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THE WORLD OF VISUAL COMPUTING

# Introduction to the Direct3D 11 Graphics Pipeline

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# Key Takeaways

- Direct3D 11 focuses on
  - Increasing scalability,
  - Improving the development experience,
  - Extending the reach of the GPU,
  - Improving Performance.
- Direct3D 11 is a strict superset of D3D 10 & 10.1
  - Adds support for new features
  - Start developing on Direct3D 10/10.1 today
- Available on Windows Vista & future Windows operating systems
- Supports 10 / 10.1 level hardware

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# Outline

- Drilldown
  - Tessellation
  - Compute Shader
  - Multithreading
  - Dynamic Shader Linkage
  - Improved Texture Compression
  - Quick Glance at Other Features
- Availability

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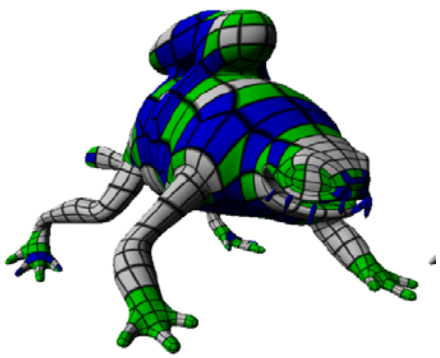
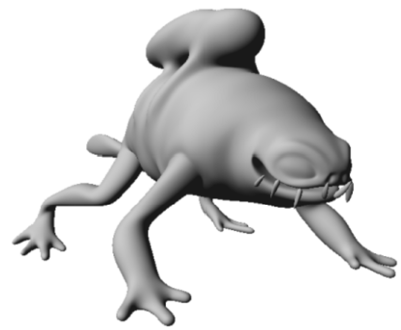
# Character Authoring Pipeline

(Rocket Frog Taken From Loop &Schaefer, "Approximating Catmull-Clark Subdivision Surfaces with Bicubic Patches“)

