A Trip Down The (2011) Rasterization Pipeline

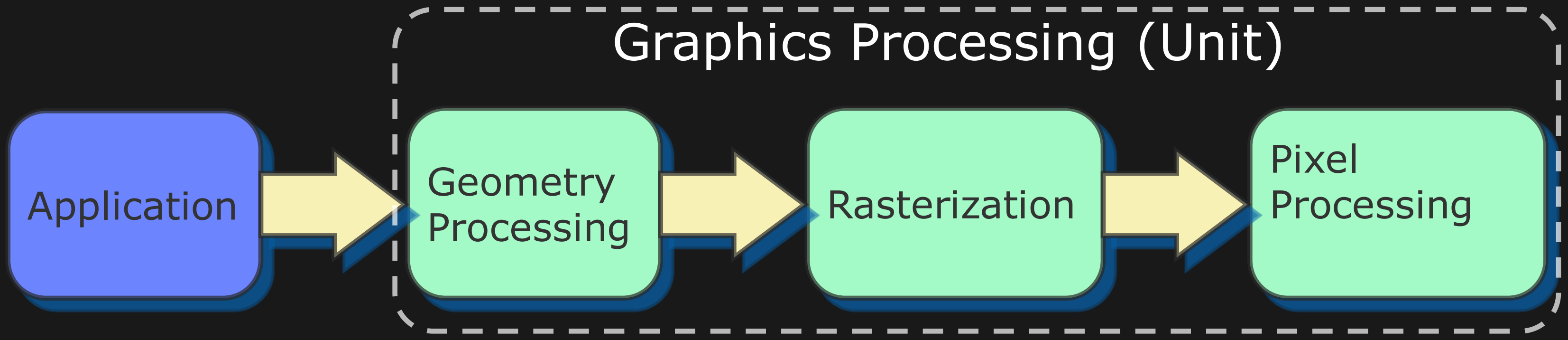
Aaron Lefohn - Intel / University of Washington
Mike Houston – AMD / Stanford

This talk

- Overview of the real-time rendering pipeline available in ~2011 corresponding to graphics APIs:
  - DirectX 11
  - OpenGL 4.x

- Discuss
  - What changes from DX9 to DX11
  - Key uses of these new features

General Rasterization Pipeline

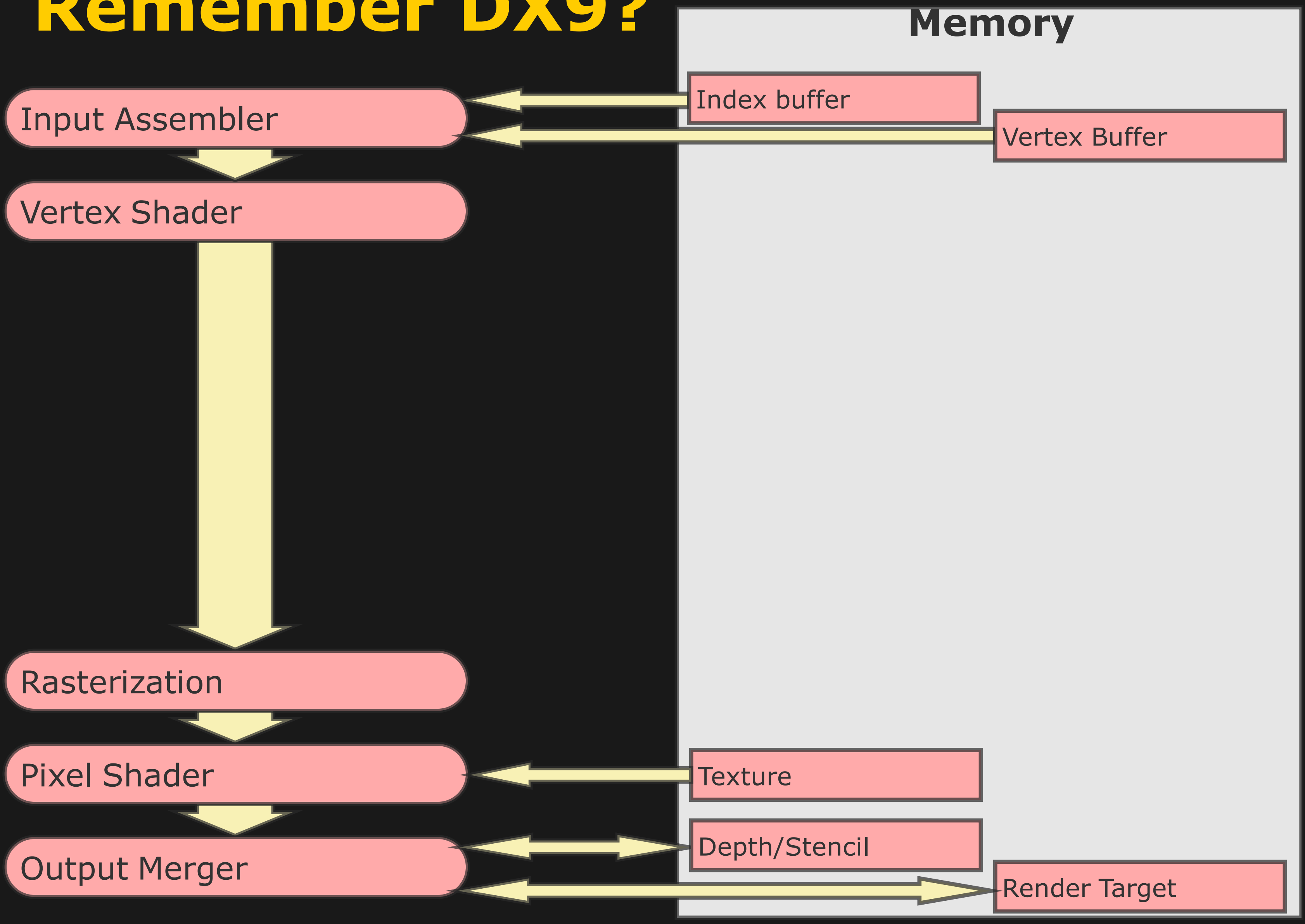


- Geometry processing:
  - Transforms geometry, generates more geometry, computes per-vertex attributes
- Rasterization:
  - Sets up a primitive (e.g., triangle), and finds all samples inside the primitive
- Pixel processing
  - Interpolates vertex attributes, and computes pixel color

Slide by Tomas Akenine-Möller

DX10

Remember DX9?



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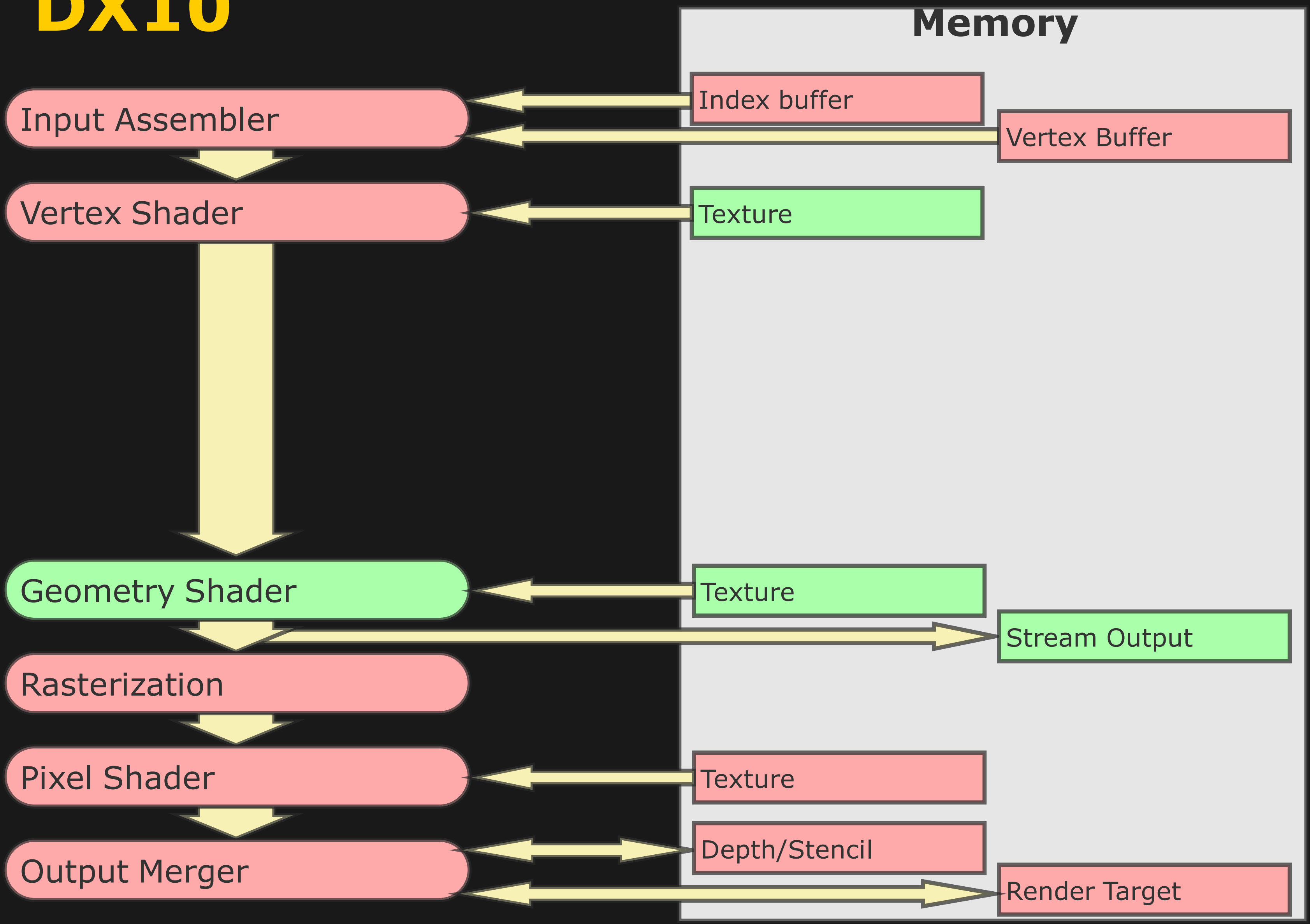
DX10



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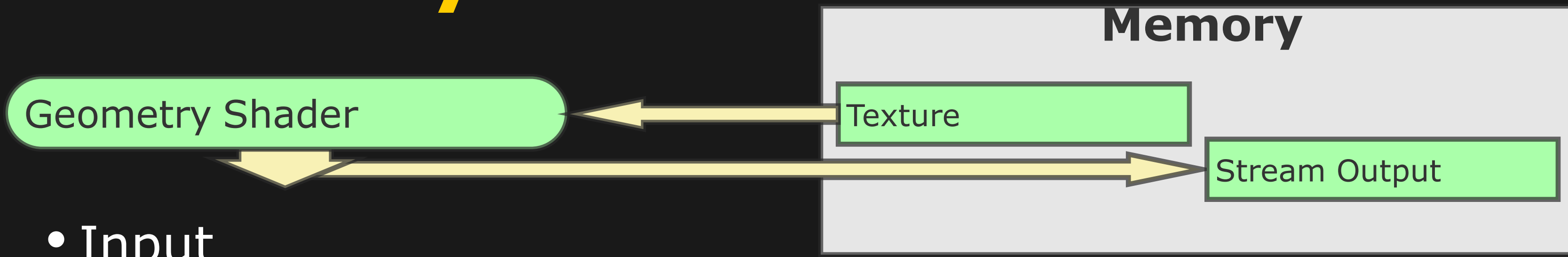
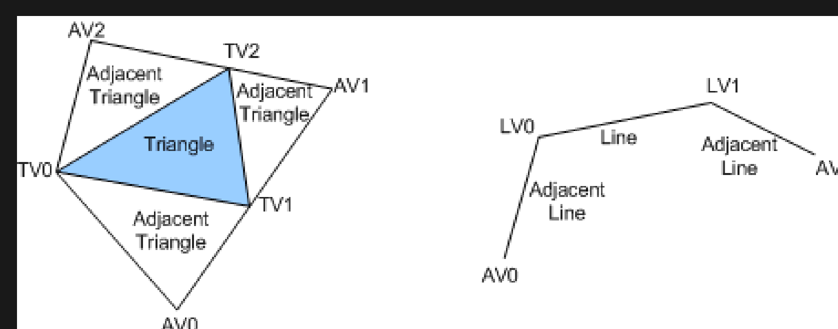
DX10 Increased Shading Capability

