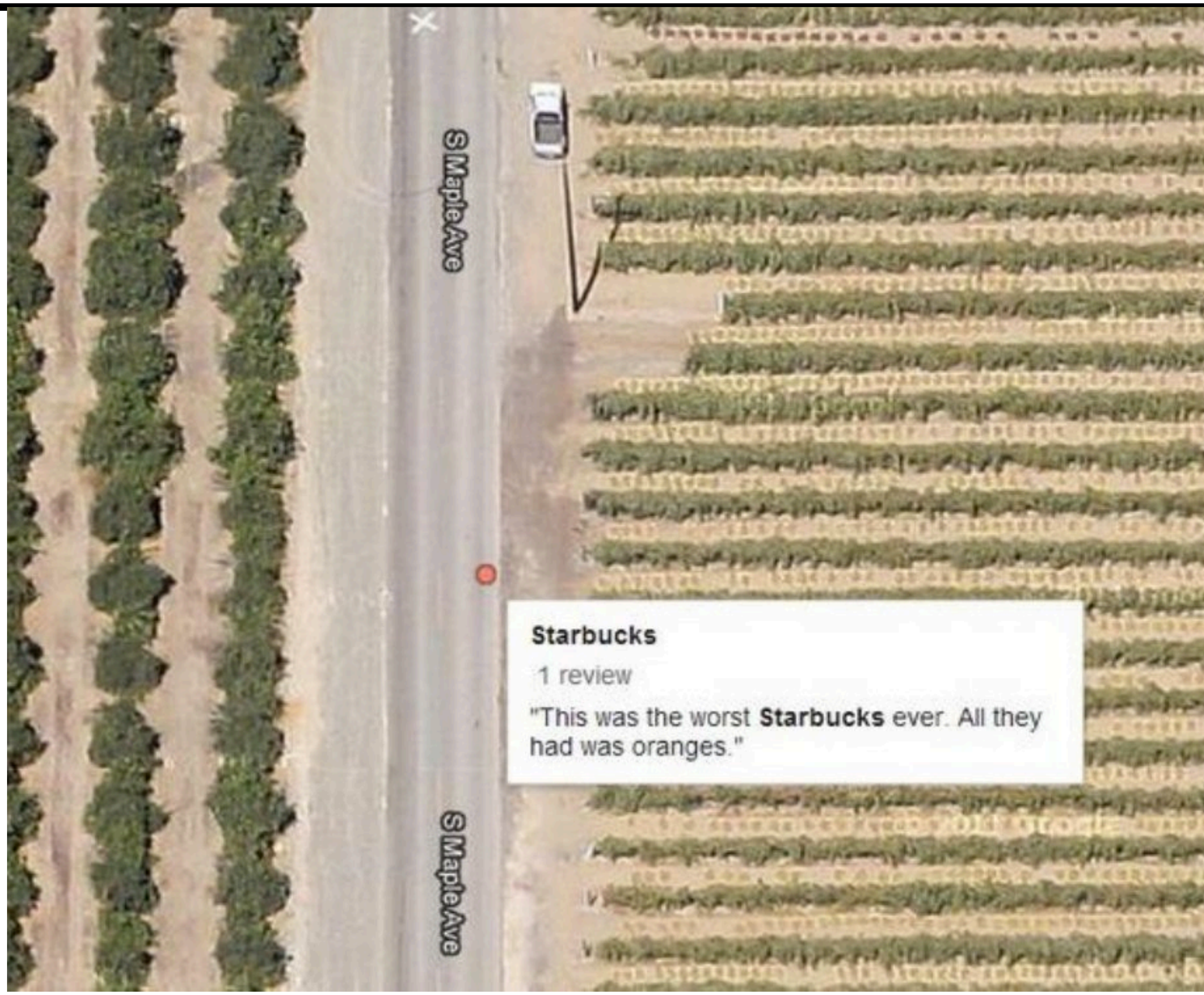
Stream Processing



Single Chip Design



The Scourge


S Maple Ave
Starbucks
1 review
"This was the worst Starbucks ever. All they had was oranges."
S Maple Ave

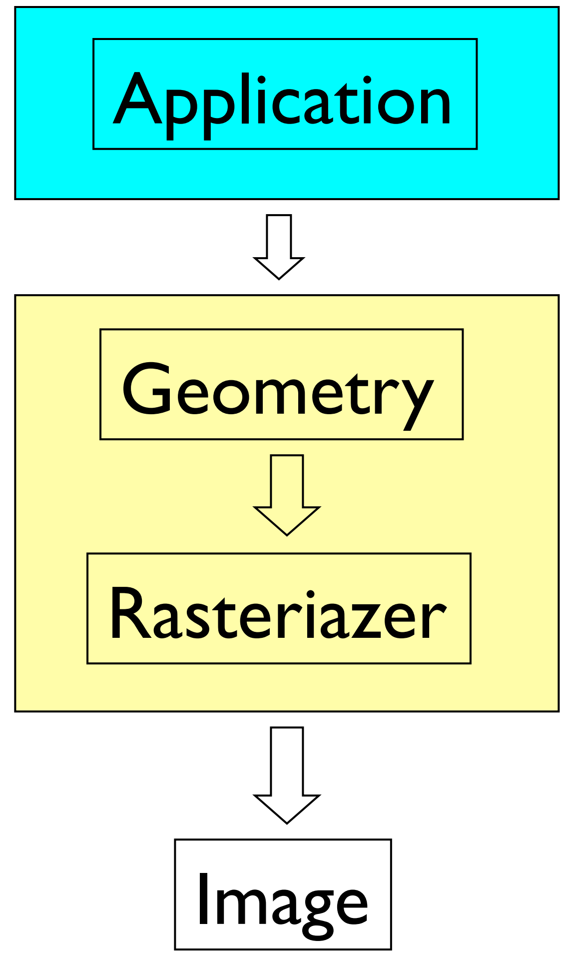
Pros Und Cons !

- Very Efficient For
  - Fast Parallel Floating Point Processing
  - Single Instruction Multiple Data Operations
  - High Computation per Memory Access

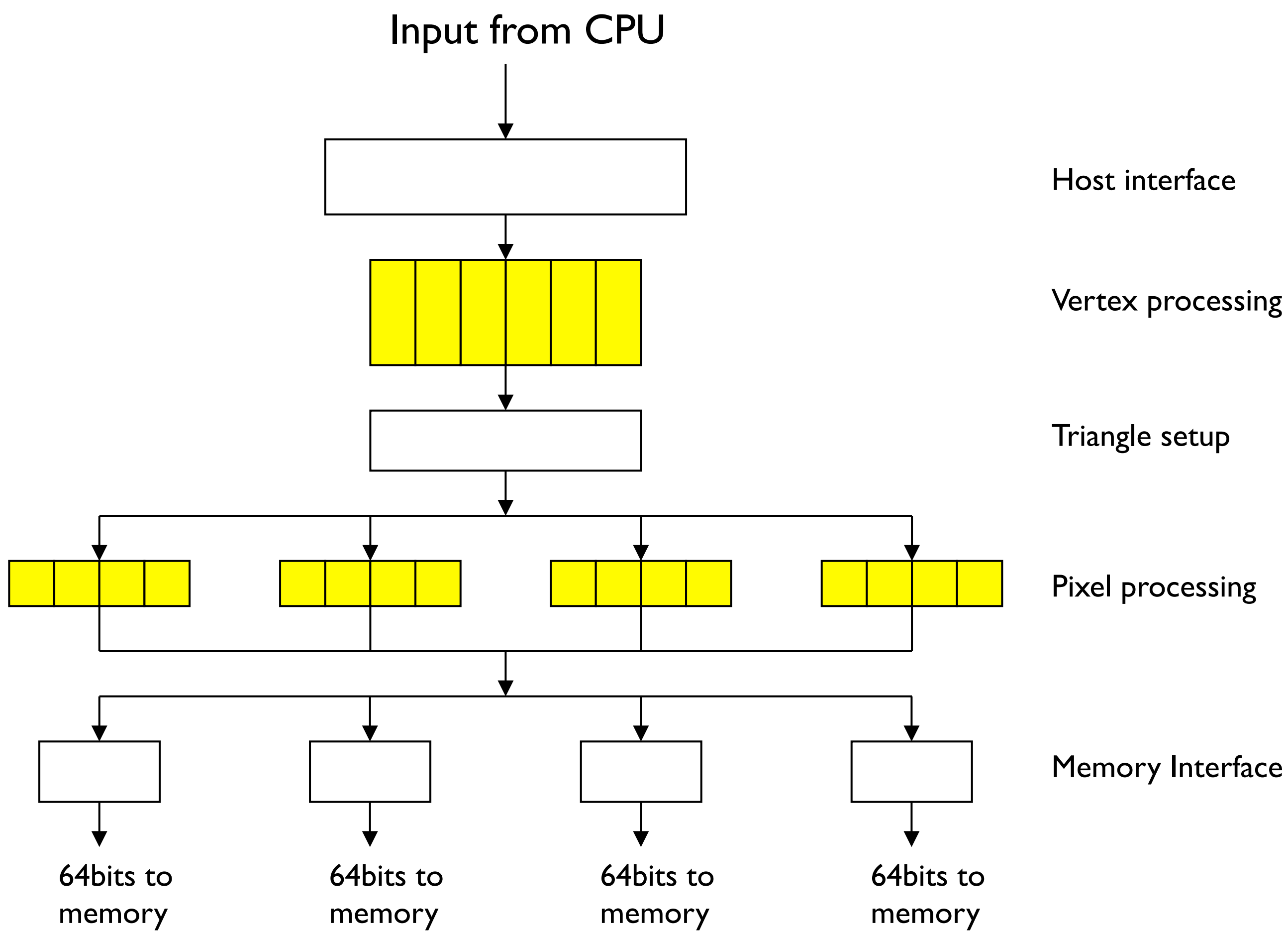
- Not As Efficient For
  - Double Precision
  - Logical Operations on Integer Data
  - Branching-Intensive Operations
  - Random Access, Memory-Intensive Operations