Sub-D Modeling

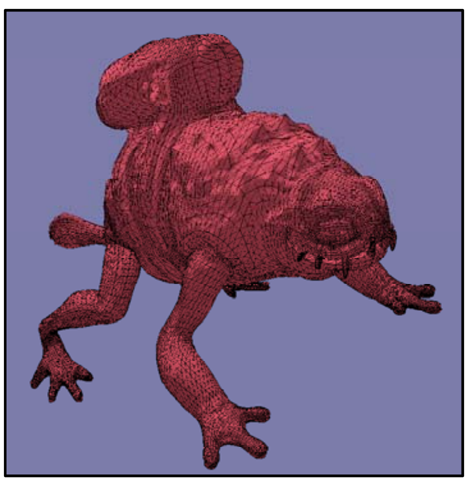


Animation

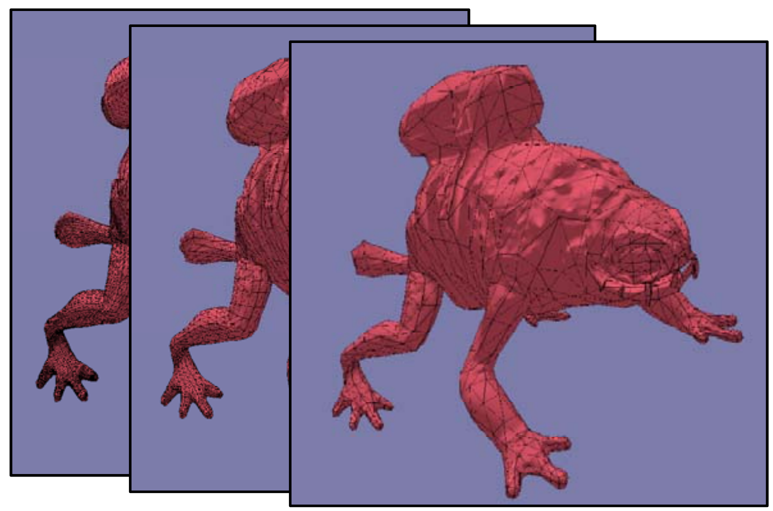


Displacement Map

Polygon Mesh



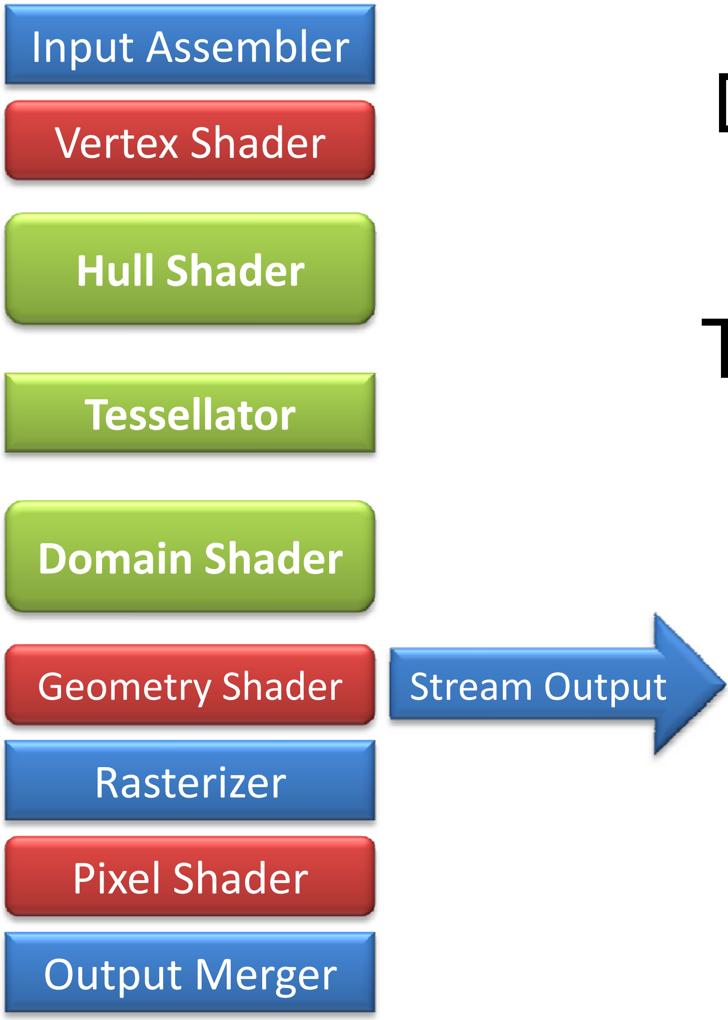
Generate LODs



# Character Authoring (Cont'd)

- Trends
  – Denser meshes, more detailed characters
    - ~5K triangles -> 30-100K triangles
  – Complex animations
    - Animations on polygon mesh vertices more costly
- Result
  – Integration in authoring pipeline painful
  – Larger memory footprints causing painful I/O issues
- Solution
  – Use the higher-level surface representation longer
    - Animate control cage (~5K vertices)
    - Generate displacement & normal maps