- In addition to adding a new pipeline stage, DX10 greatly increased programmability of vertex and fragment stages
  - All shader stages have same limitations (unified shading cores)
  - Pixel/fragment shaders “grow up”
    - Instruction limits, register limits, flow control, etc.
    - Well-specified floating point precision requirements
    - Write up to 8, fp32x4 outputs per fragment

Geometry Shader



- Input
  - Vertices of a *full* primitive (1 for point, 2 for line, 3 for triangle)
  - Vertices of edge-*adjacent* primitives
  - Primitive ID - allows to fetch or compute per-face data
- Output
  - Point-, line- or triangle strip
  - Sent to rasterizer or vertex buffer in memory
  - Variable output size
    - makes it hard to parallelize



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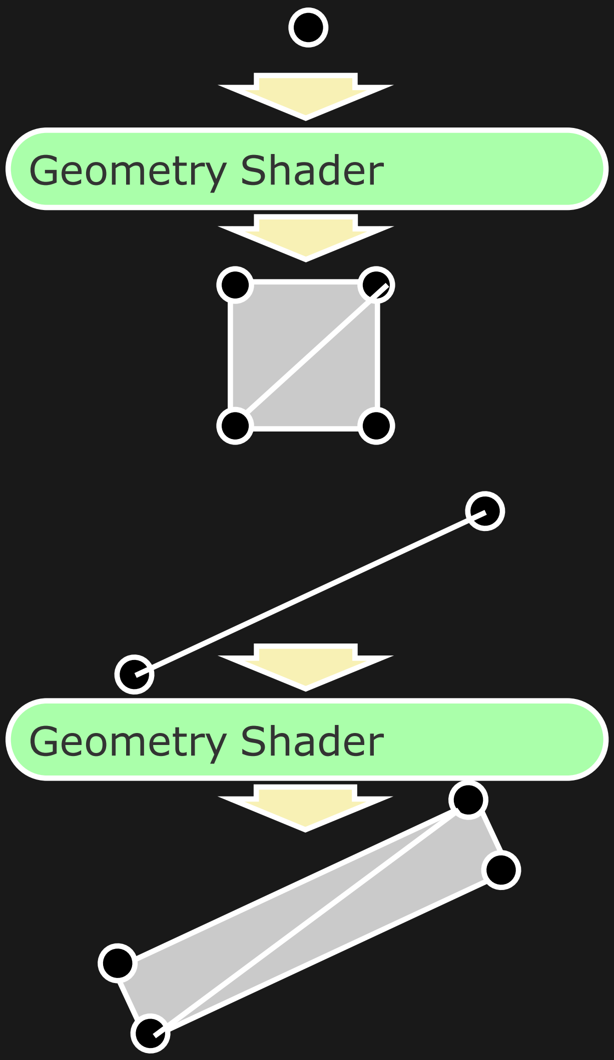
Geometry Shader

- Usage examples
  - **Point Sprite Tessellation**: The shader takes in a single vertex and generates four vertexes (two output triangles) that represent the four corners of a quad
  - **Wide Line Tessellation**: The shader receives two line vertexes and generates four vertexes for a quad that represents a widened line.
  - Other uses: generation of shadow volumes and cube maps



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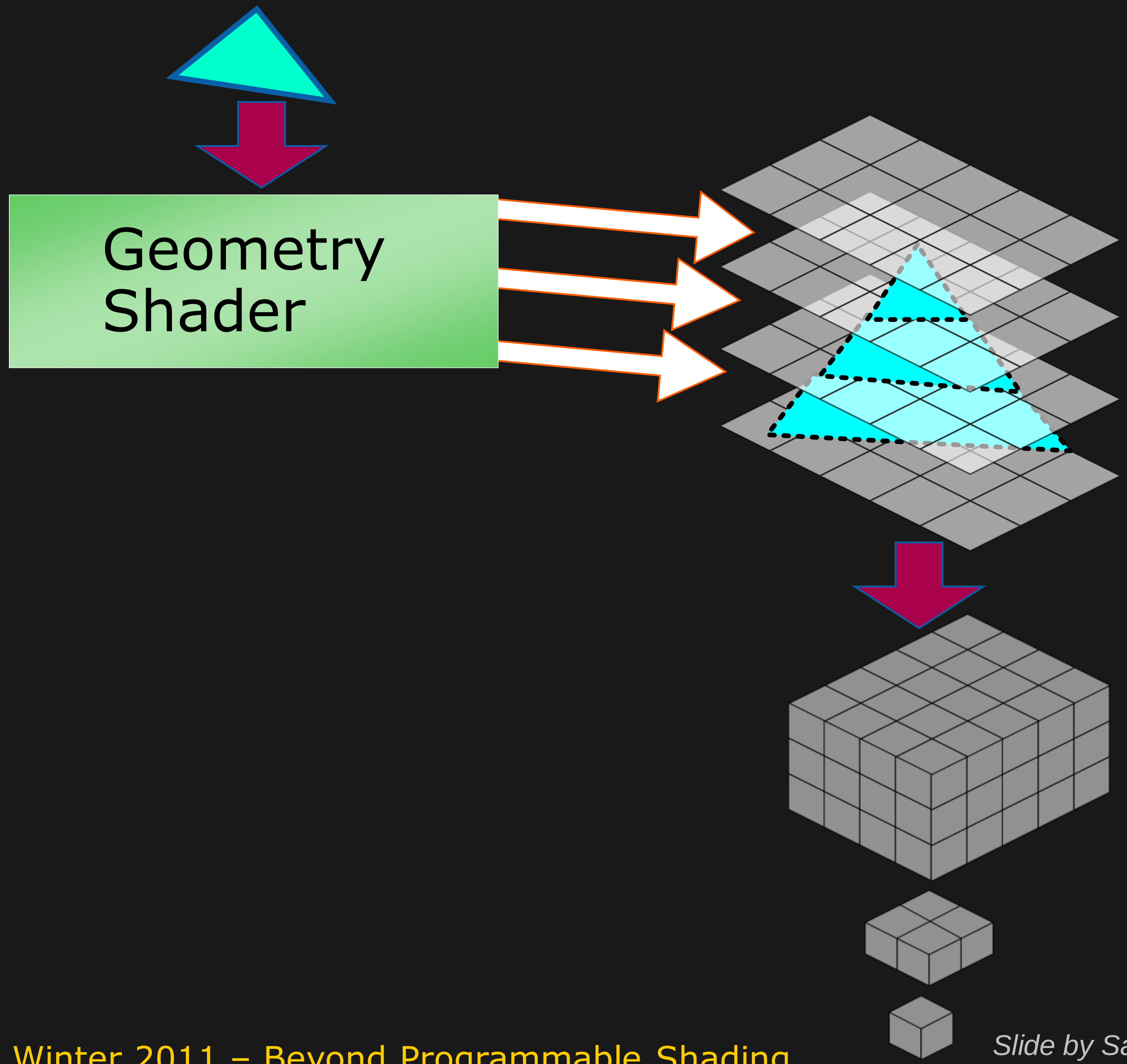
Point Sprites and Wide Lines

- Smoke represented by point sprites
  - Points converted to quads in geometry shader
- Hair represented by "wide lines"
  - Lines converted to quads in geometry shader

Images from "Adaptive Volumetric Shadow Maps," EGSR 2010, Salvi et al.

Render-To-Volume



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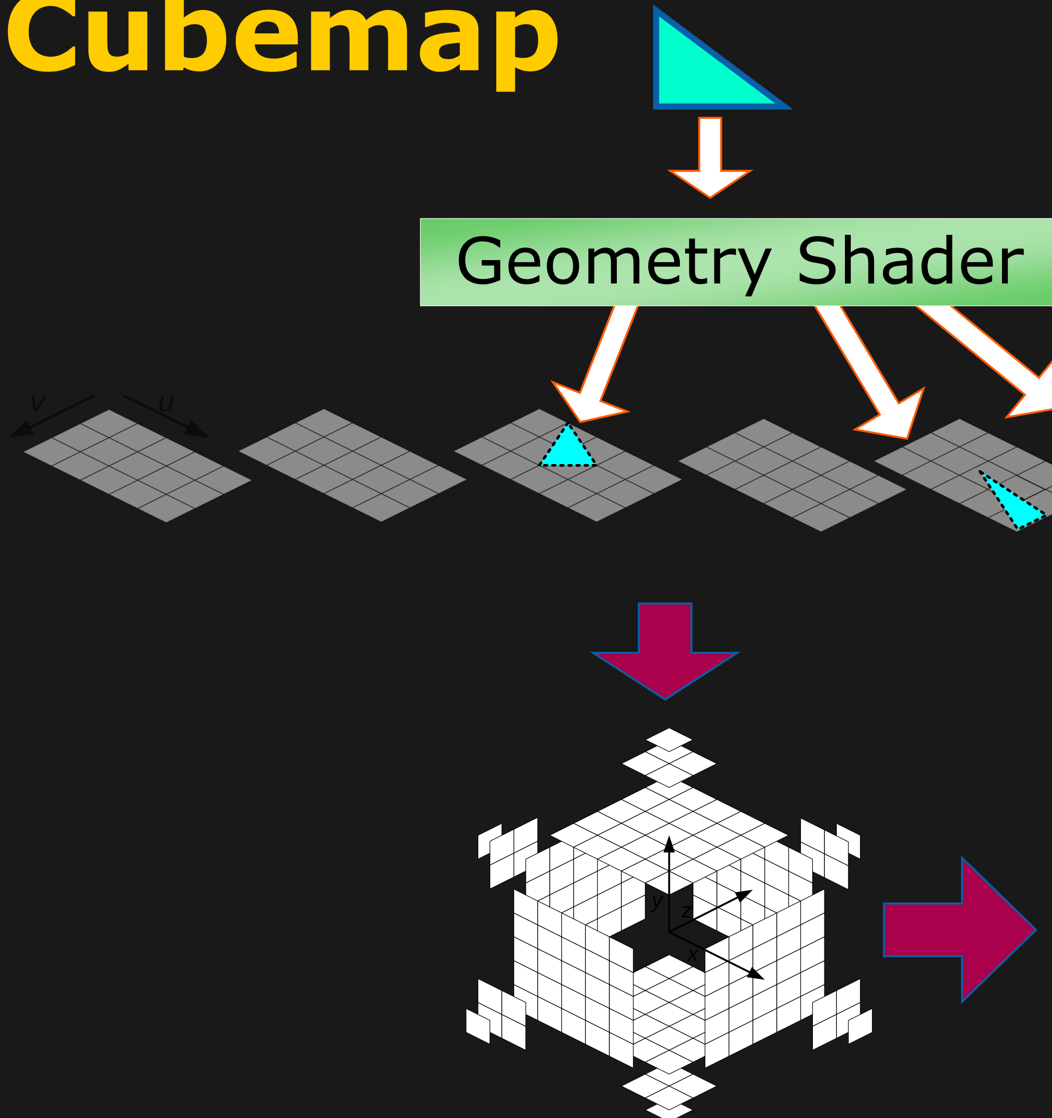
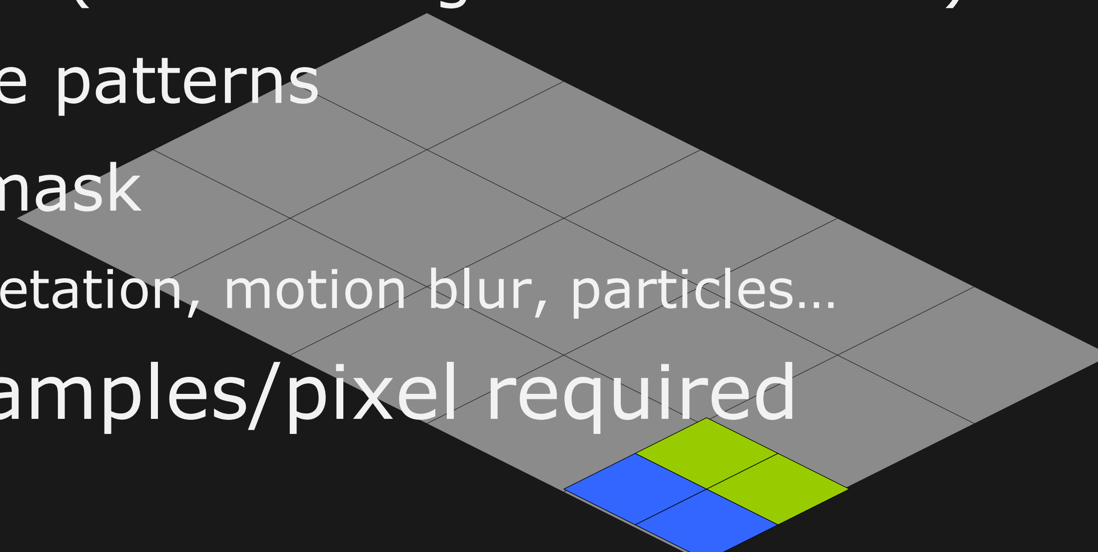
Single Pass Render-To-Cubemap