The Rendering Pipeline

- Three conceptual stages
- A stage is pipeline & runs in parallel
- Performance set by slowest stage
- Modern graphics systems:
  - Software
  - hardware

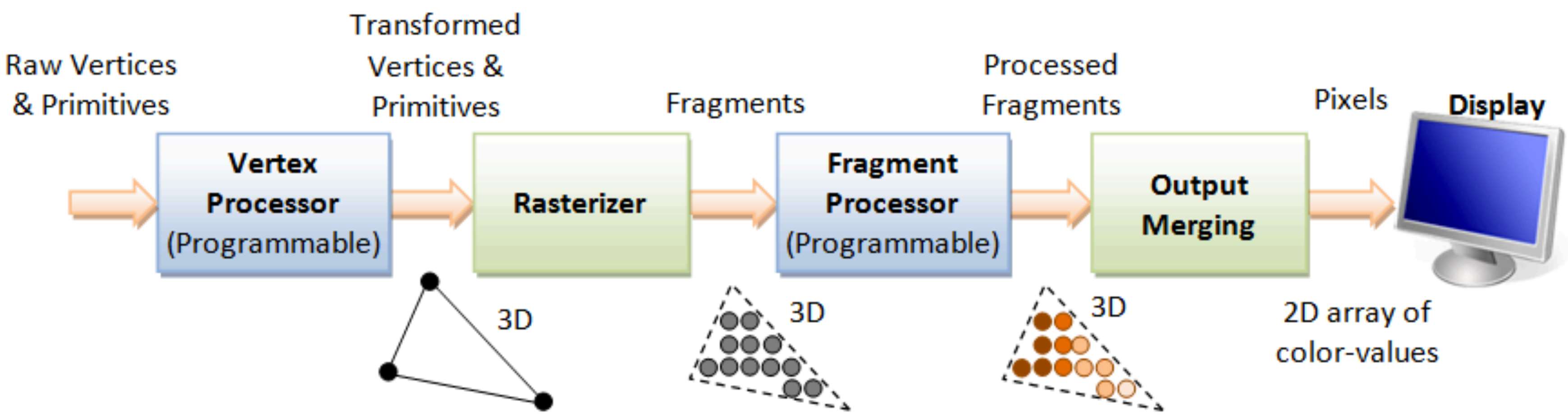


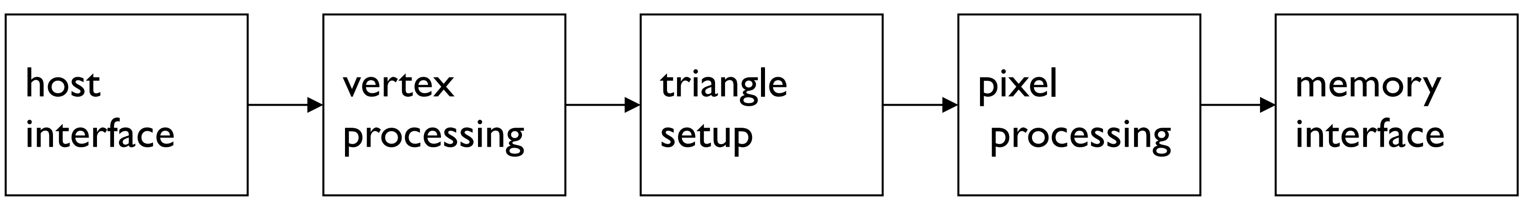
Eine modern GPU



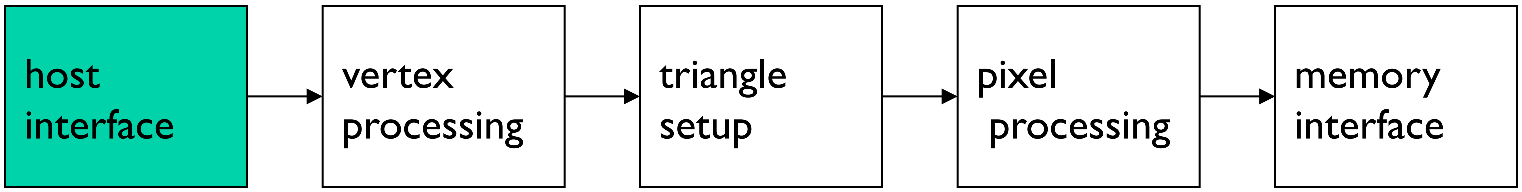
THE OHIO STATE UNIVERSITY
DEPARTMENT OF COMPUTER SCIENCE AND ENGINEERING

Hardware Rendering Pipeline





Host Interface

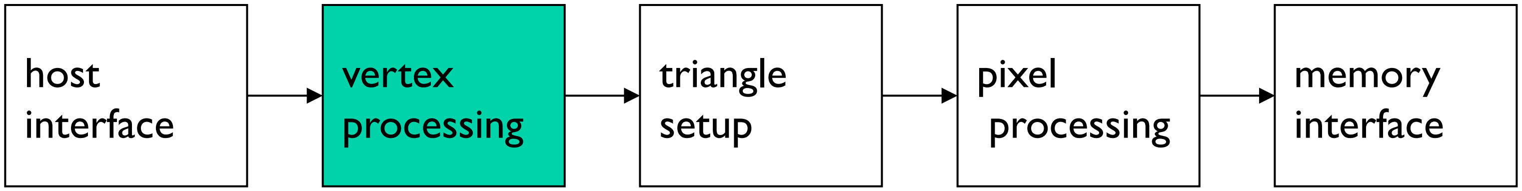


- ✓ Communication bridge between CPU & GPU
- ✓ Input: Commands from CPU; geometry information from memory
- ✓ Output: *Stream* of vertices in object space with associated information - normals, texture coordinates, per vertex color etc.

Transform Spaces

→ Object Space

Vertex Processing



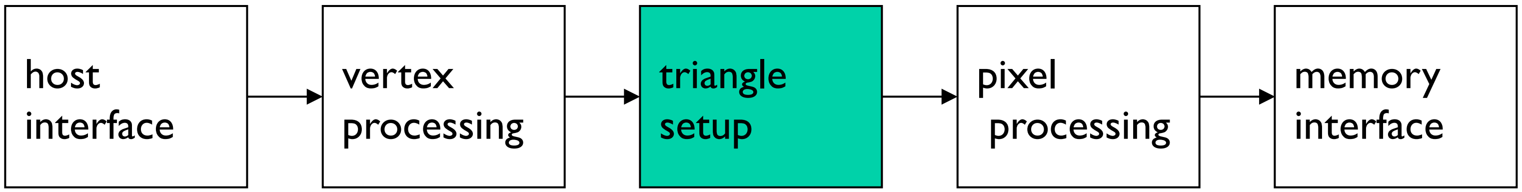
- ✓ Input: Vertices from host interface in object space
- ✓ Output: Vertices in screen space - No new vertices; no vertices are discarded

- ✓ Operations: Simple linear transformation, or a complex operation morphing effects
- ✓ What: Normals, texcoords etc are also transformed

Transform Spaces

Object Space → Screen Space

Triangle Setup

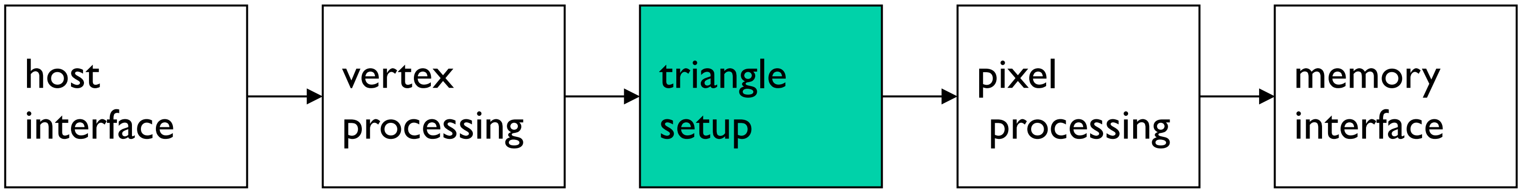


- ✓ Input: Screen space geometry
- ✓ Output: Raster/Pixels or Fragments
- ✓ Operation: Each fragment has attributes computed with perspective-correct interpolation of triangle vertices