# Direct3D 11 Pipeline




Direct3D 10 pipeline

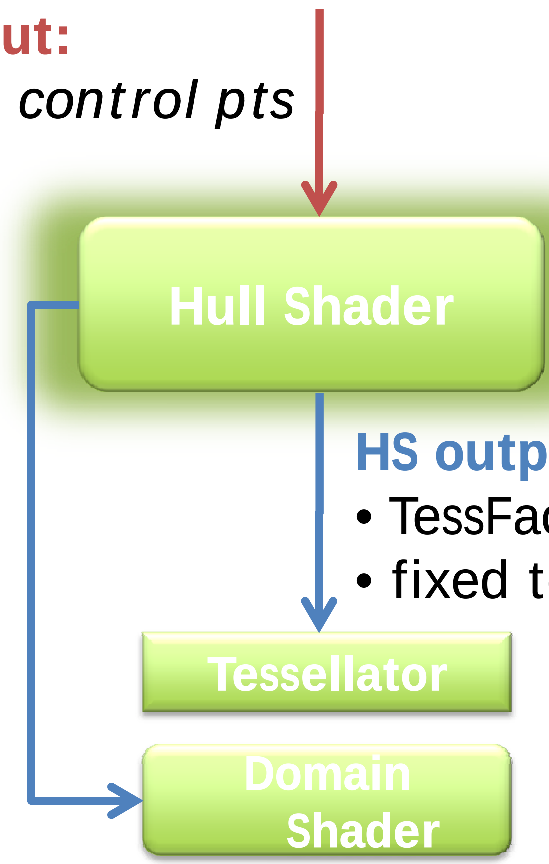
*Plus*

Three new stages for Tessellation

# Hull Shader (HS)

**HS input:**
*patch control pts*

One Hull Shader invocation per patch




**HS output:**
Patch control pts after Basis conversion

**HS output:**
- TessFactors (how much to tessellate)
- fixed tessellator mode declarations

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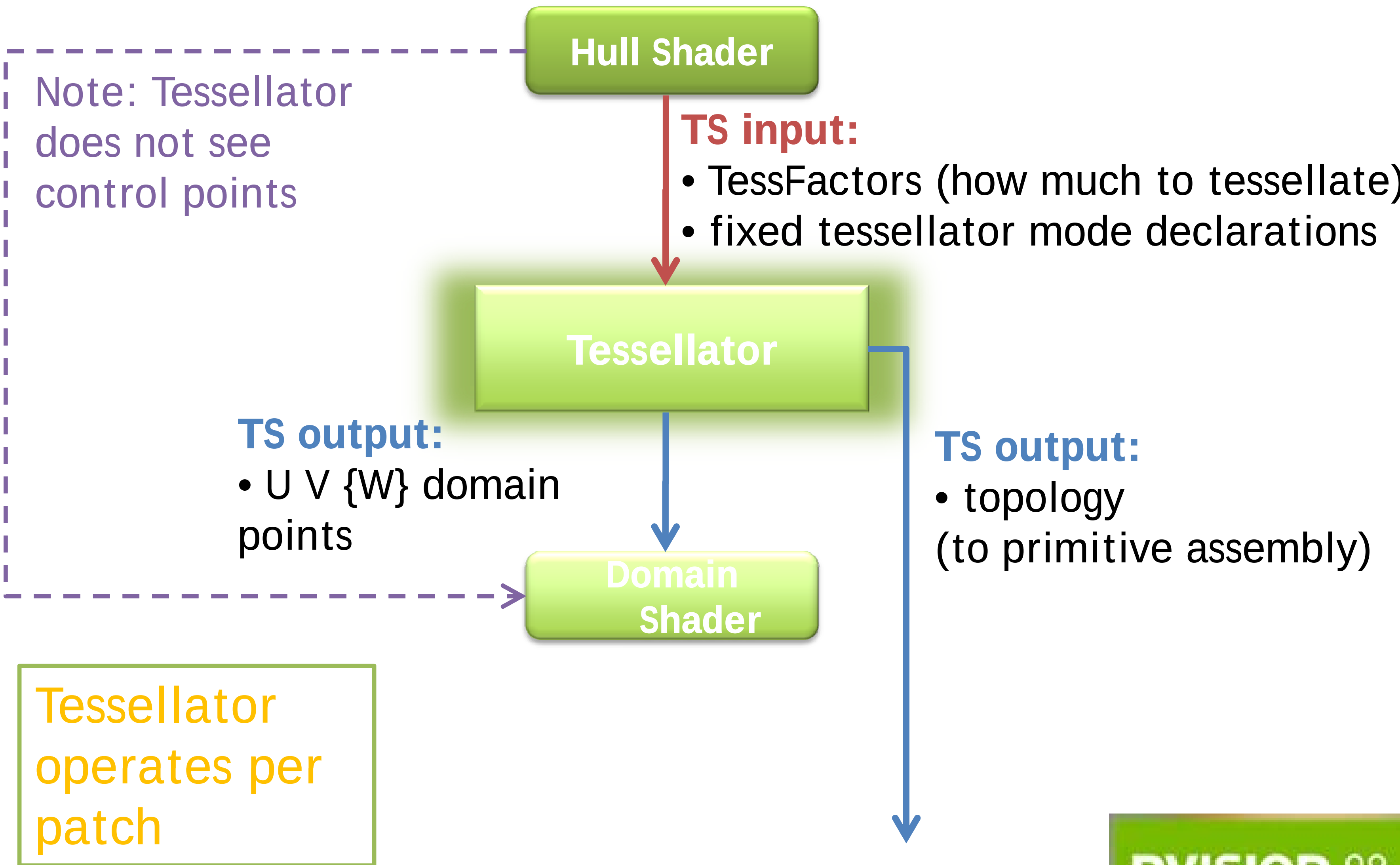
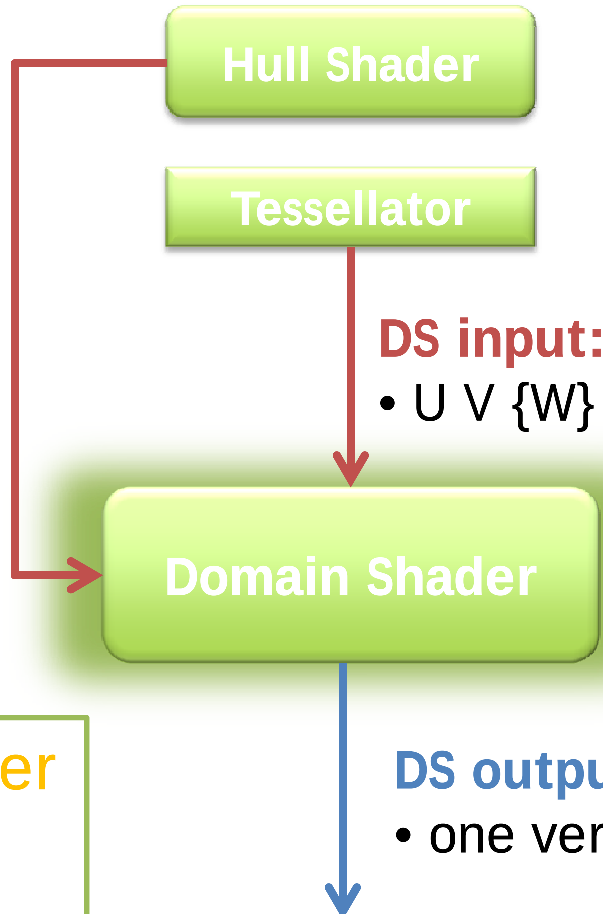
# Fixed-Function Tessellator (TS)