Direct3D 10.1 Features
Full anti-aliasing control

- Application control over:
  - Multi-sample AA (smooth edges)

    or
  - Super-sample AA (smooth edges and interior)
  - Selecting sample patterns
  - Pixel coverage mask
    - High-quality vegetation, motion blur, particles…
- Minimum of 4 samples/pixel required



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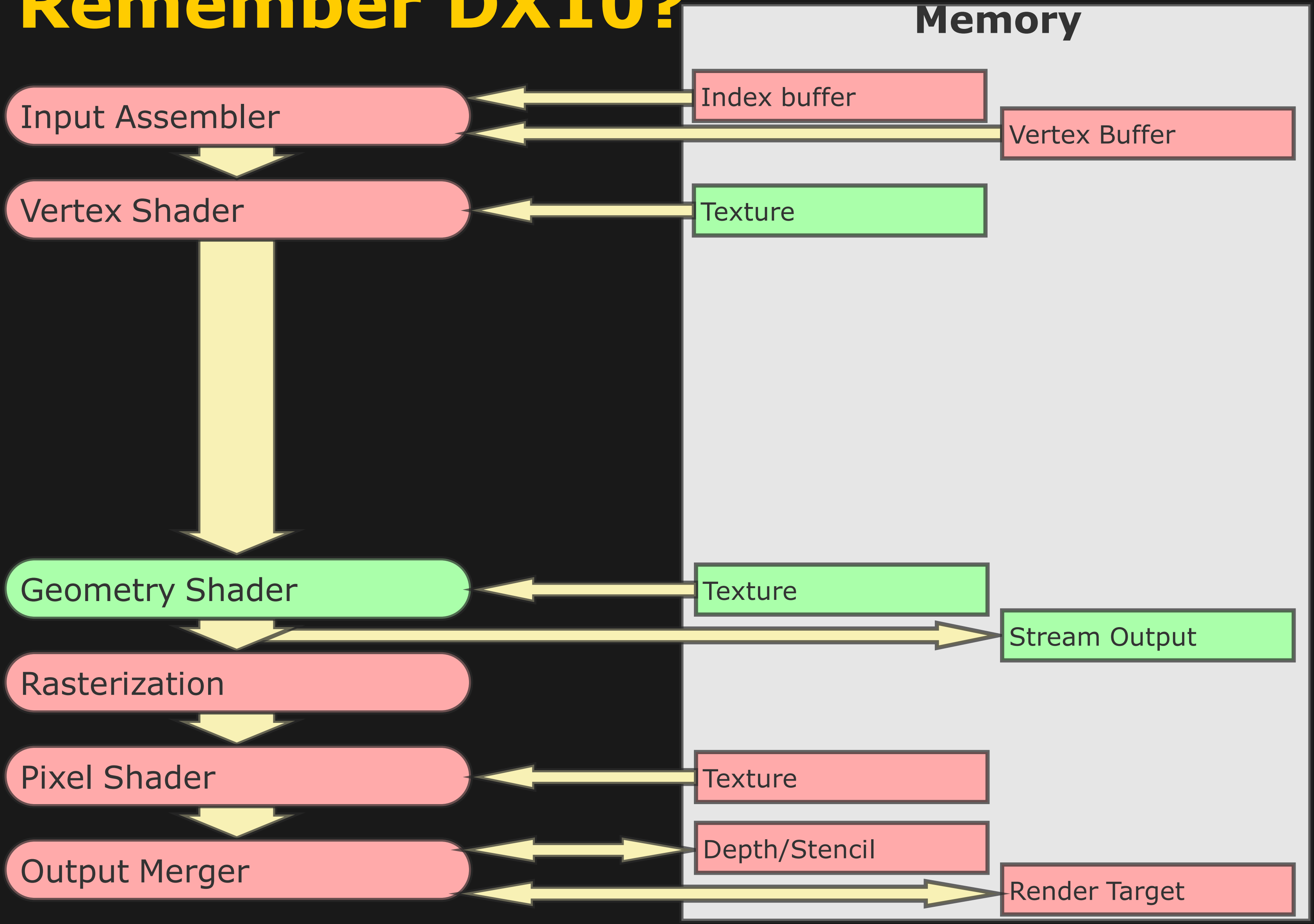
DX11

Remember DX10?



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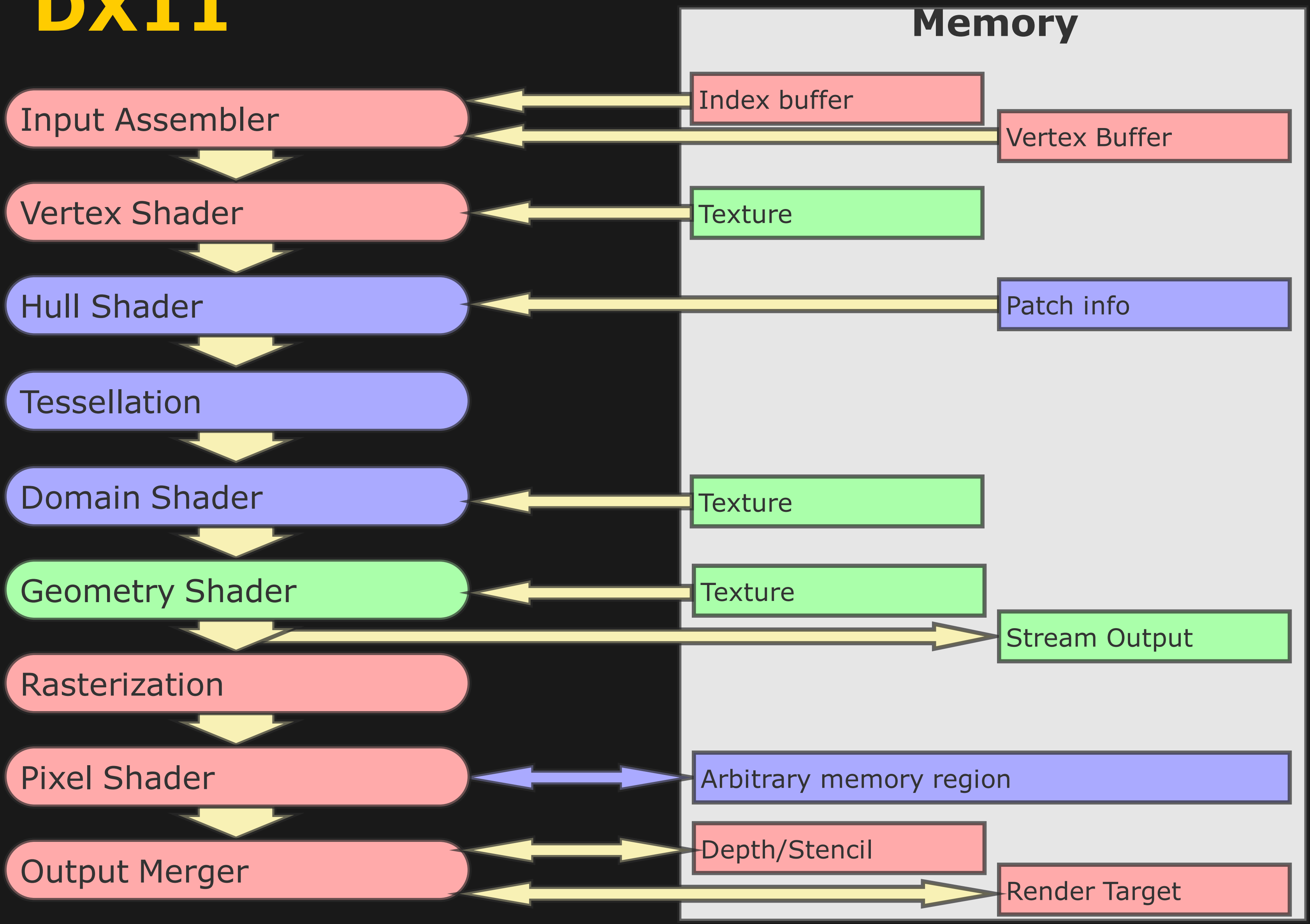
DX11



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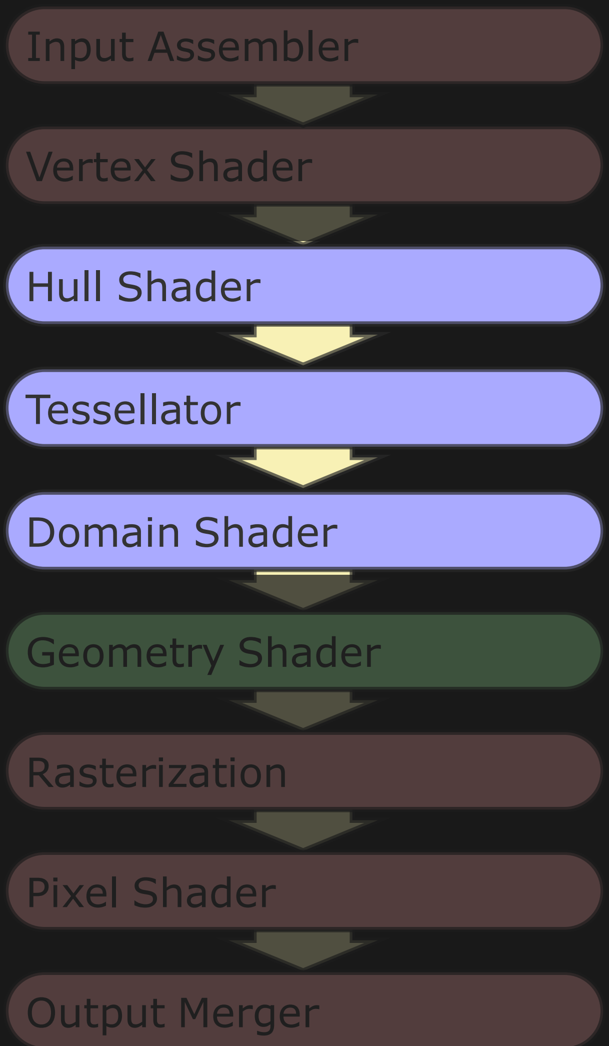
DX11 Tessellation example: Displaced subdivision surfaces

Slide by Tomas Akenine-Möller

DX11 - new stages for tessellation



- New ***Programmable*** stages
  - Hull Shader
  - Domain Shader
- Fixed Function Stage
  - Tessellator