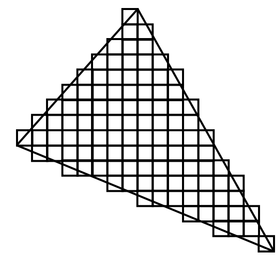
Transform Spaces

Screen Space → Raster/Fragment

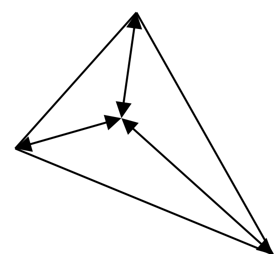
Triangle Setup - Optimizations



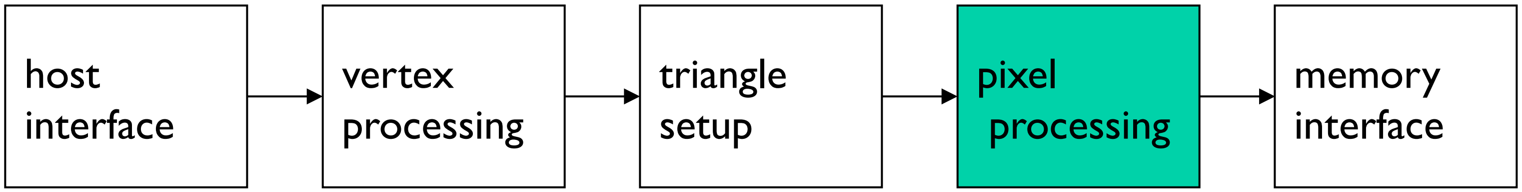
- ✓ O 1: Cull back-facing or outside viewing frustum



- ✓ O 2: Hidden Surface Removal
- ✓ O 3: Fragment is generated if and only if its center is inside the triangle

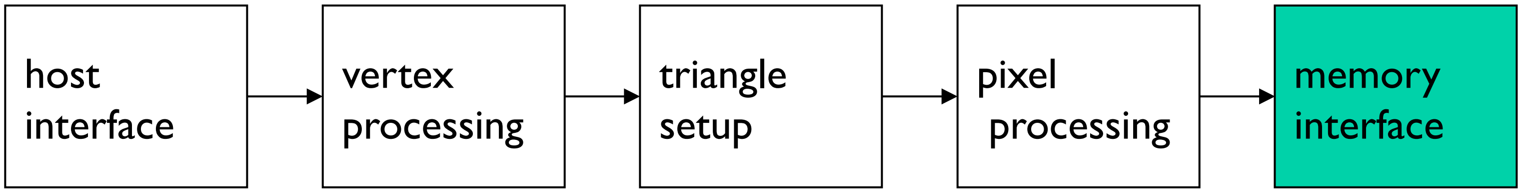


Fragment Processing



- ✓ Input: Fragments & attributes - position, normal, texcoord etc.
- ✓ Output: Final color for pixel
- ✓ Operations: Texture mapping & math operations
- ✓ Caveat: Bottleneck(s)

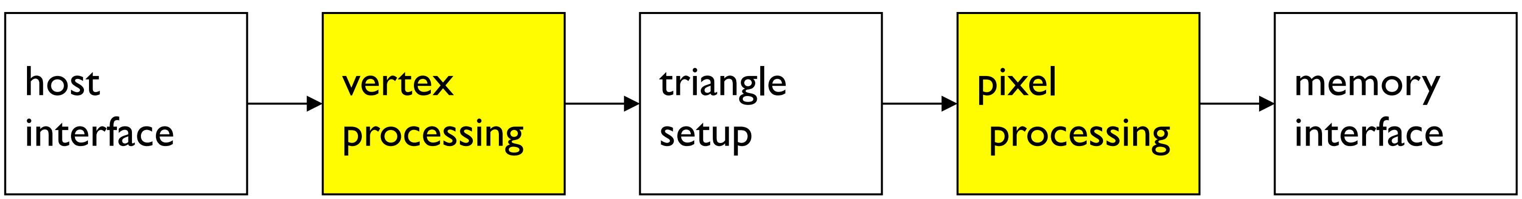
Memory Interface



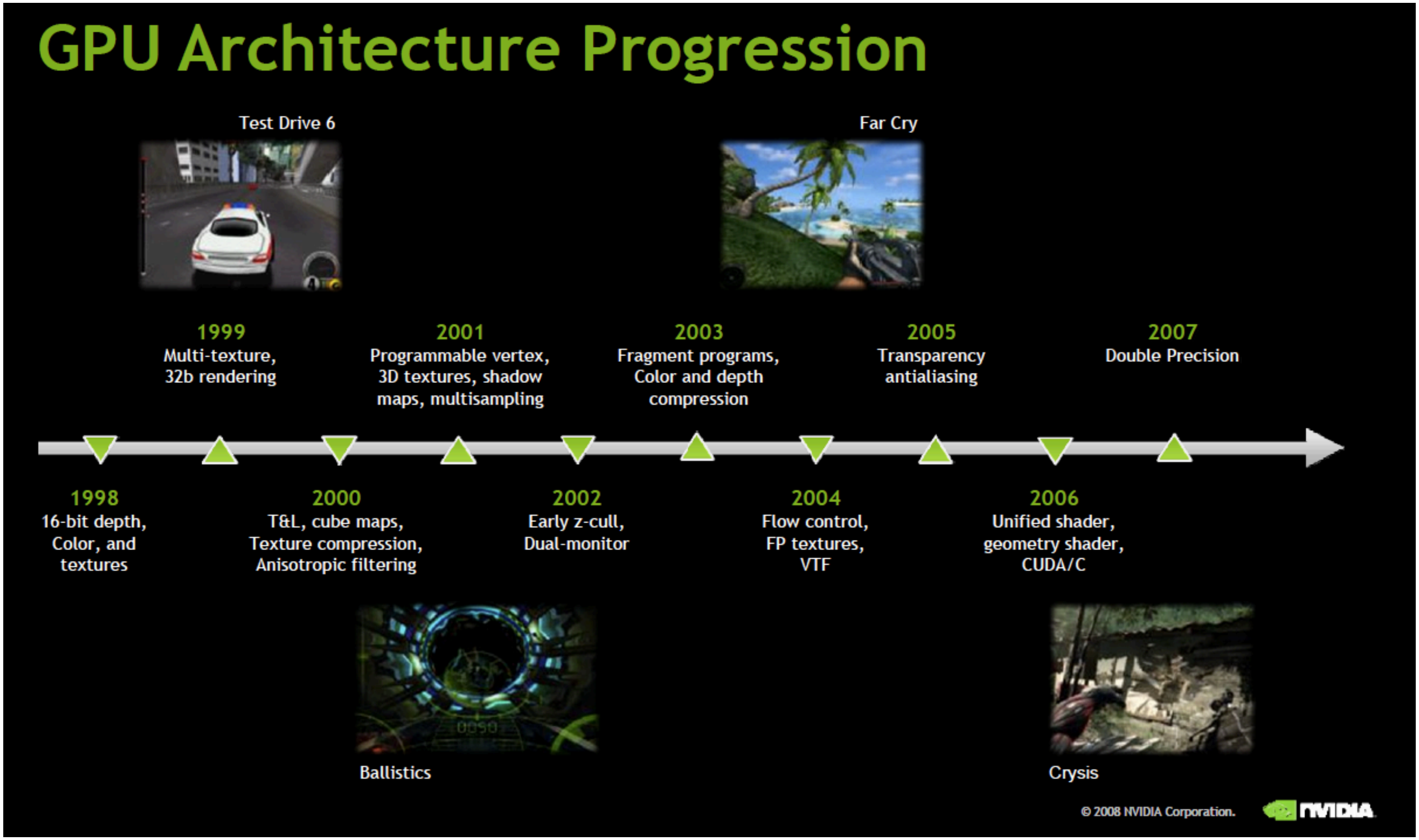
- ✓ Input: Fragment
- ✓ Output: framebuffer operations

Programmability

- ✓ Vertex, fragment processing, triangle set-up programmable
- ✓ Programs executed for every vertex and every fragment
- ✓ Fully customizable geometry and shading effects