# Domain Shader (DS)



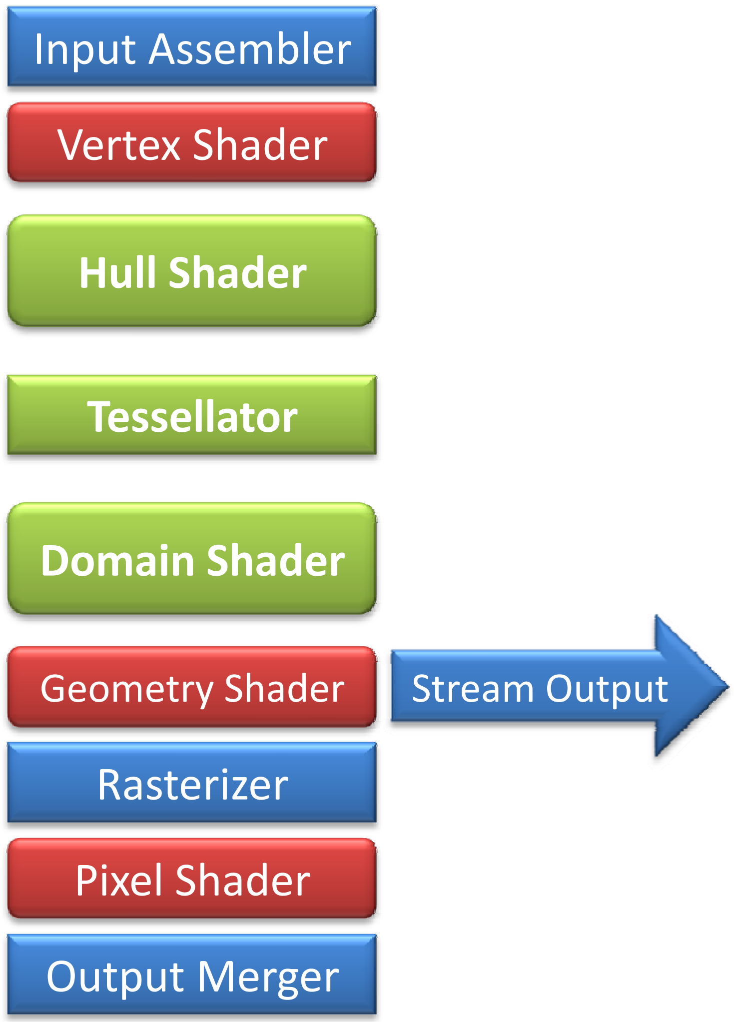

**DS input:**
- control points
- TessFactors

**DS input:**
- U V {W} domain points

**DS output:**
- one vertex

One Domain Shader invocation per point from Tessellator

# Direct3D 11 Pipeline




- D3D11 HW Feature
- D3D11 Only
- Fundamental primitive is patch (not triangle)
- Superset of Xbox 360 tessellation