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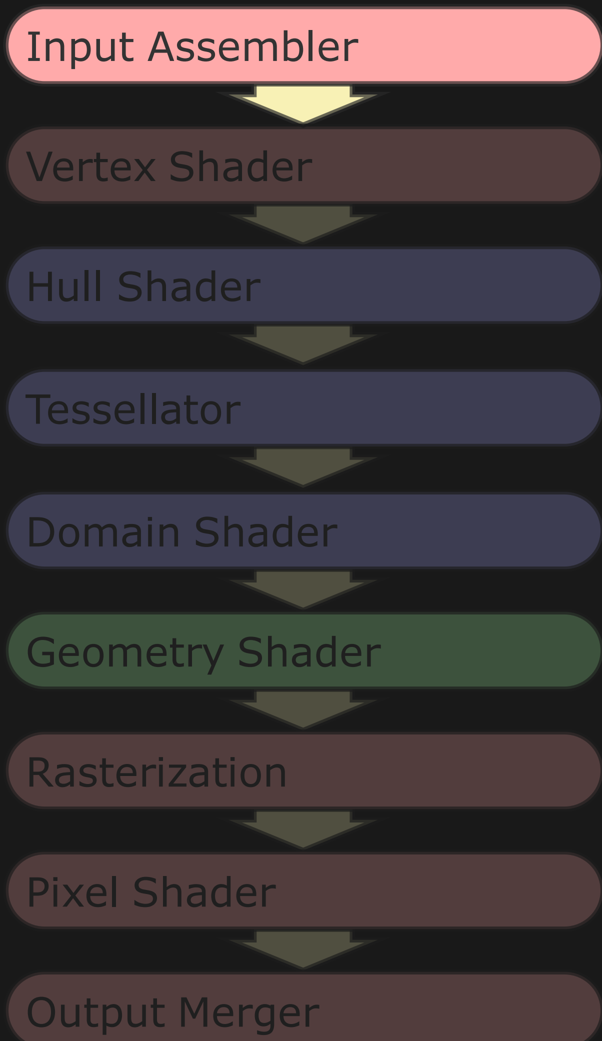
Tessellation - Input Assembler



- New Patch primitive type
- Outputs vertices to vertex shader and patch control points to hull shader

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Tessellation - Vertex Shader

- One invocation per *control point*
- For example, skin/animate the control points

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Hull Shader

- HS works on an entire patch
- HS can access all the input and output control points
- Typical functions
  - Assigns edge LODs
  - Change the basis

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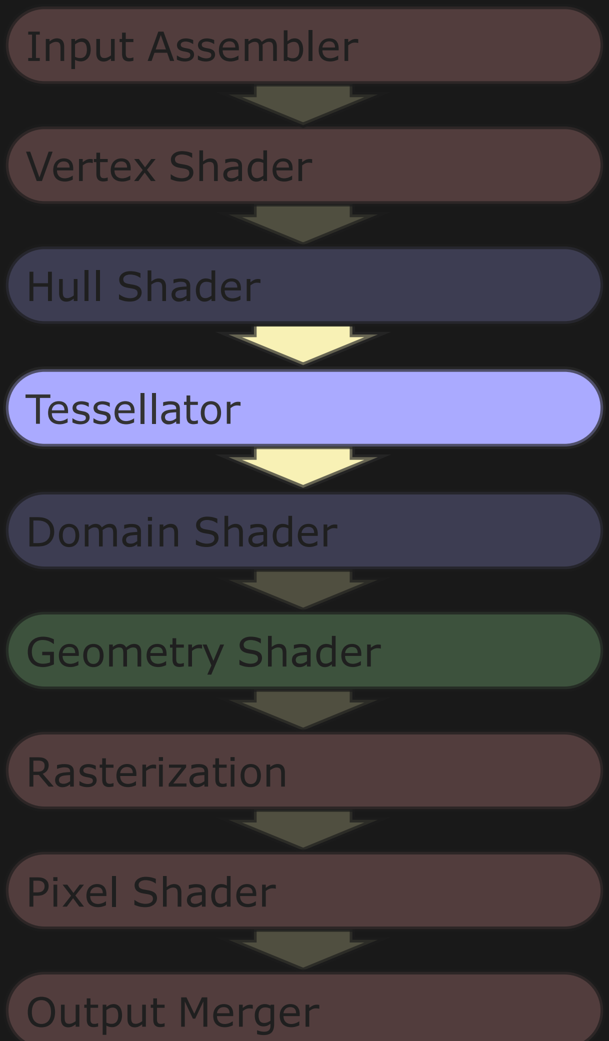
Tessellator



- TS inputs are edge LODs and additional knob values
  - Inner tessellation + tess mode
- TS generates (*u*,*v*) coordinates and connectivity information
- The (*u*,*v*) coordinates are in the domain [0,1]
  - Calculated using fixed point math to ensure water tight edges

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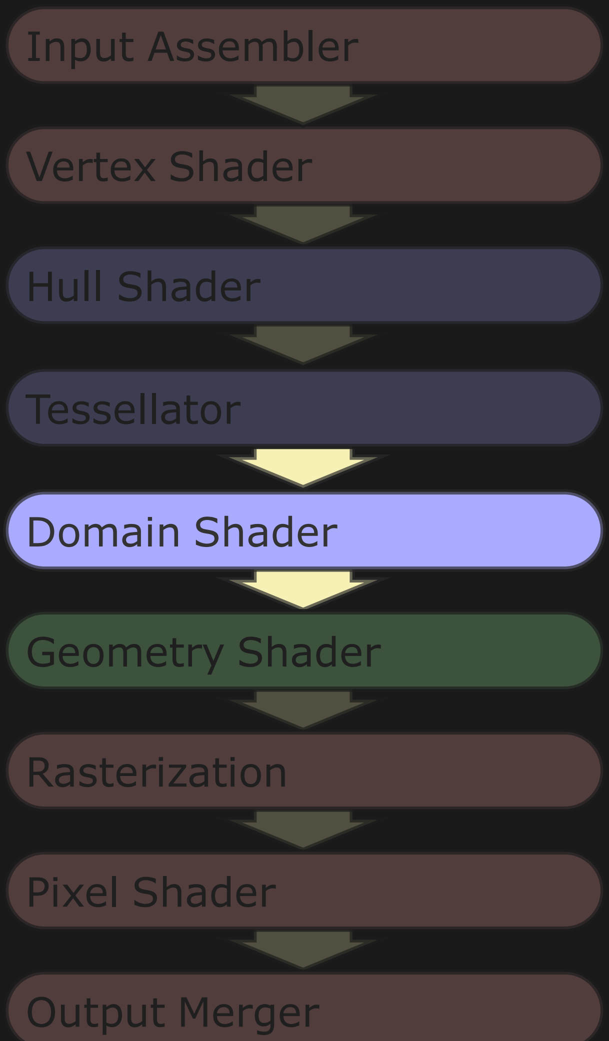
Domain Shader



- One domain shader invocation per (u,v) pair
- DS gets (u,v) from tessellator and control points from HS
- Computes a real 3D point from a domain location (u,v)
  - For example, displace the point using displacement map
  - Project the point
- Calculate auxiliary per vertex data
  - Texture coordinates
  - Tangent space vectors

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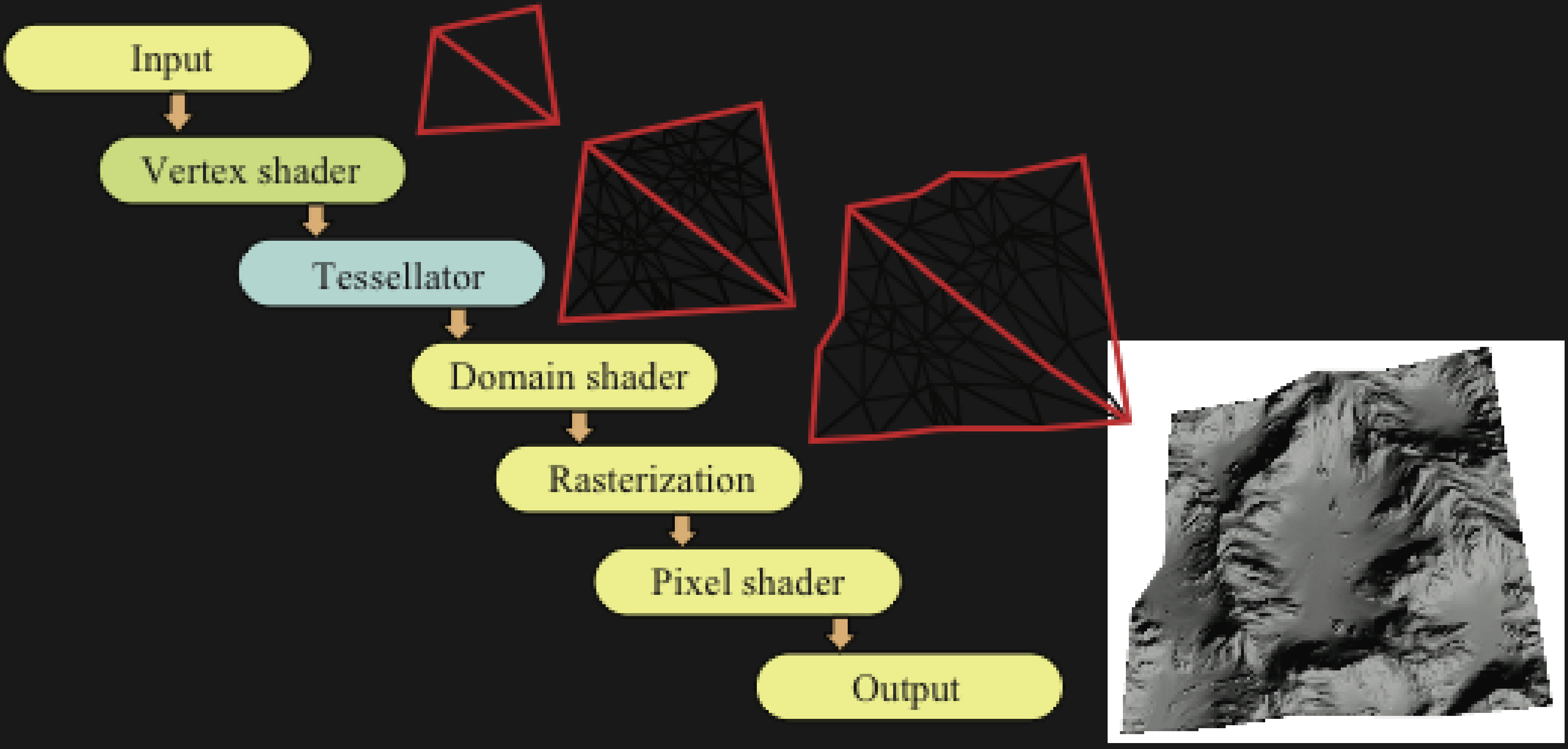
An example through the tessellation pipeline