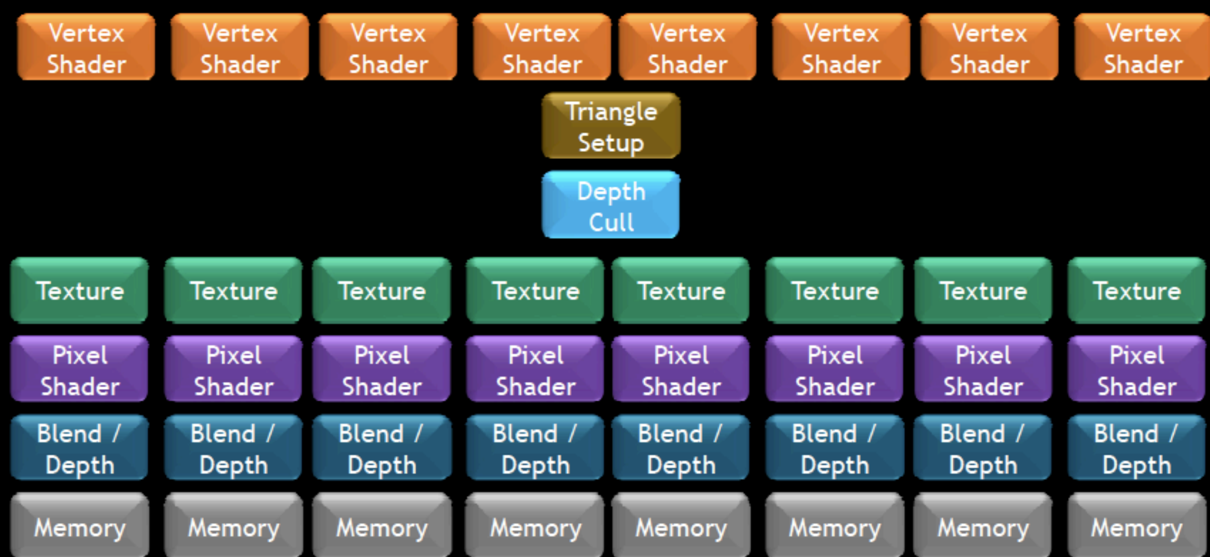


Advanced Musings



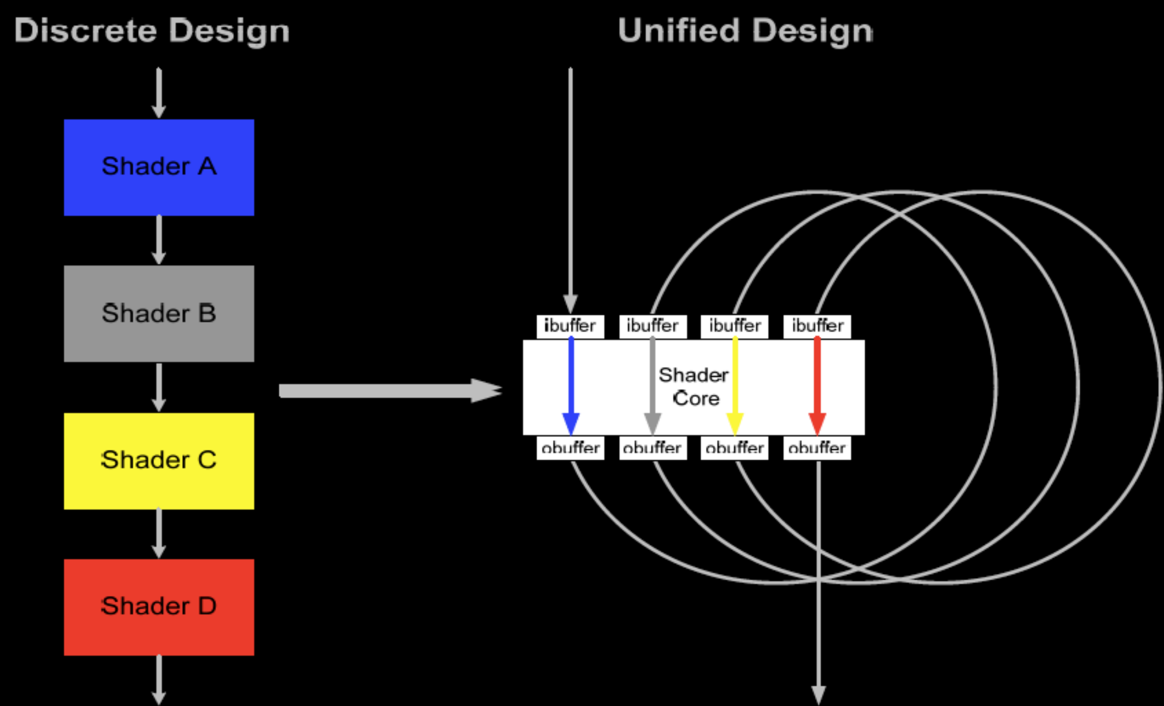
(courtesy: nvidia)

GPU Architecture 2003



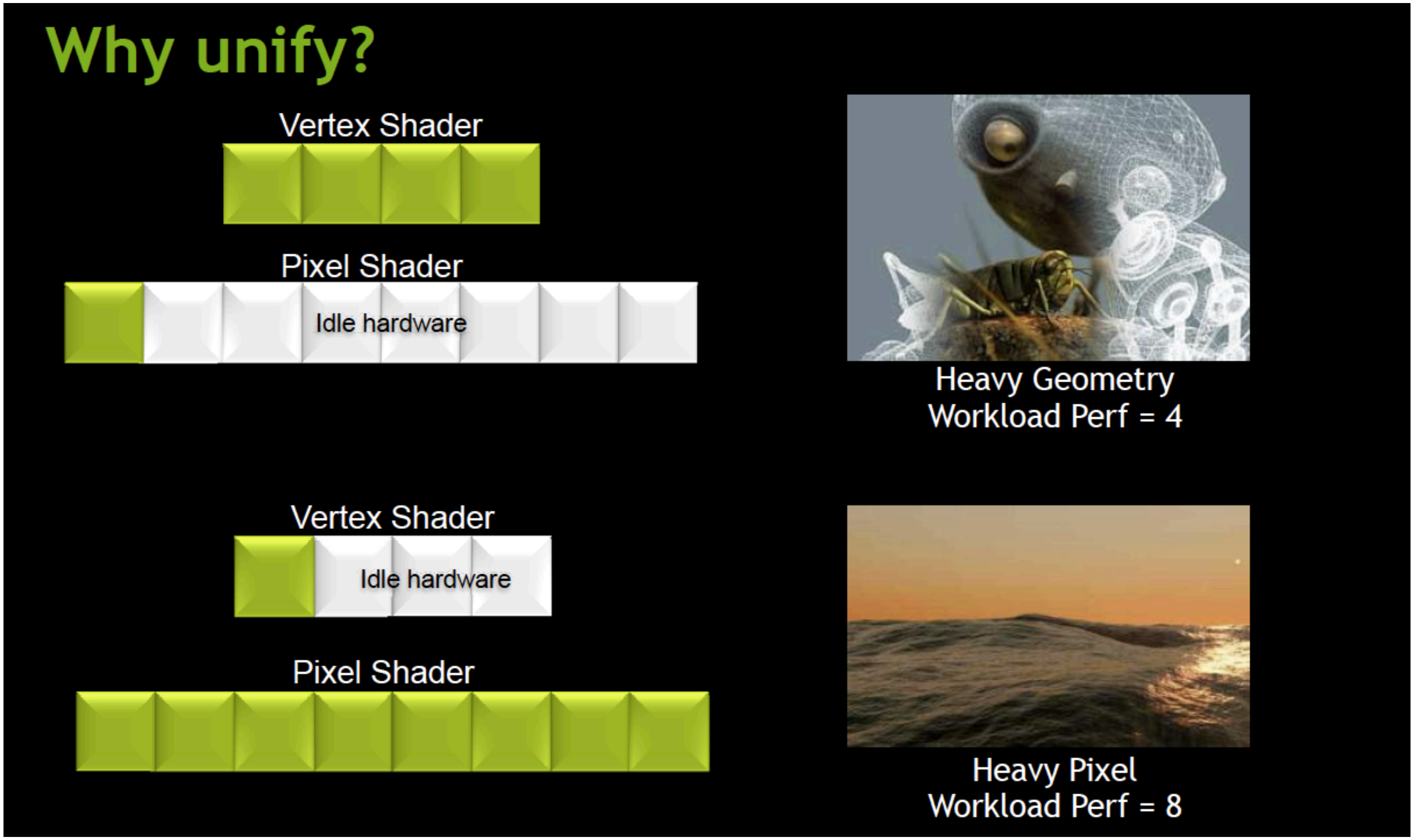
(courtesy: nvidia)

Modern GPU's: Unified Architecture



Vertex shaders, pixel shaders, etc. become *threads* running different programs on flexible cores

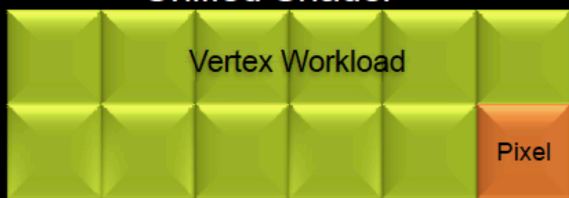
(courtesy: nvidia)

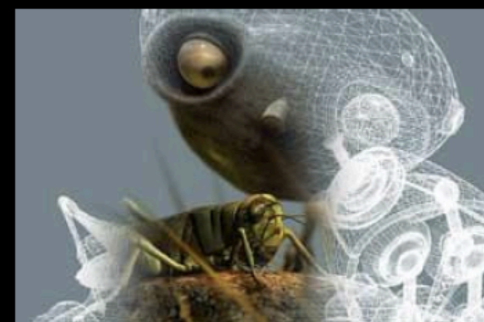


(courtesy: nvidia)

Why unify?