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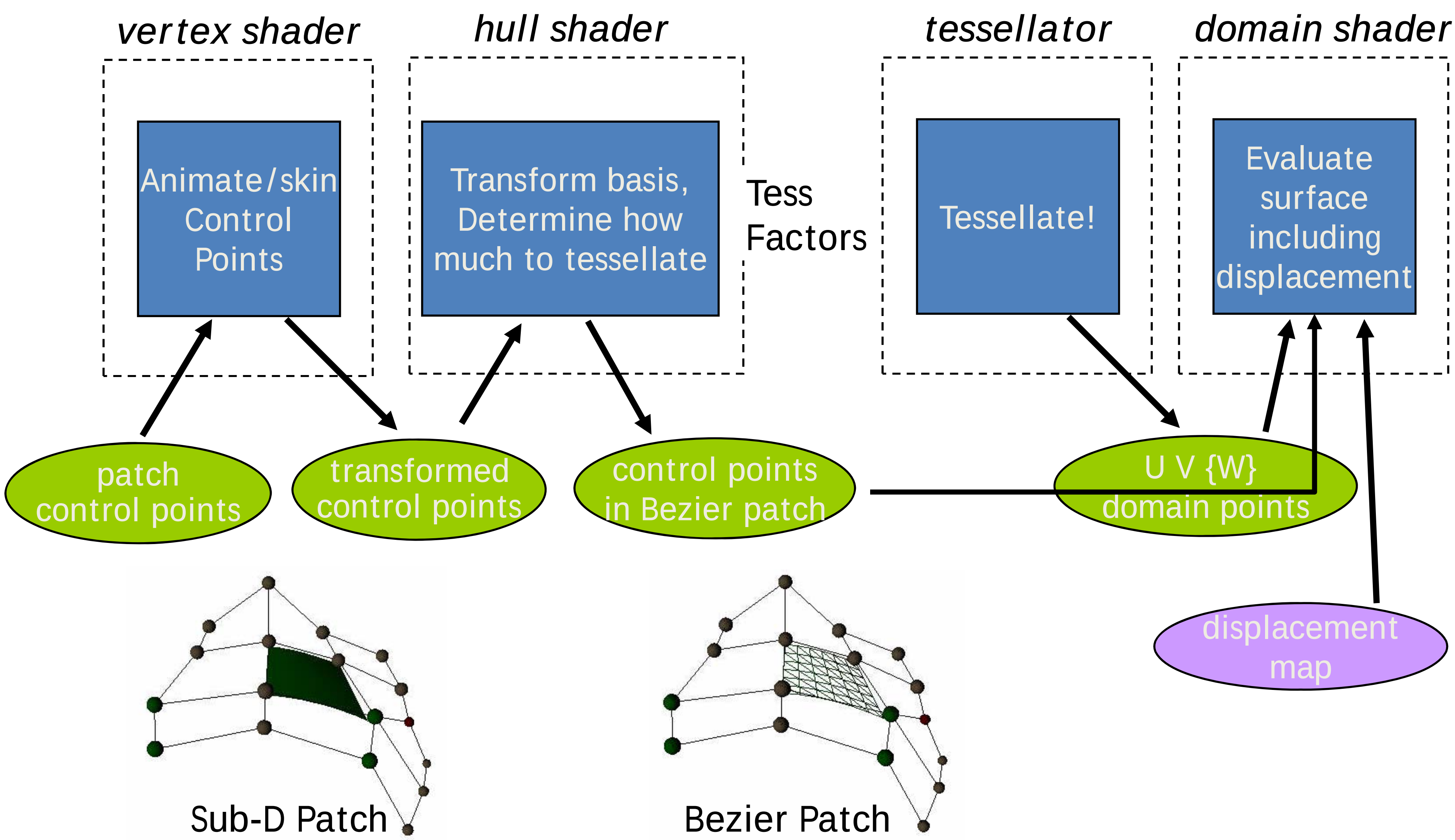
# Example Surface Processing Pipeline

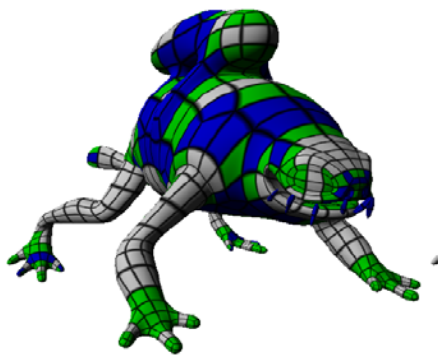
Single-pass process!



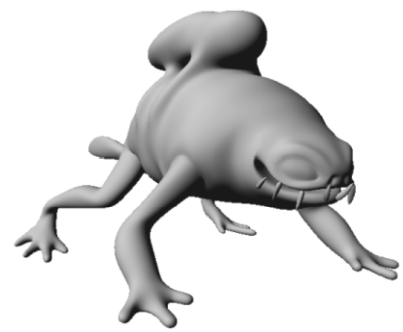
# New Authoring Pipeline

(Rocket Frog Taken From Loop &Schaefer, "Approximating Catmull-Clark Subdivision Surfaces with Bicubic Patches“)