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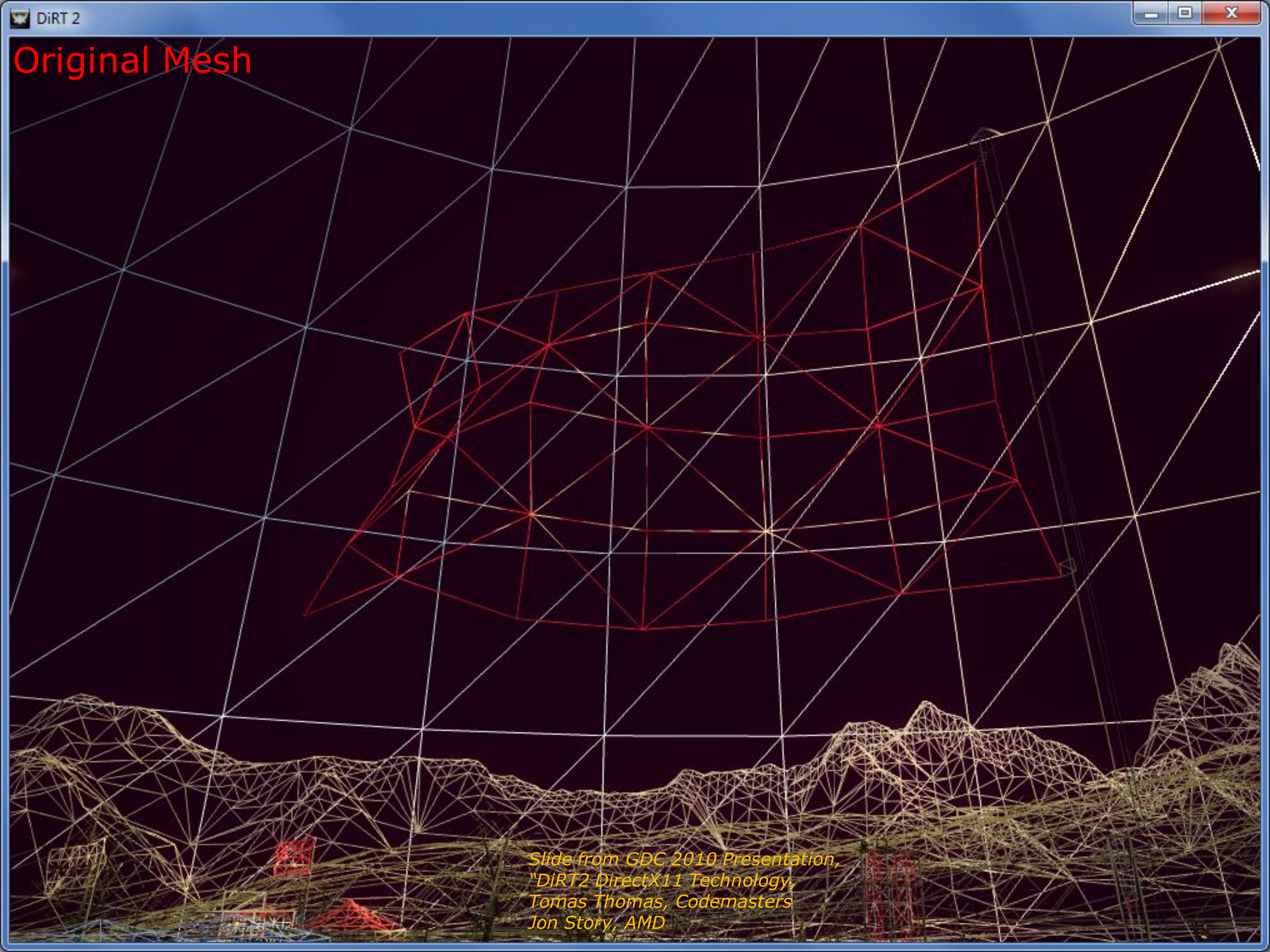
DX11 Tessellation Examples: Codemasters DiRT2

Slides from “DiRT2 DirectX 11 Technology“, Thomas and Story, GDC 2010


DiRT 2
Original Mesh
brembo
Slide from GDC 2010 Presentation,
"DiRT2 DirectX11 Technology,
Tomas Thomas, Codemasters
Jon Story, AMD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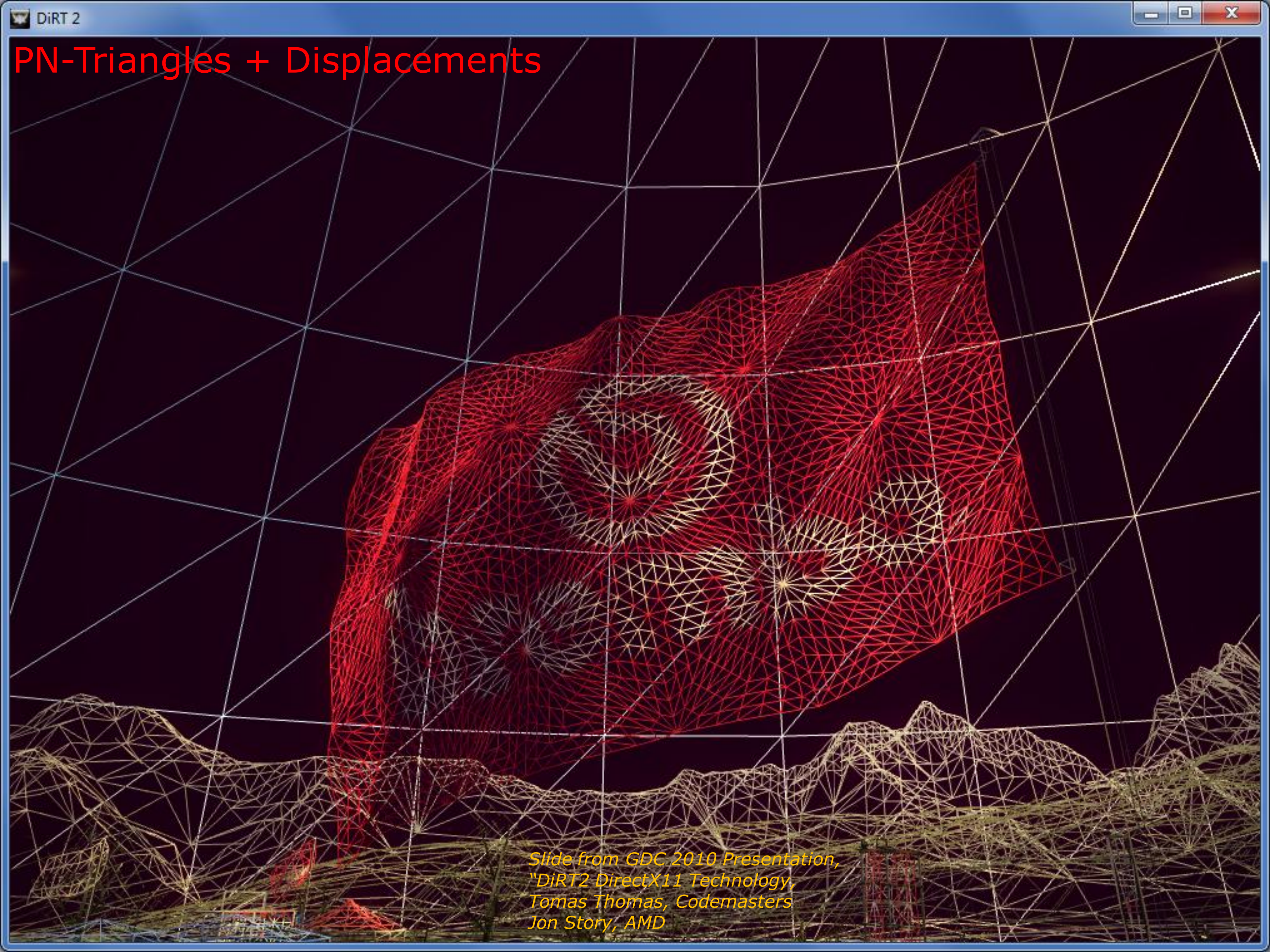
DiRT 2
PN-Triangles + Displacements
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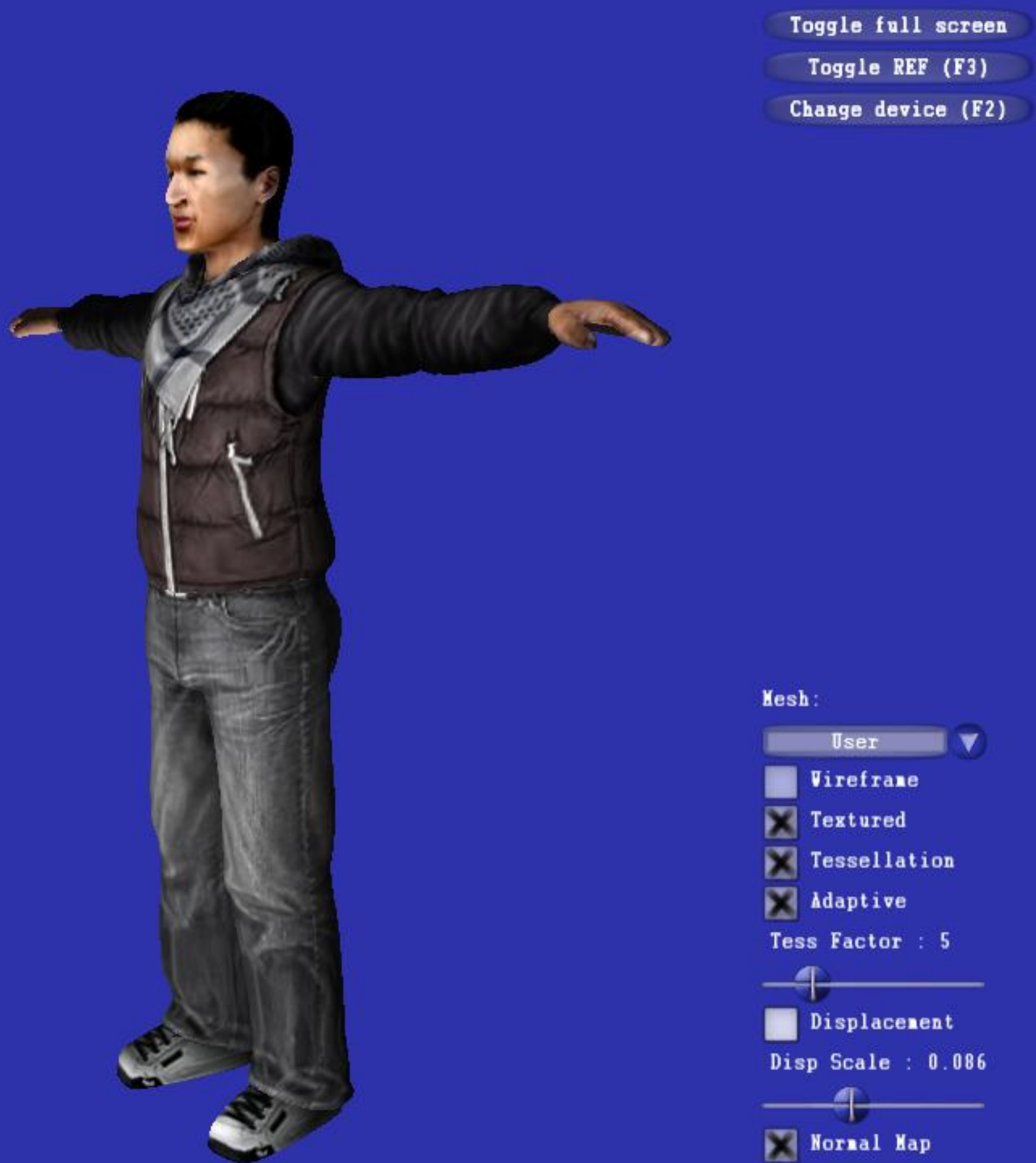
PN-Triangles



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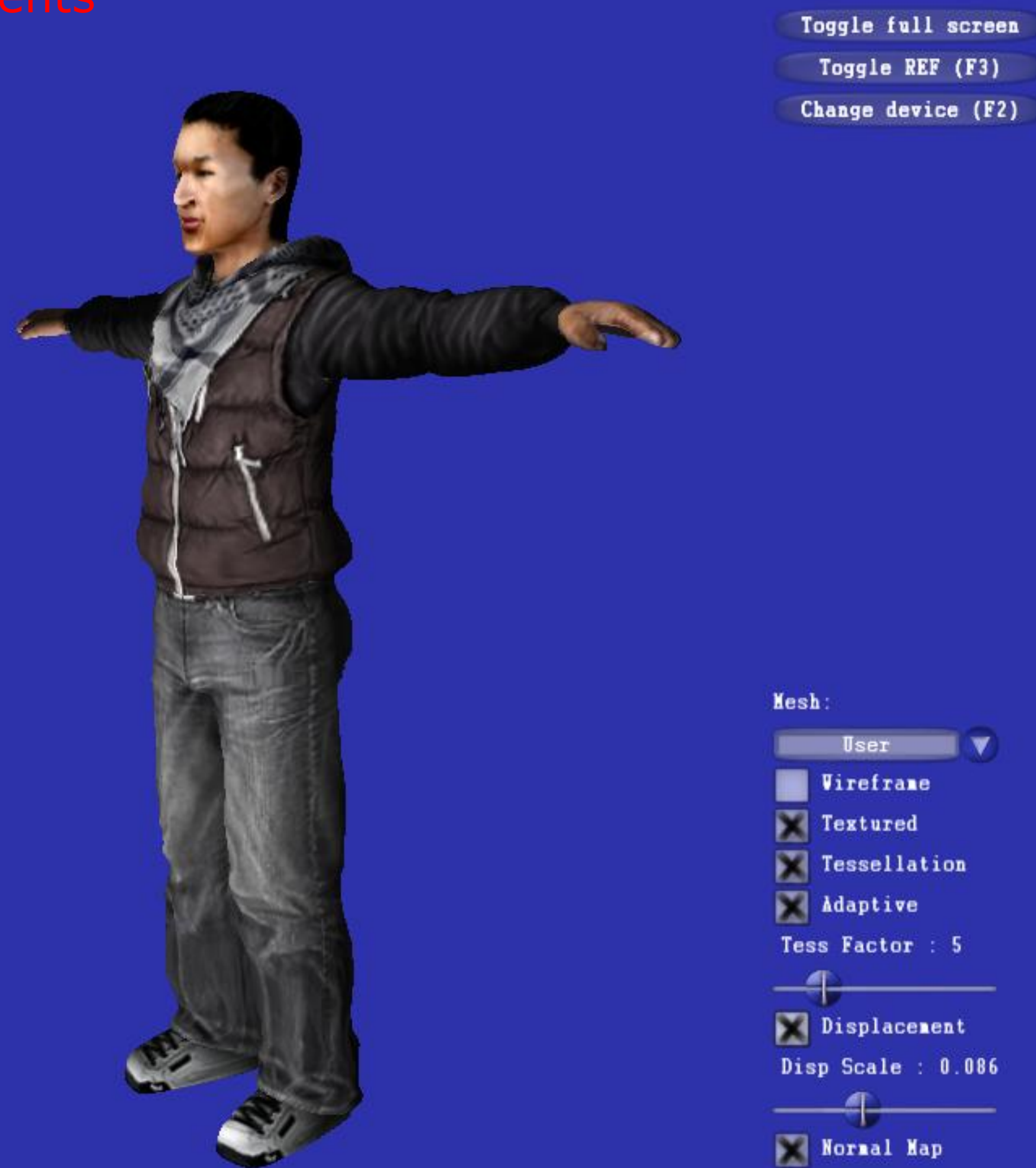