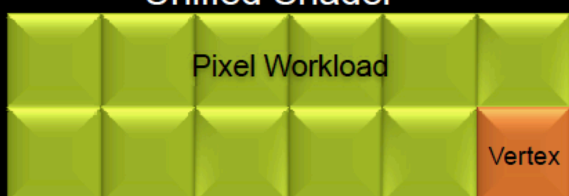
Unified Shader

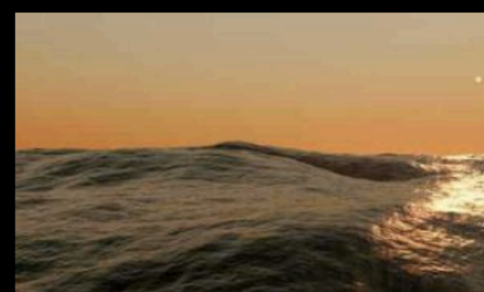




Heavy Geometry
Workload Perf = 11

Unified Shader

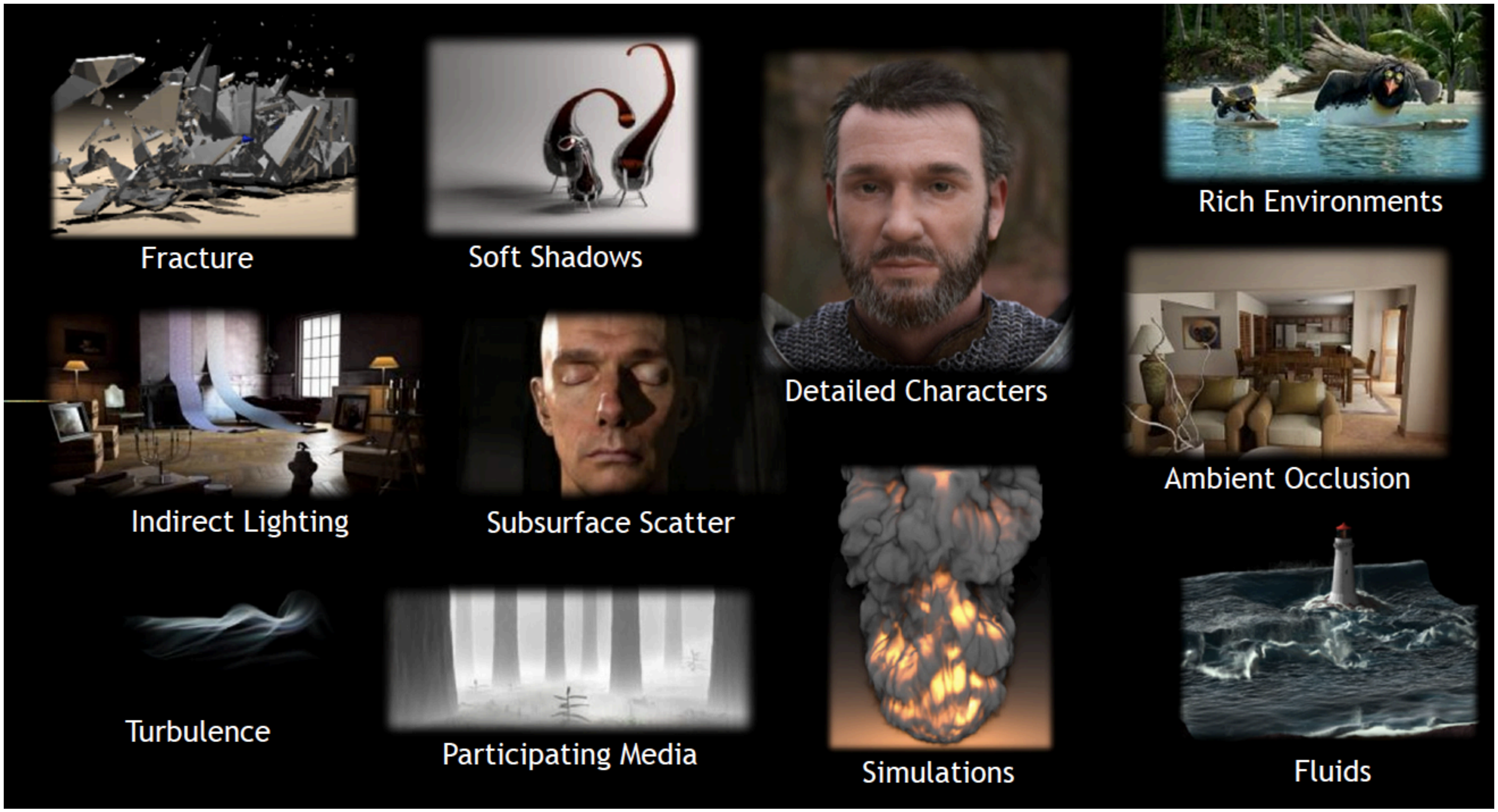




Heavy Pixel
Workload Perf = 11

(courtesy: nvidia)

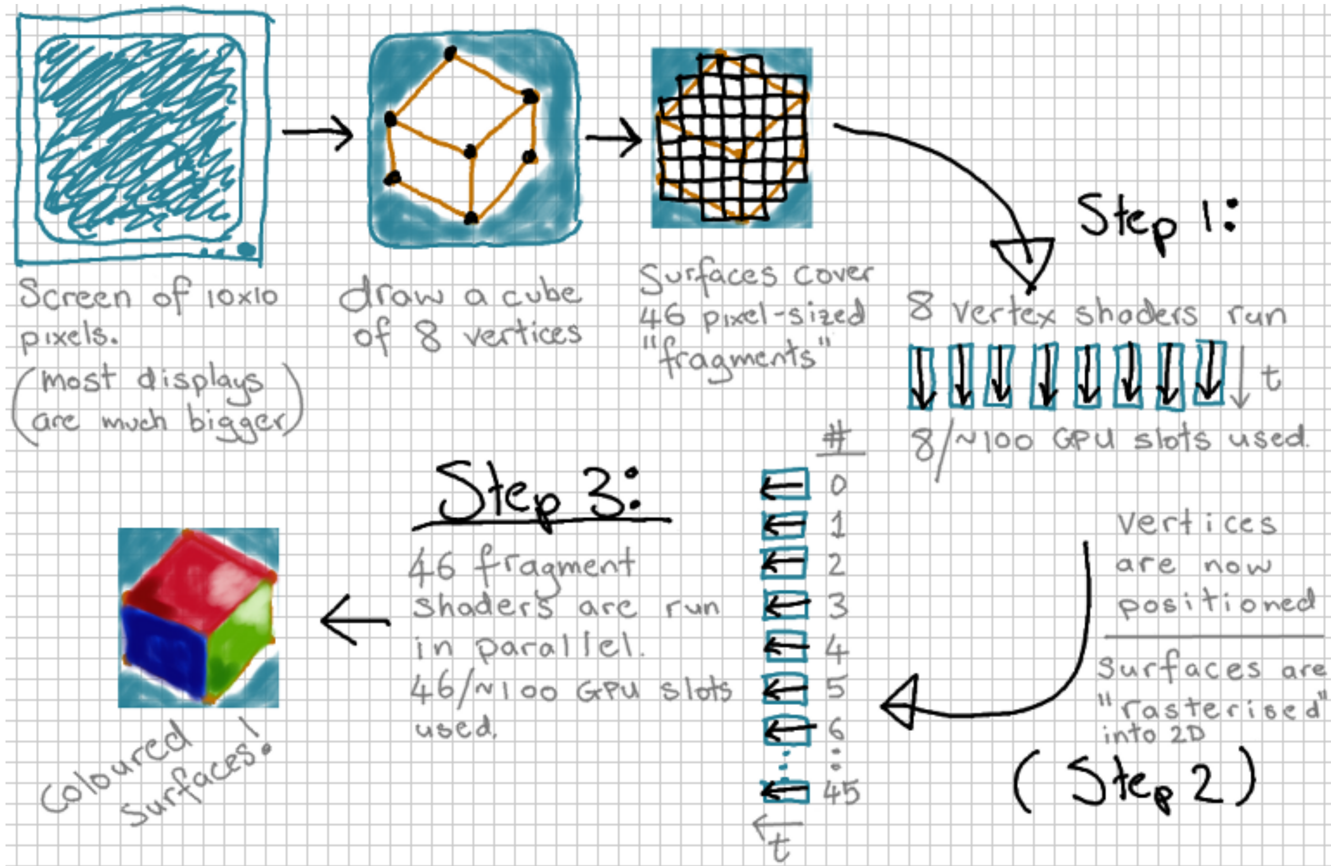
The Holy Grail - Realism



(courtesy: nvidia)


MINION XING

Software



Screen of 10x10 pixels.
(most displays are much bigger)
draw a cube of 8 vertices
Surfaces cover 46 pixel-sized "fragments"
Step 1:
8 vertex shaders run
t
8/~100 GPU slots used.
vertices are now positioned
Surfaces are "rasterised" into 2D
(Step 2)
#
0
1
2
3
4
5
6
45
t
Step 3:
46 fragment shaders are run in parallel.
46/~100 GPU slots used.
Coloured Surfaces!