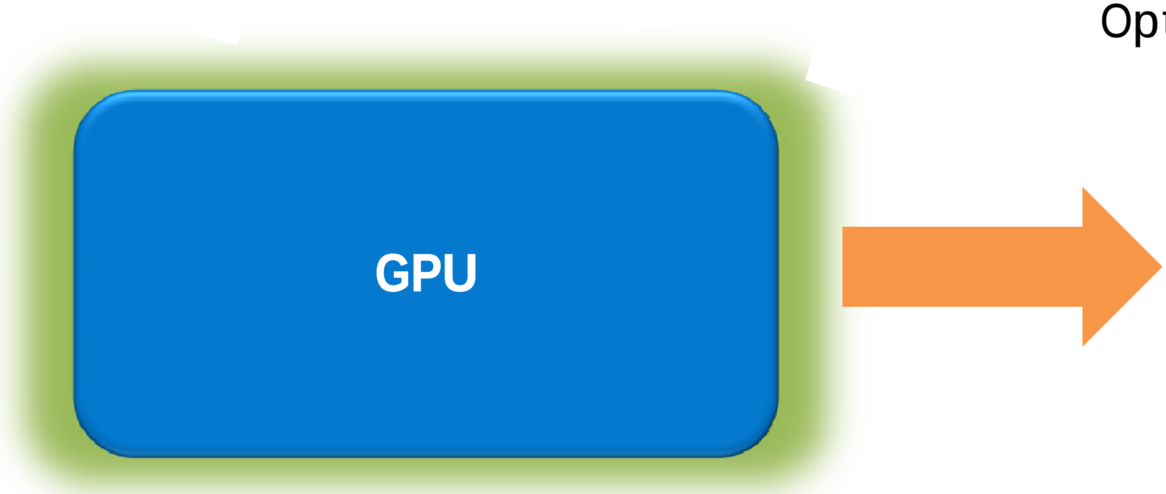
Sub-D Modeling



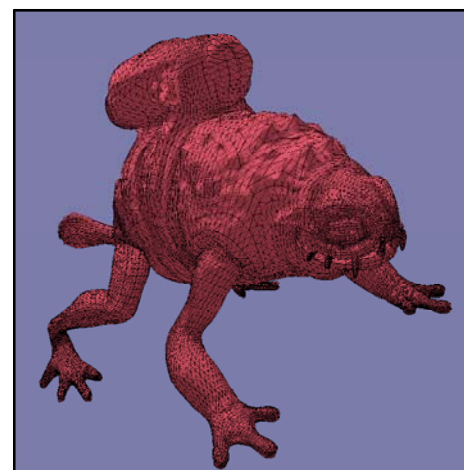
Animation



Displacement Map




Optimally Tessellated Mesh



# Tessellation: Summary

- Provides
  - Smooth silhouettes
  - Richer animations for less
- Scale visual quality across hardware configurations
- Supports performance improvements
  - Coarse model = compression, faster I/O to GPU
  - Cheaper skinning and simulation
  - Improve pixel shader quad utilization
  - Scalable rendering for each end user's hardware
- Render content as artists intend it!

# Outline

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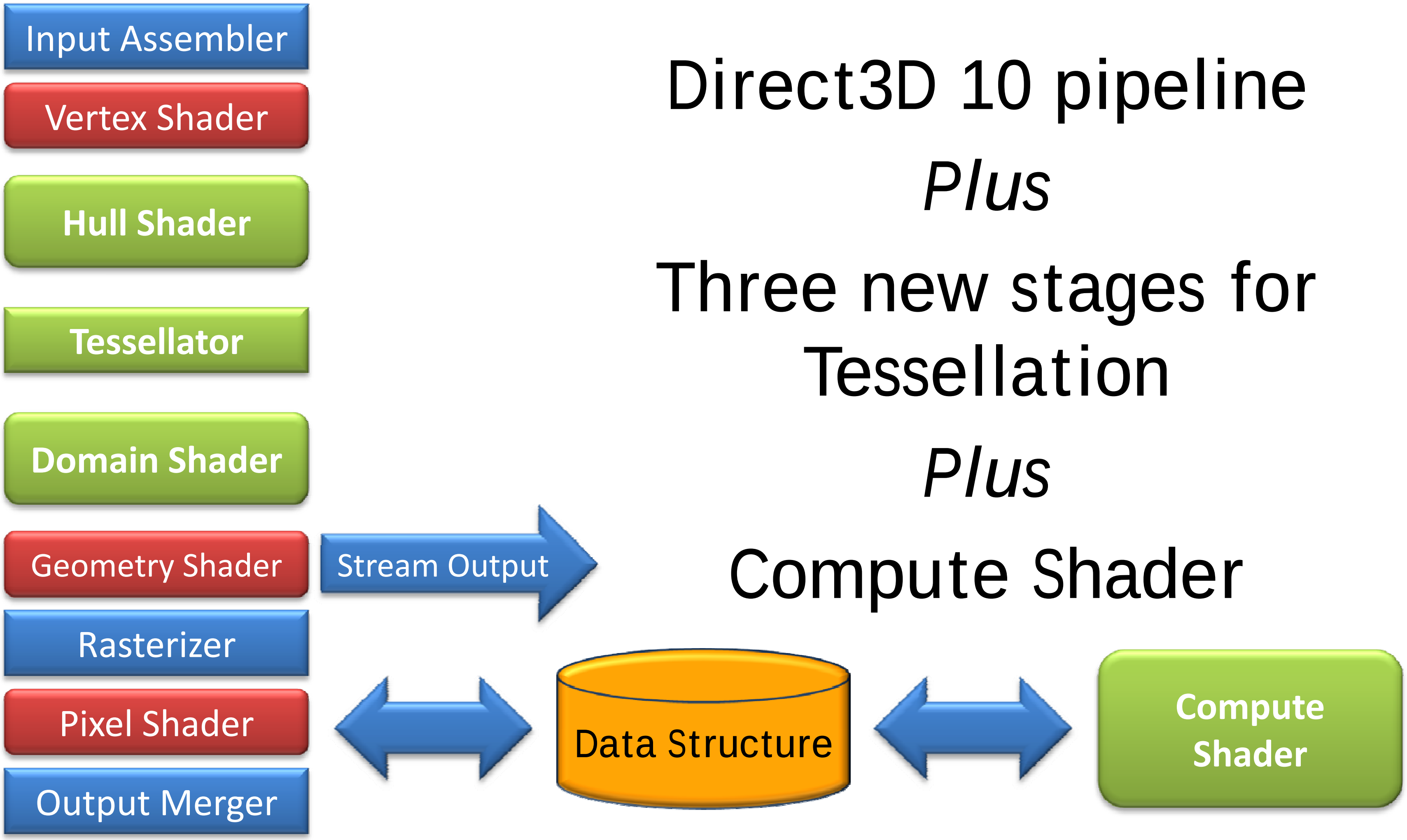
# GPGPU & Data Parallel Computing

- GPU performance continues to grow
- Many applications scale well to massive parallelism without tricky code changes
- Direct3D is the API for talking to GPU
- How do we expand Direct3D to *GP*GPU?