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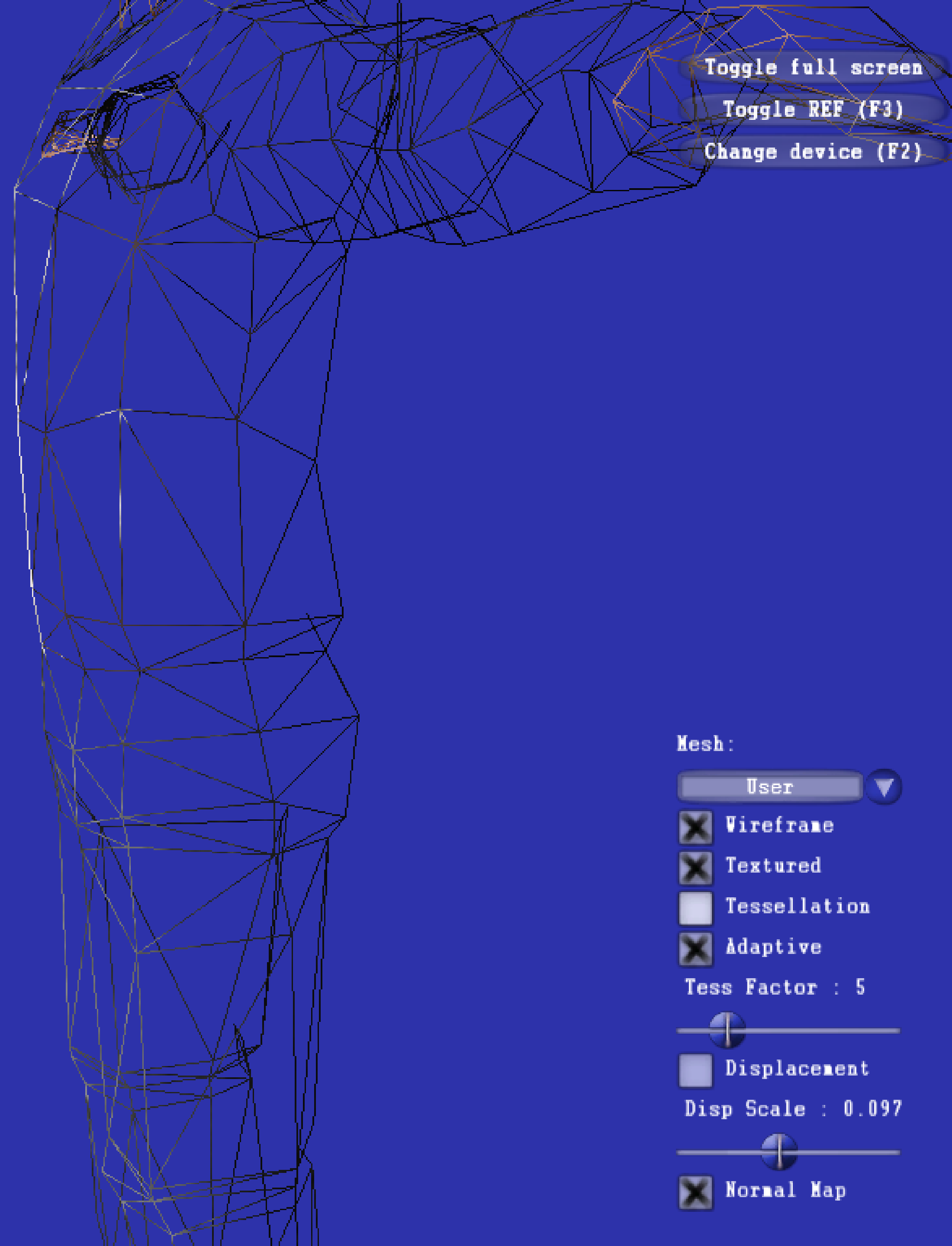

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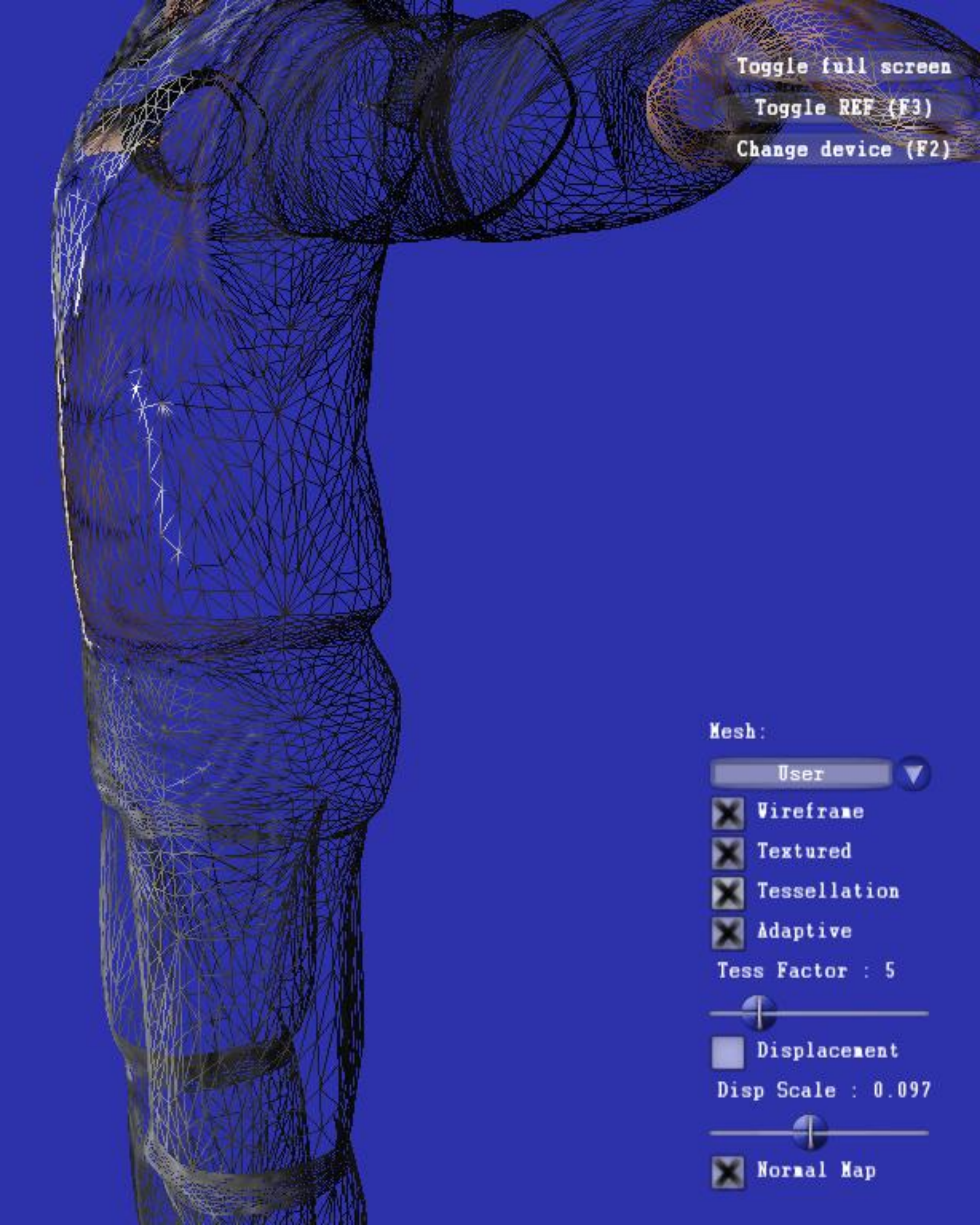

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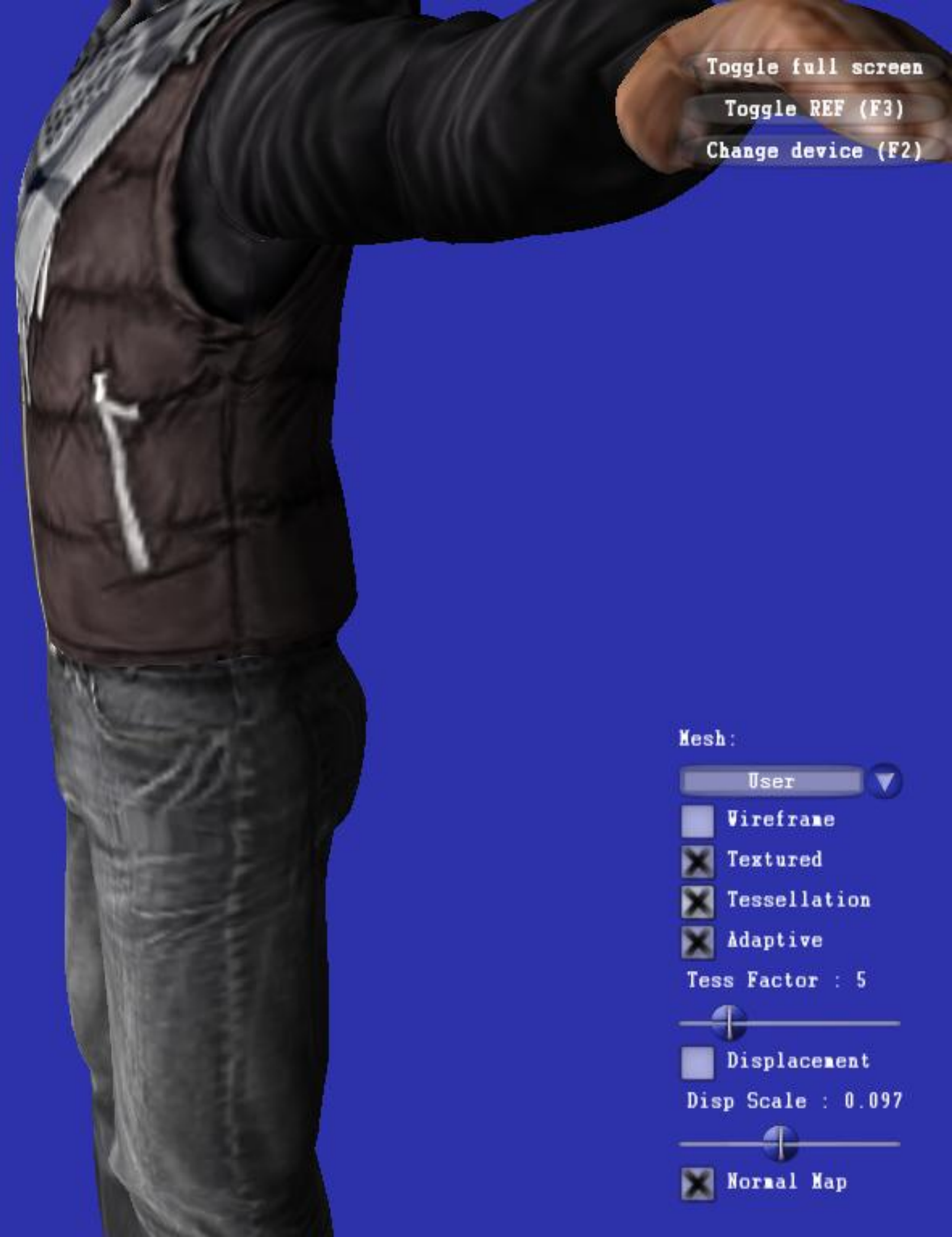