GL

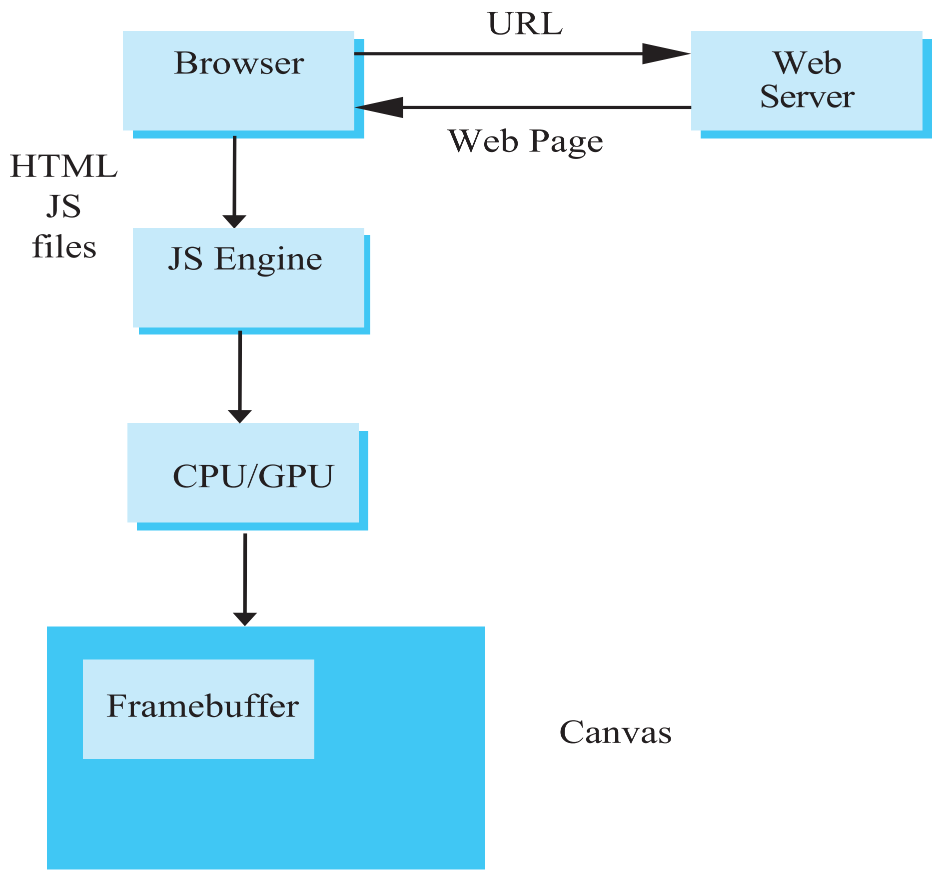
OpenGL

GLSL

WebGL

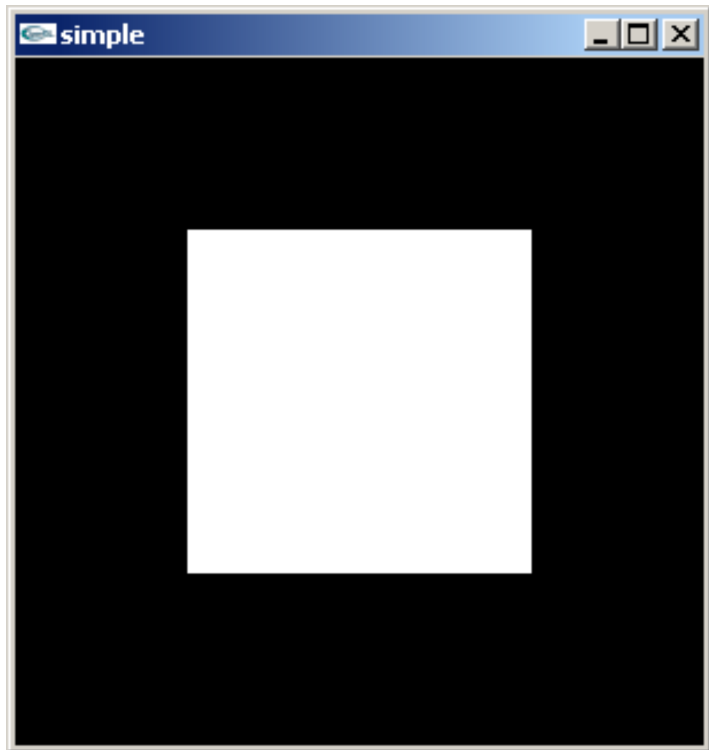
WebGL

Execution in Browser



A OpenGL Simple Program

Generate a square on a solid background



Back In My Day ☺

```
#include <GL/glut.h>
void mydisplay(){
        glClear(GL_COLOR_BUFFER_BIT);
        glBegin(GL_QUAD;
                glVertex2f(-0.5, -0.5);
                glVertex2f(-0,5, 0,5);
                glVertex2f(0.5, 0.5);
                glVertex2f(0.5, -0.5);
        glEnd()
}
int main(int argc, char** argv){
        glutCreateWindow("simple");
        glutDisplayFunc(mydisplay);
        glutMainLoop();
}
```

What happened?

- Most OpenGL functions deprecated
  - immediate vs retained mode
  - make use of GPU
- Makes heavy use of state variable default values that no longer exist
  - Viewing
  - Colors
  - Window parameters
- However, processing loop is the same

THE OHIO STATE UNIVERSITY DEPARTMENT OF COMPUTER SCIENCE AND ENGINEERING

Event Loop

- Remember that the sample program specifies a render function which is a *event listener* or *callback* function
  - Every program should have a render callback
  - For a static application we need only execute the render function once
  - In a dynamic application, the render function can call itself recursively but each redrawing of the display must be triggered by an event

Lack of Object Orientation

- All versions of OpenGL are not object oriented so that there are multiple functions for a given logical function
- Example: sending values to shaders
  - **gl.uniform3f**
  - **gl.uniform2i**
  - **gl.uniform3dv**
- Underlying storage mode is the same

THE OHIO STATE UNIVERSITY
DEPARTMENT OF COMPUTER SCIENCE AND ENGINEERING

WebGL function format

function name

dimension

gl.uniform3f(x,y,z)

belongs to WebGL canvas

x,y,z are variables

gl.uniform3fv(p)

p is an array

WebGL constants

- Most constants are defined in the canvas object
  - In desktop OpenGL, they were in #include files such as **gl.h**
- Examples
  - **desktop OpenGL**
    - **glEnable(GL_DEPTH_TEST);**
  - **WebGL**
    - **gl.enable(gl.DEPTH_TEST)**
  - **gl.clear(gl.COLOR_BUFFER_BIT)**

WebGL and GLSL

- WebGL requires shaders and is based less on a state machine model than a data flow model
- Most state variables, attributes and related pre 3.1 OpenGL functions have been deprecated
- Action happens in shaders
- Job of application is to get data to GPU

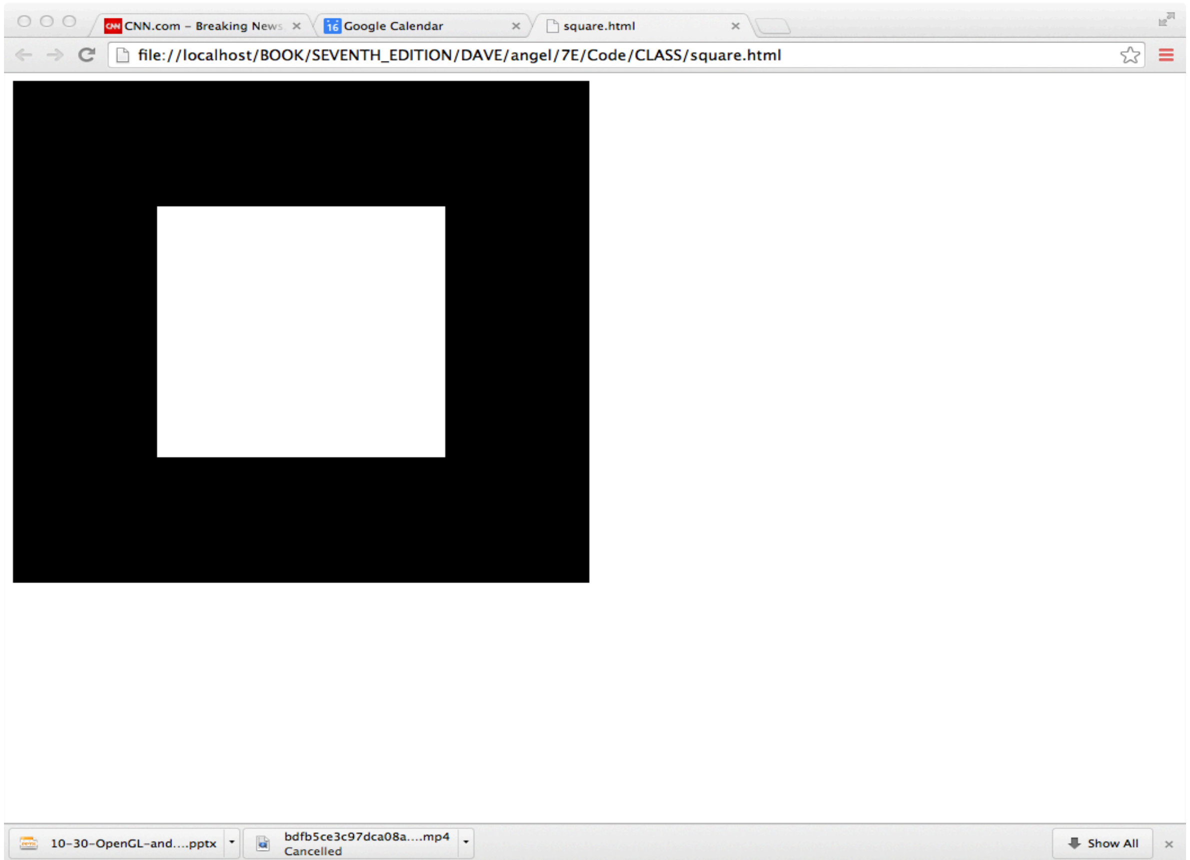
THE OHIO STATE UNIVERSITY
DEPARTMENT OF COMPUTER SCIENCE AND ENGINEERING

GLSL

- OpenGL Shading Language
- C-like with
  - Matrix and vector types (2, 3, 4 dimensional)
  - Overloaded operators
  - C++ like constructors
- Similar to Nvidia's Cg and Microsoft HLSL
- Code sent to shaders as source code
- WebGL functions compile, link and get information to shaders

THE OHIO STATE UNIVERSITY
DEPARTMENT OF COMPUTER SCIENCE AND ENGINEERING

Square Program



WebGL

- Five steps
  - Describe page (HTML file)
    - request WebGL Canvas
    - read in necessary files
  - Define shaders (HTML file)
    - could be done with a separate file (browser dependent)
  - Compute or specify data (JS file)
  - Send data to GPU (JS file)
  - Render data (JS file)

square.html

```
<!DOCTYPE html>
<html>
<head>
<script id="vertex-shader" type="x-shader/x-vertex">

attribute vec4 vPosition;
void main()
{
    gl_Position = vPosition;
}
</script>

<script id="fragment-shader" type="x-shader/x-fragment">

precision mediump float;

void main()
{
    gl_FragColor = vec4( 1.0, 1.0, 1.0, 1.0 );
}
</script>
```