# Direct3D 11 Pipeline




Direct3D 10 pipeline

*Plus*

Three new stages for Tessellation

*Plus*

Compute Shader

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# Integration with Direct3D

- Fully supports all Direct3D resources
- Targets graphics/media data types
- Evolution of DirectX HLSL
- Graphics pipeline updated to emit general data structures...
- ...which can then be manipulated by compute shader...
- And then rendered by Direct3D again

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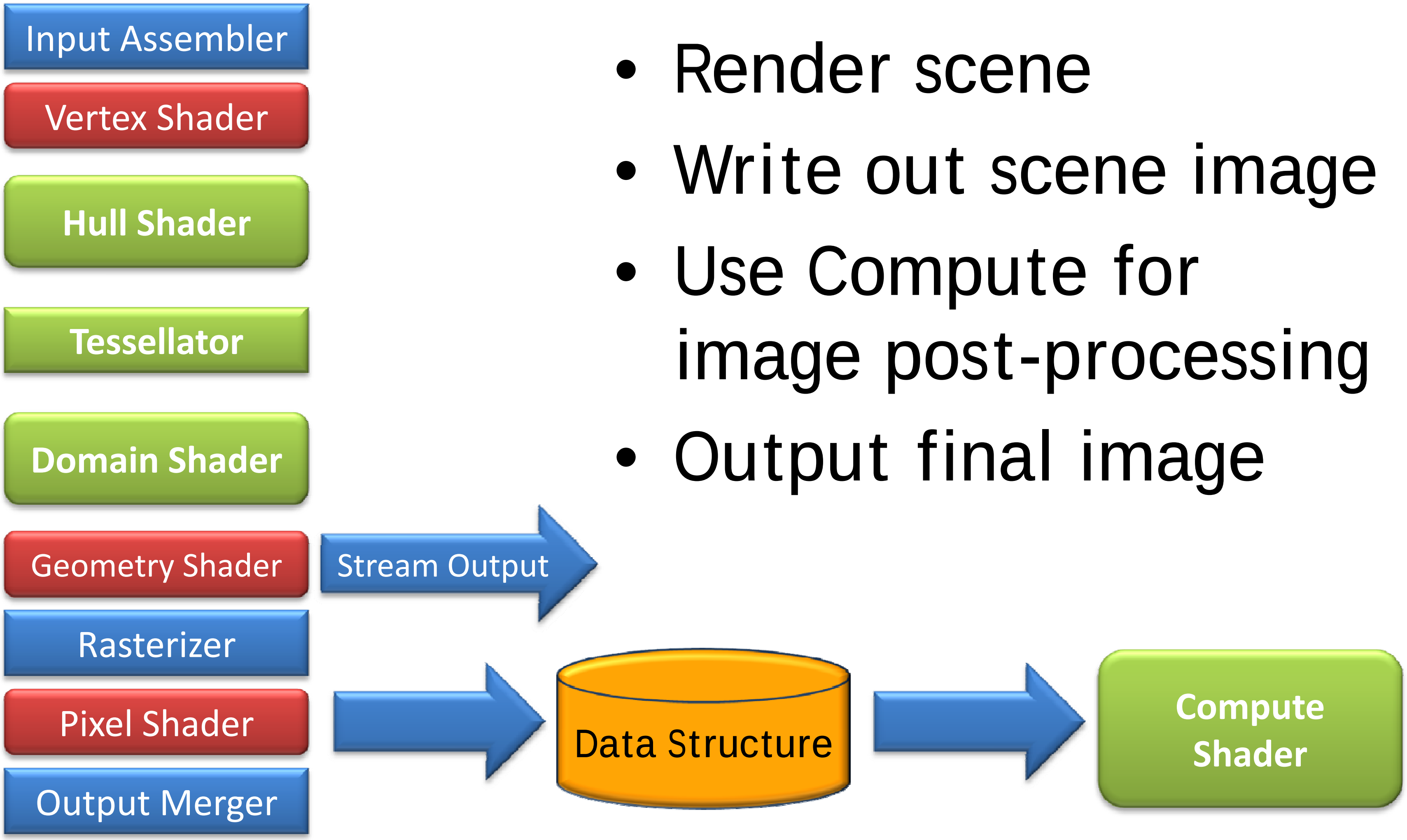
# Example Scenario