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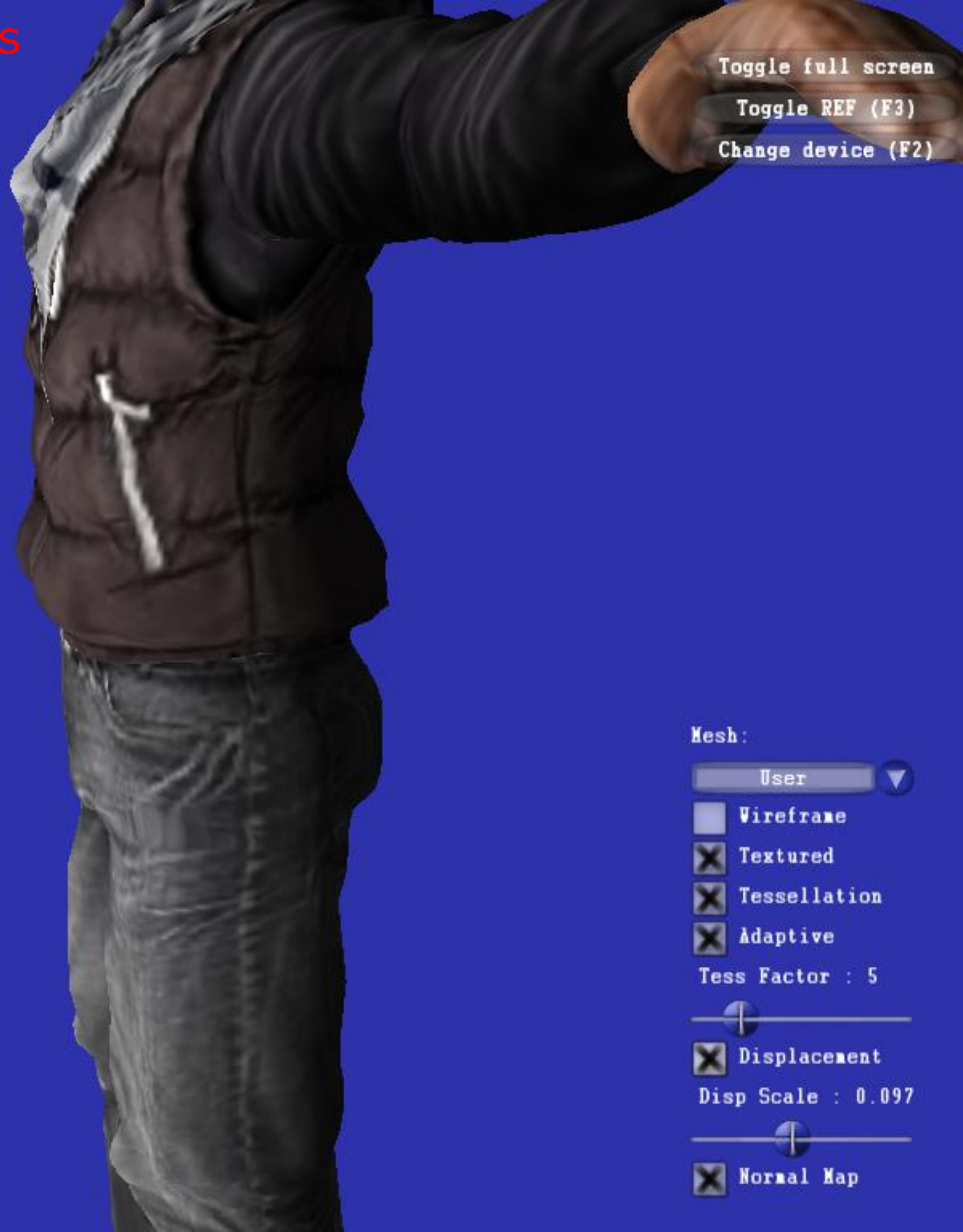

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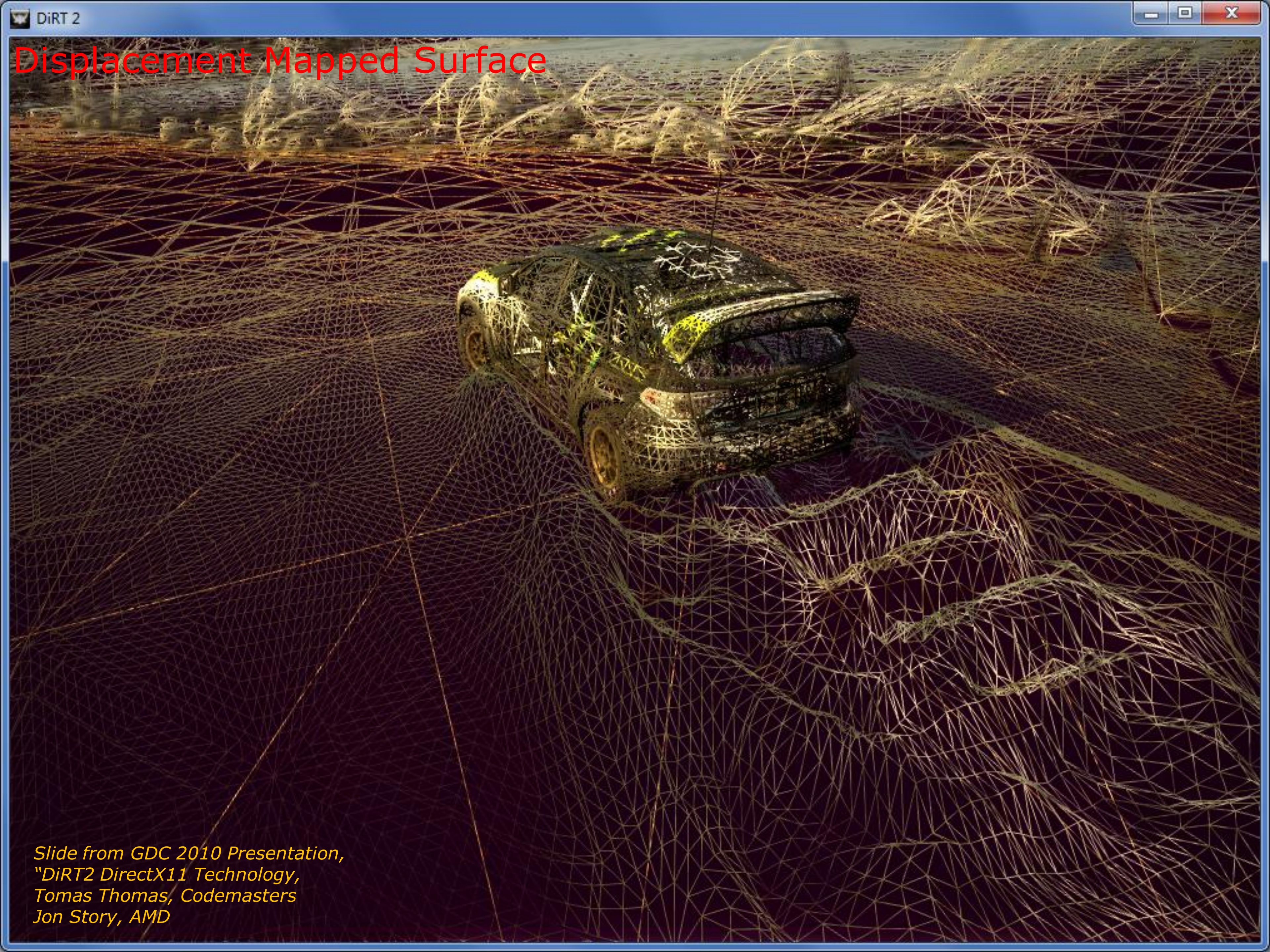
DiRT 2
Displacement Mapped Surface
Slide from GDC 2010 Presentation,
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Tomas Thomas, Codemasters
Jon Story, AMD


Displacement Mapping: OFF
REPLAY
ATI RADEON PREMIUM GRAPHICS
x4

Displacement Mapping: ON

DX11 Pixel Shader

DirectX11 Pixel Shader Changes

- Read and write anywhere in memory
  - "Unordered access views" (UAVs)
  - Pixel shaders can now write somewhere other than pixel position (!)
- Atomic read-modify-write operations
  - add, subtract, min, max, compare-exchange, …, or, xor

DX11 Pixel Shader Implications

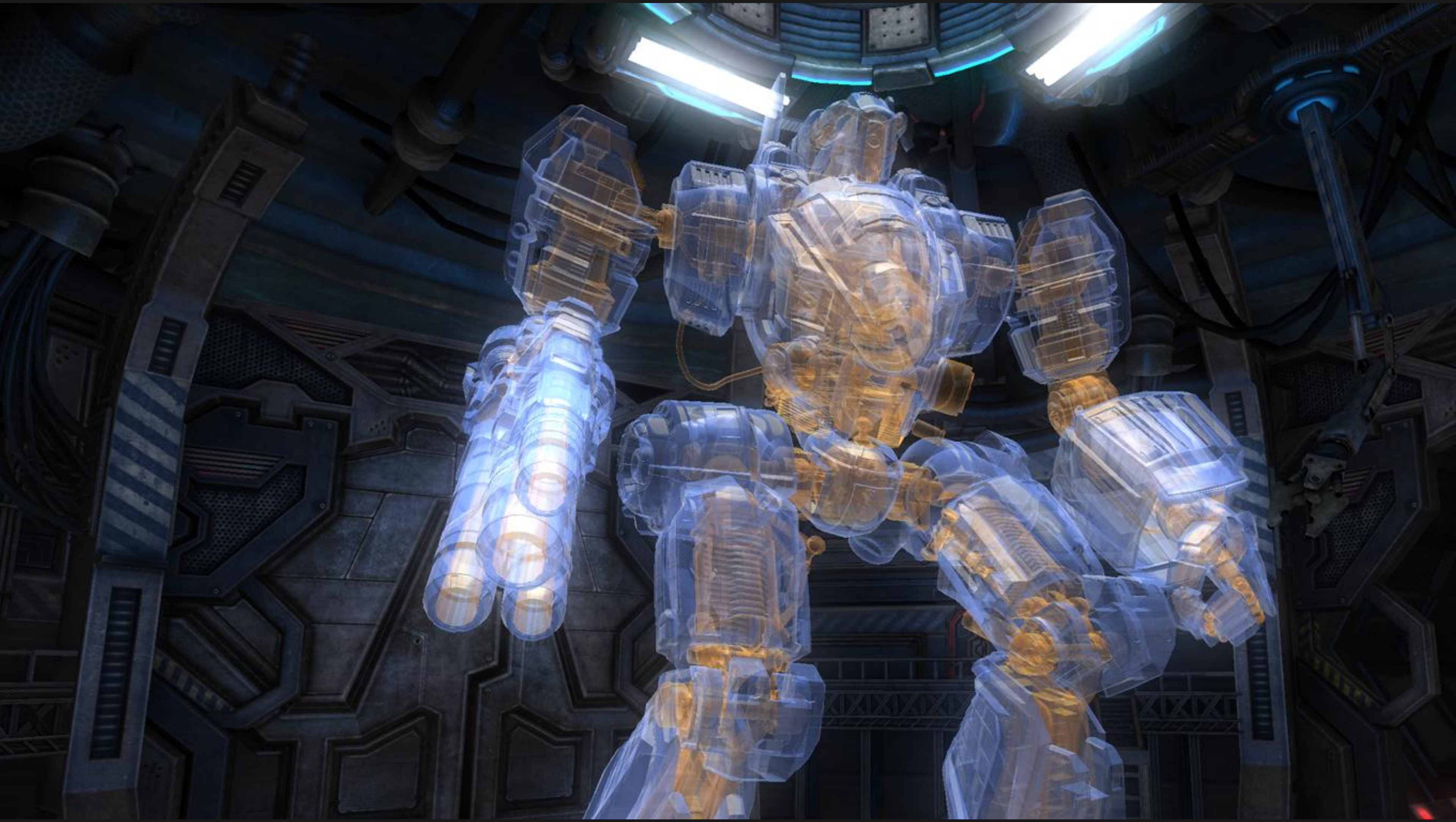
- ***Pixel shaders can build data structures other than images***
  - Scatter/gather and atomic operations
  - “Render to user-defined data structure”

- Limitations
  - Atomic RMW operations only on 32-bit integers (no atomic struct RMW)
  - No critical sections / mutexes

Real-time A-Buffer Generation

Pixel Shader 5 Example

Order Independent Transparency I



"Real-Time Concurrent Linked List Construction on the GPU,"
Yang et al., EGSR 2010

The Problem with Transparency

With Sorting

"Real-Time Concurrent Linked List Construction on the GPU,"
Yang et al., EGSR 2010

Skeleton hidden

No Sorting

Arm appears in front of body

Sorting is hard!