Shaders

- We assign names to the shaders that we can use in the JS file
- These are trivial pass-through (do nothing) shaders that which set the two required built-in variables
  - gl_Position
  - gl_FragColor
- Note both shaders are full programs
- Note vector type vec2
- Must set precision in fragment shader

square.html (cont)

```html
<script type="text/javascript" src="../Common/webgl-utils.js"></script>
<script type="text/javascript" src="../Common/initShaders.js"></script>
<script type="text/javascript" src="../Common/MV.js"></script>
<script type="text/javascript" src="square.js"></script>
</head>

<body>
<canvas id="gl-canvas" width="512" height="512">
Oops ... your browser doesn't support the HTML5 canvas element
</canvas>
</body>
</html>
```

Files

- ../Common/webgl-utils.js: Standard utilities for setting up WebGL context in Common directory on website
- ../Common/initShaders.js: contains JS and WebGL code for reading, compiling and linking the shaders
- ../Common/MV.js: our matrix-vector package
- square.js: the application file

square.js

```
var gl;
var points;

window.onload = function init(){
        var canvas = document.getElementById( "gl-canvas" );

    gl = WebGLUtils.setupWebGL( canvas );
    if ( !gl ) { alert( "WebGL isn't available" );
 }
    // Four Vertices

    var vertices = [
        vec2( -0.5, -0.5 ),
        vec2(  -0.5,  0.5 ),
        vec2(  0.5, 0.5 ),
        vec2( 0.5, -0.5)
    ];
```

Notes

- **onload**: determines where to start execution when all code is loaded
- canvas gets WebGL context from HTML file
- vertices use vec2 type in MV.js
- JS array is not the same as a C or Java array
  - object with methods
  - vertices.length // 4
- Values in clip coordinates

square.js (cont)

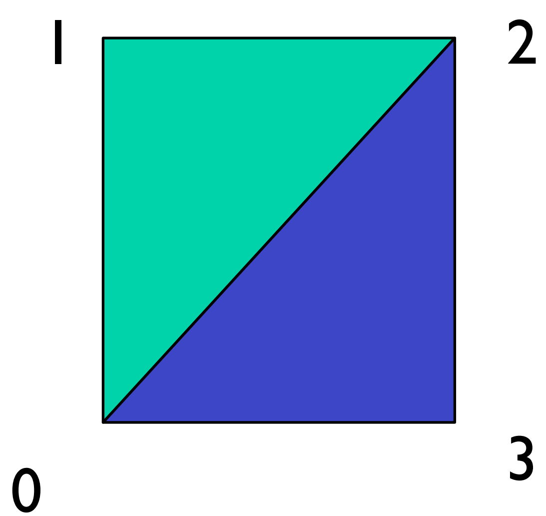
```
//  Configure WebGL

gl.viewport( 0, 0, canvas.width, canvas.height );
gl.clearColor( 0.0, 0.0, 0.0, 1.0 );

 //  Load shaders and initialize attribute buffers

var program = initShaders( gl, "vertex-shader", "fragment-shader" );
gl.useProgram( program );

 // Load the data into the GPU

var bufferId = gl.createBuffer();
gl.bindBuffer( gl.ARRAY_BUFFER, bufferId );
gl.bufferData( gl.ARRAY_BUFFER, flatten(vertices), gl.STATIC_DRAW );

 // Associate out shader variables with our data buffer

var vPosition = gl.getAttribLocation( program, "vPosition" );
gl.vertexAttribPointer( vPosition, 2, gl.FLOAT, false, 0, 0 );
gl.enableVertexAttribArray( vPosition );
```

Notes

- **initShaders** used to load, compile and link shaders to form a program object
- Load data onto GPU by creating a **vertex buffer object** on the GPU
  - Note use of flatten() to convert JS array to an array of float32's
- Finally we must connect variable in program with variable in shader
  - need name, type, location in buffer

square.js (cont)

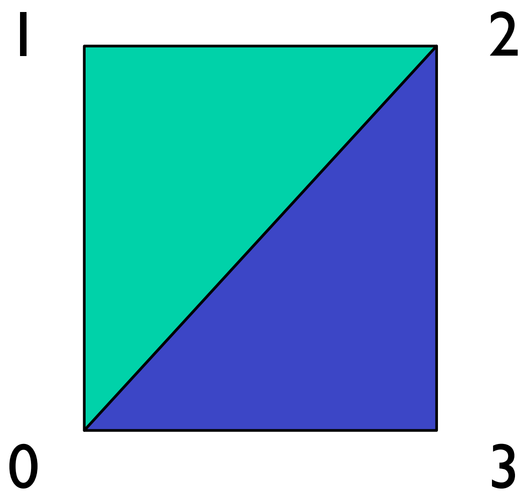
```
    render();
};

function render() {
    gl.clear( gl.COLOR_BUFFER_BIT );
    gl.drawArrays( gl.TRIANGLE_FAN, 0, 4 );
}
```

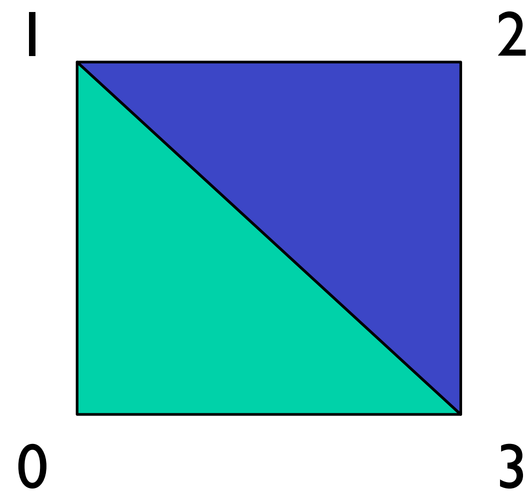


Triangles, Fans or Strips

gl.drawArrays(gl.TRIANGLES, 0, 6); // 0, 1, 2, 0, 2, 3

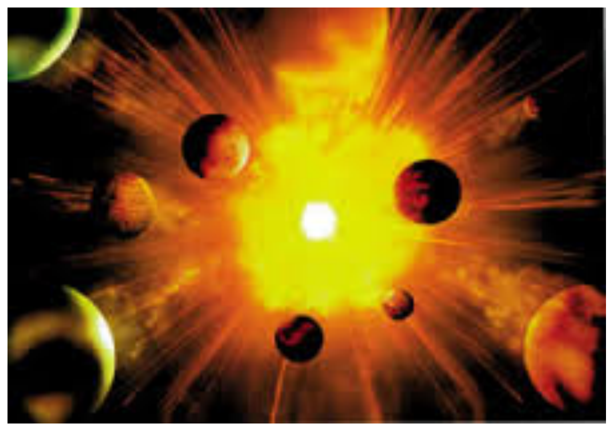
gl.drawArrays(gl.TRIANGLE_FAN, 0, 4); // 0, 1 , 2, 3



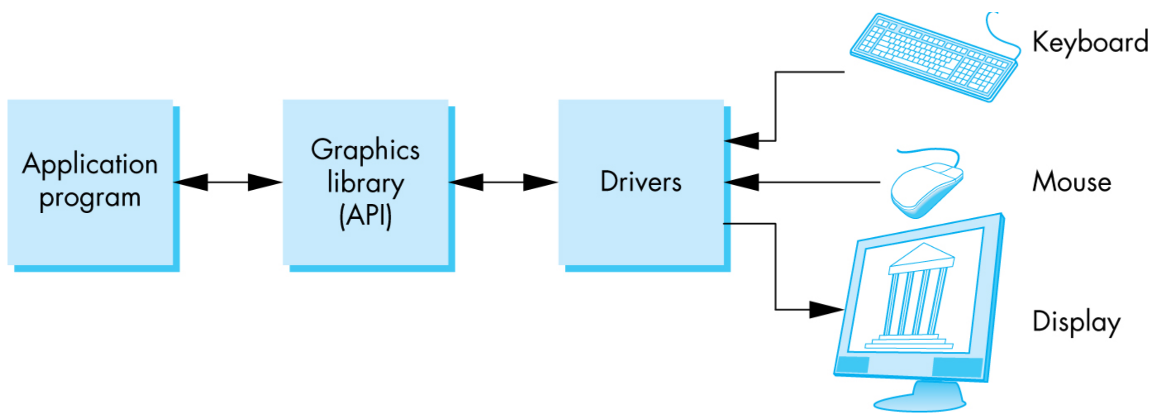


gl.drawArrays(gl.TRIANGLE_STRIP, 0, 4); // 0, 1, 3, 2

BigBang of *GL*



OpenGL Architecture



Graphical APIs

- 1973 - two committees to propose a standard graphics API
  - Graphical Kernel System (GKS)
    - 2D but contained good workstation model
  - Core
    - Both 2D and 3D
  - GKS adopted as IS0 and later ANSI standard (1980s)
- GKS not easily extended to 3D (GKS-3D)
  - Far behind hardware development

THE OHIO STATE UNIVERSITY DEPARTMENT OF COMPUTER SCIENCE AND ENGINEERING

PHIGS and X

- Programmers Hierarchical Graphics System (PHIGS)
  - Arose from CAD community
  - Database model with retained graphics (structures)
- X Window System
  - DEC/MIT effort
  - Client-server architecture with graphics
- PEX combined the two
  - Not easy to use (all the defects of each)

THE OHIO STATE UNIVERSITY
DEPARTMENT OF COMPUTER SCIENCE AND ENGINEERING

SGI and GL

- Silicon Graphics (SGI) revolutionized the graphics workstation by implementing the pipeline in hardware (1982)
- To access the system, application programmers used a library called GL
- With GL, it was relatively simple to program three dimensional interactive applications

THE OHIO STATE UNIVERSITY DEPARTMENT OF COMPUTER SCIENCE AND ENGINEERING

OpenGL

The success of GL lead to OpenGL (1992), a platform-independent API that was

- Easy to use
- Close enough to the hardware to get excellent performance
- Focus on rendering
- Omitted windowing and input to avoid window system dependencies

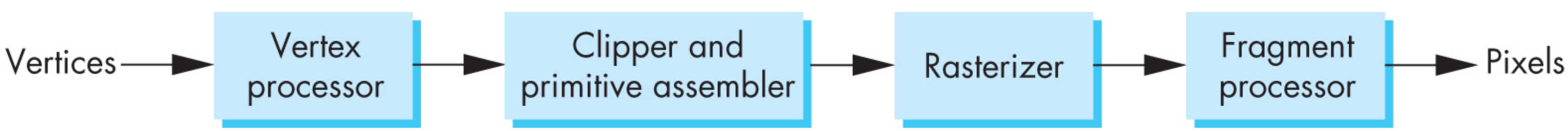
OpenGL Evolution

Originally controlled by an Architectural Review Board (ARB)

- Members included SGI, Microsoft, Nvidia, HP, 3DLabs, IBM,…….
- Now Khronos Group
- Was relatively stable (through version 2.5)
  - Backward compatible
  - Evolution reflected new hardware capabilities
    - 3D texture mapping and texture objects
    - Vertex and fragment programs
- Allows platform specific features through extensions

Modern OpenGL

- Performance is achieved by using GPU rather than CPU
- Control GPU through programs called shaders
- Application's job is to send data to GPU
- GPU does all rendering



Immediate Mode Graphics

- Geometry specified by vertices
  - Locations in space(2 or 3 dimensional)
  - Points, lines, circles, polygons, curves, surfaces
- Immediate mode
  - Each time a vertex is specified in application, its location is sent to the GPU
  - Old style uses **glVertex**
  - Creates bottleneck between CPU and GPU
  - Removed from OpenGL 3.1 and OpenGL ES 2.0

Retained Mode Graphics

- Put all vertex attribute data in array
- Send array to GPU to be rendered immediately
- Almost OK but problem is we would have to send array over each time we need another render of it
- Better to send array over and store on GPU for multiple renderings

THE OHIO STATE UNIVERSITY
DEPARTMENT OF COMPUTER SCIENCE AND ENGINEERING

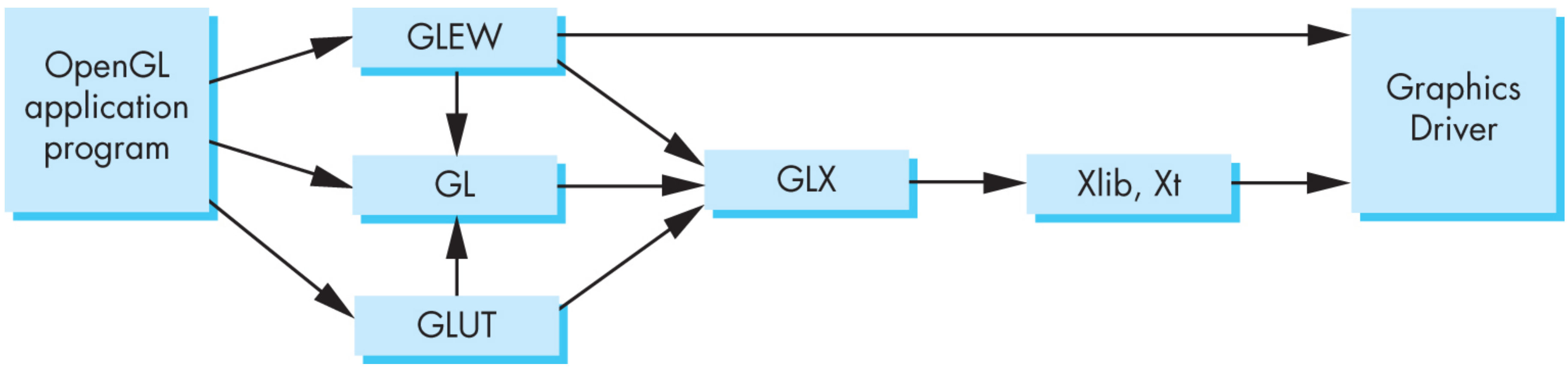
OpenGL 3.1

- Totally shader-based
  - No default shaders
  - Each application must provide both a vertex and a fragment shader
- No immediate mode
- Few state variables
- Most 2.5 functions deprecated
- Backward compatibility not required
  - Exists a compatibility extension

Other Versions

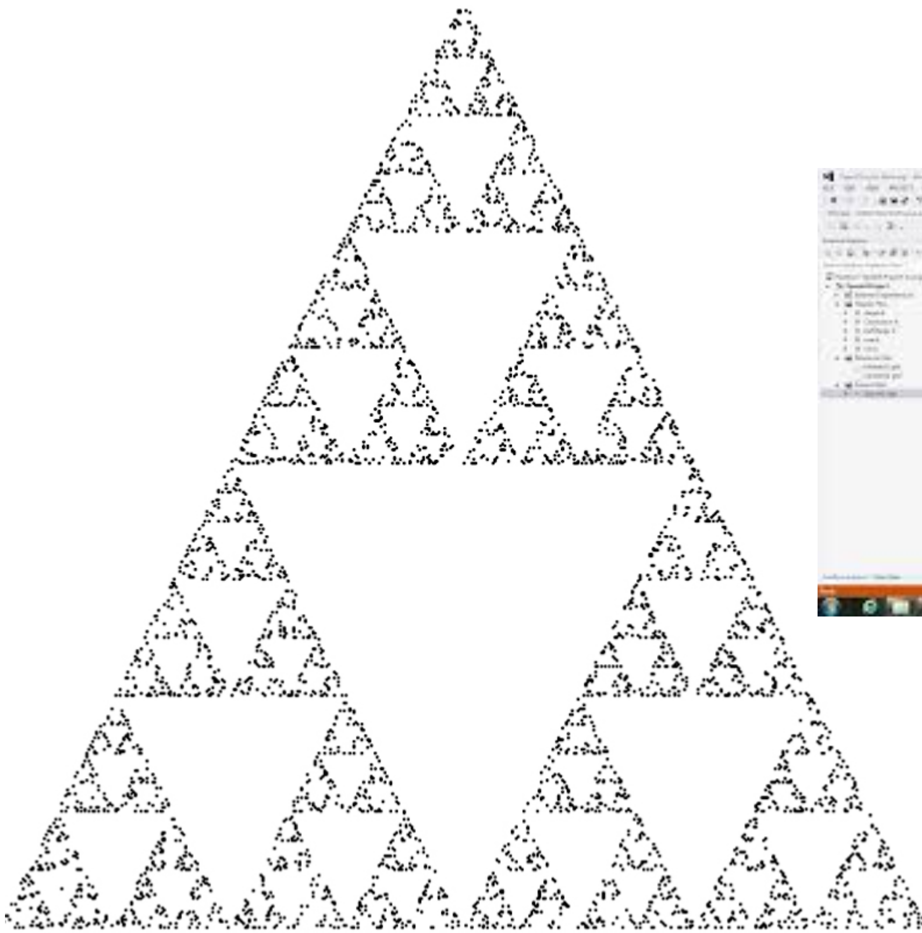
- OpenGL ES
  - Embedded systems
  - Version 1.0 simplified OpenGL 2.1
  - Version 2.0 simplified OpenGL 3.1
    - Shader based
- WebGL
  - Javascript implementation of ES 2.0
  - Supported on newer browsers
- OpenGL 4.1, 4.2, …..
  - Add geometry, tessellation, compute shaders

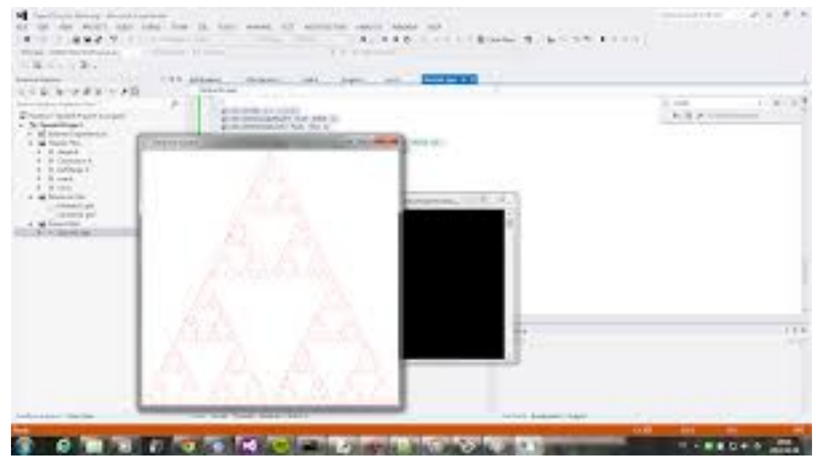
Software Organization



The End

Next – Sierpinski in GLSL





DEPARTMENT OF COMPUTER SCIENCE AND ENGINEERING