Solution: Sort Fragments Per Pixel

- Create A-Buffer using DX11 rendering pipeline
  - "The A -buffer, an antialiased hidden surface method," Carpenter, SIGGRAPH 1984
- Render pass 1
  - Store linked list of fragments per-pixel in 2 separate buffers
    - UAV 1: Storage for all [RGBA,Z,next] values from all fragments
    - UAV 2: "Image-sized" storage for a head pointer per pixel position
- Render pass 2
  - Full-screen pass that sorts and blends fragments to create pixel color

DX11 A-Buffer

- Pros
  - Correct solution to order-independent transparency
  - Runs at interactive rates on current hardware
- Cons
  - A-buffers use unbounded amount of memory
  - Performance variable depending on order fragments stored in memory

DX11 ComputeShader / DirectCompute

- "Out-of-pipeline" new programming model for "general" computation, designed to interact tightly with the graphics API (language is HLSL)
- Similar in semantics and capability to OpenCL and CUDA
- We will discuss DirectCompute later in the course

Summary

- Jump from DX9 to DX11 (OGL2 to OGL4)
  - Adds 4 new pipeline stages (hull, tessellator, domain, geometry)
  - Makes shader stages far more general compute engines
  - Enables users to render to user-defined data structures (and defer visibility determination)
  - Greatly relaxes memory model of shaders (especially scatter/atomics)
  - Adds DirectCompute, which begins to blur lines between pipeline and user-defined parallel programs
  - Is still new wrt adoption in the game world (but a number of DX11 titles shipping)
- Get to know DX11/GL4 well---you can do *a lot* within the confines of the rendering pipeline

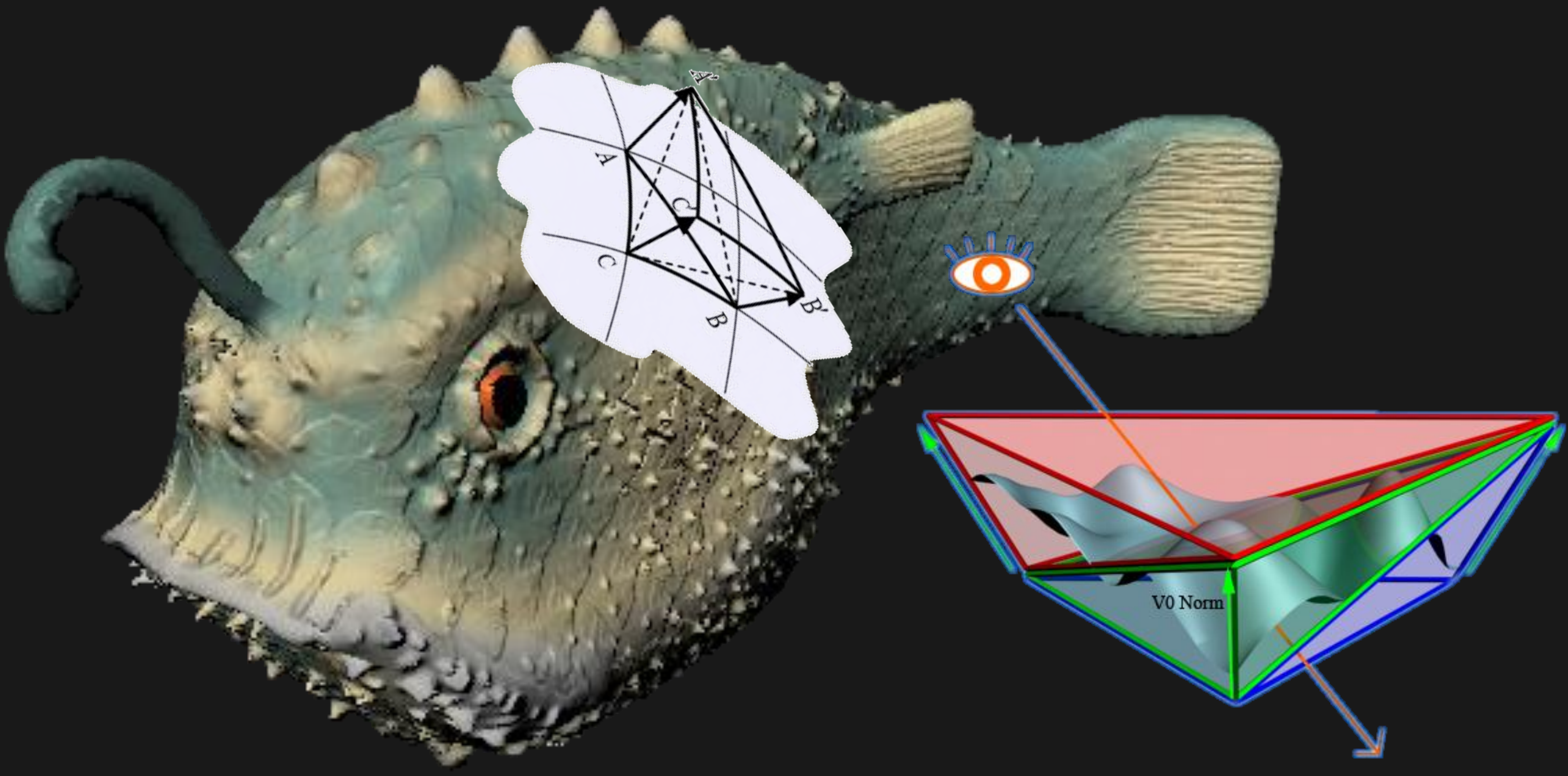
Backup

Geometry Shader Example
Shadow volume generation

Slide by Sam Glassenberg

Geometry Shader Example
Generalized displacement maps

- Displacement Mapping (Direct3D 10)



Slide by Sam Glassenberg

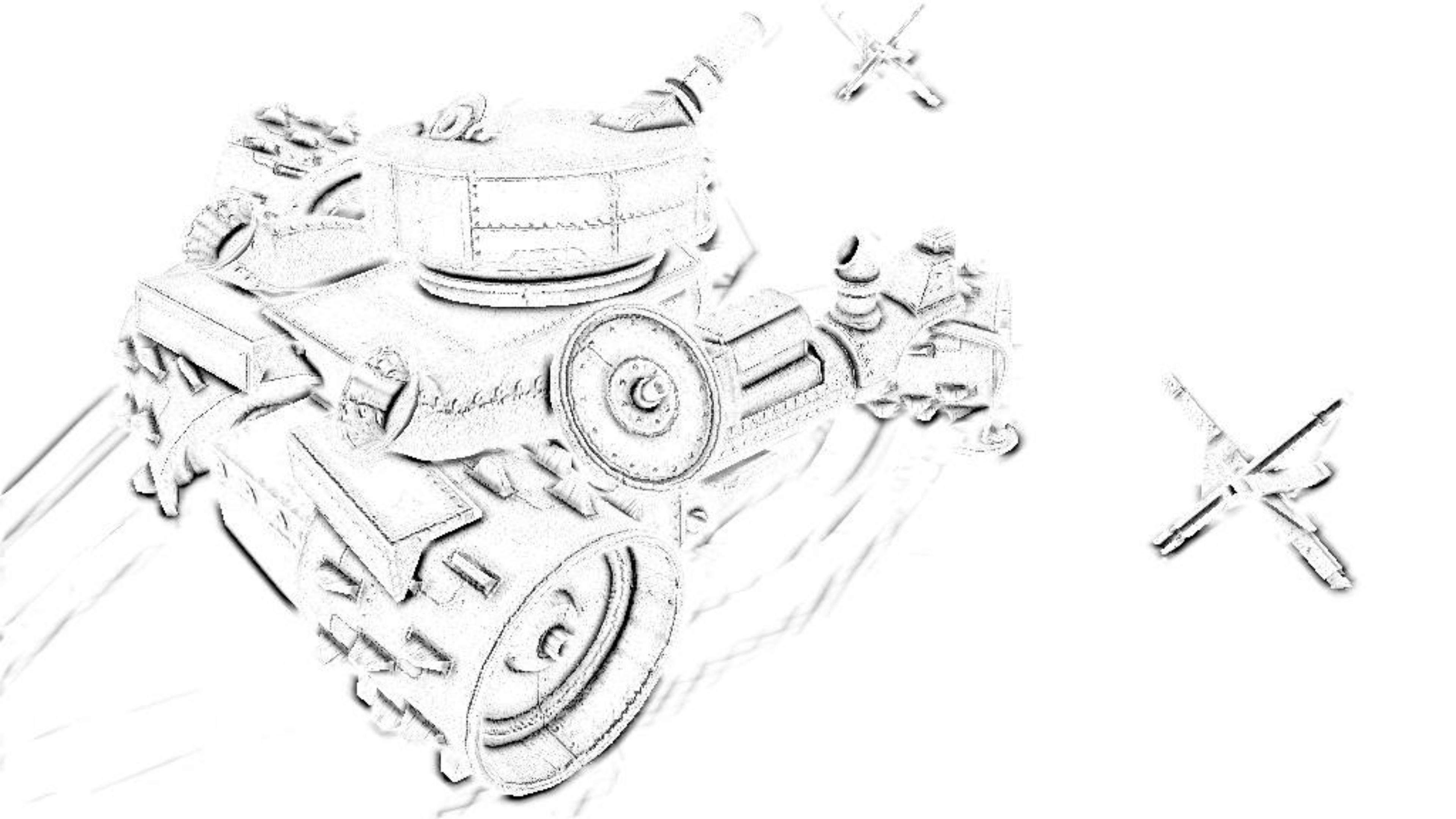
New DX10 and DX10.1 features heavily used for shadow techniques in production games

Examples of some from *"High Quality Direct3D 10.0 & 10.1 Accelerated Techniques", Story and Gruen, GDC 2009*


HDAO On (depth only)
HDAO Off (depth only)
- 40 Gathers
- No filtering needed

HDAO On (depth & normals)

- 80 **Gathers** (could use alot less)
- No filtering needed



Tom Clancy's HAWX
Publisher: Ubisoft
Developer: Ubisoft Romania

Stormrise
Publisher: SEGA
Developer: The Creative Assembly Australia

BattleForge
Publisher: EA
Developer: EA Phenomic


From DICE’s Frostbite Engine:
Uniform Shadow Filtering

From DICE's Frostbite Engine:
Unique Weight Shadow Filtering


From DICE’s Frostbite Engine:
Standard 2x2 Shadow Filtering


From DICE's Frostbite Engine:
5x5 Unique Weight Filtering

Tom Clancy`s HAWX
Publisher: Ubisoft
Developer: Ubisoft Romania
Blurred VSM

Tom Clancy`s HAWX
Publisher: Ubisoft
Developer: Ubisoft Romania
Unique Weight Shadows