- Render scene
- Write out scene image
- Use Compute for image post-processing
- Output final image

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# Target Applications

- Image/Post processing:
  - Image Reduction
  - Image Histogram
  - Image Convolution
  - Image FFT
- A-Buffer/OIT
- Ray-tracing, radiosity, etc.
- Physics
- AI

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# Compute Shader: Summary

- Enables much more general algorithms
- Transparent parallel processing model
- Full cross-vendor support
  - Broadest possible installed base

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# D3D11 Multithreading Goals

- Asynchronous resource loading
  - Upload resources, create shaders, create state objects in parallel
  - Concurrent with rendering
- Multithreaded draw & state submission
  - Spread out render work across many threads
- Limited support for per-object display lists

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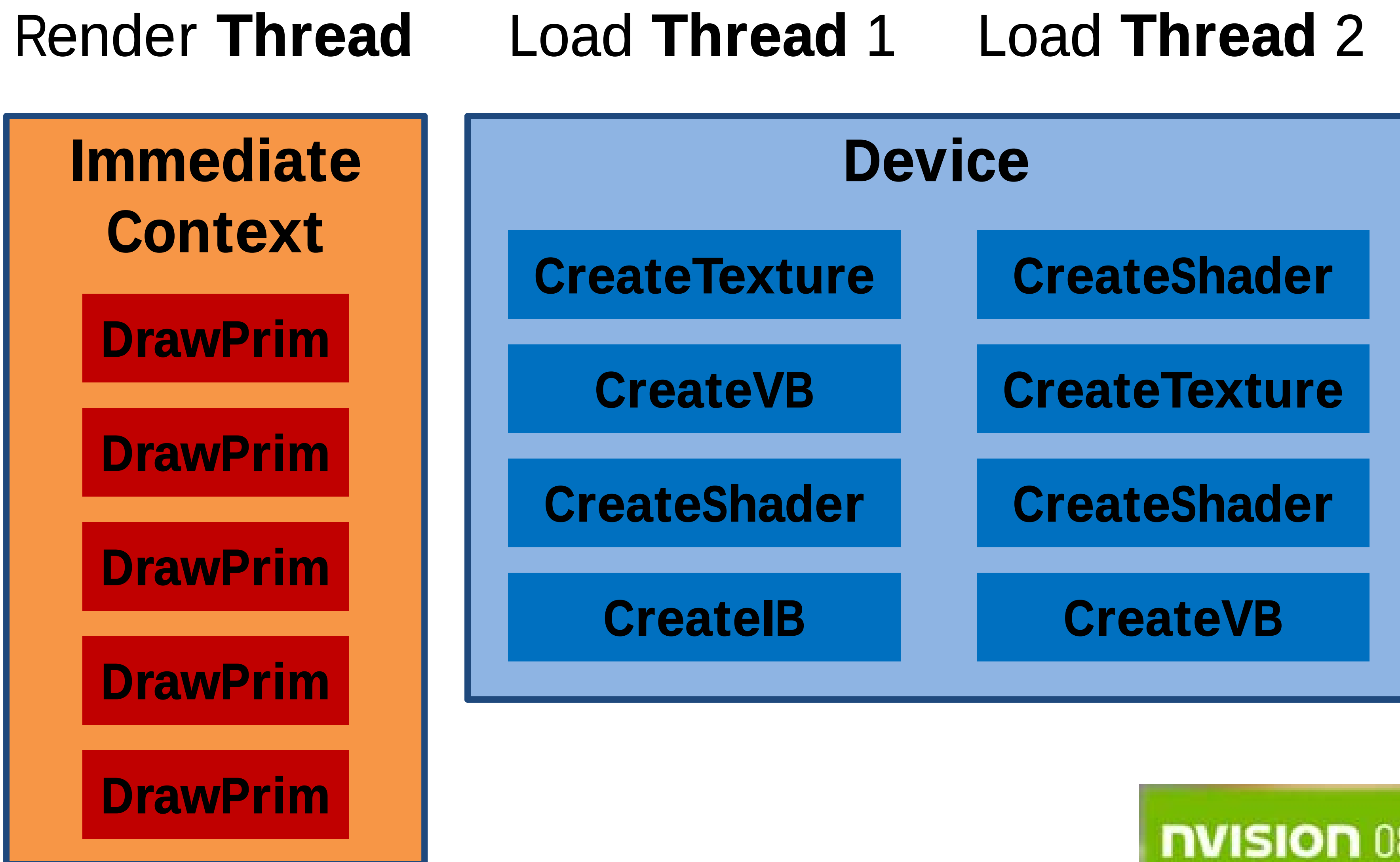
# Devices and Contexts

- D3D device functionality now split into three separate interfaces
- Device, Immediate Context, Deferred Context
  - Device has free threaded resource creation
  - Immediate Context is your single primary device for state, draws, and queries
  - Deferred Contexts are your per-thread devices for state & draws

# D3D11 Interfaces



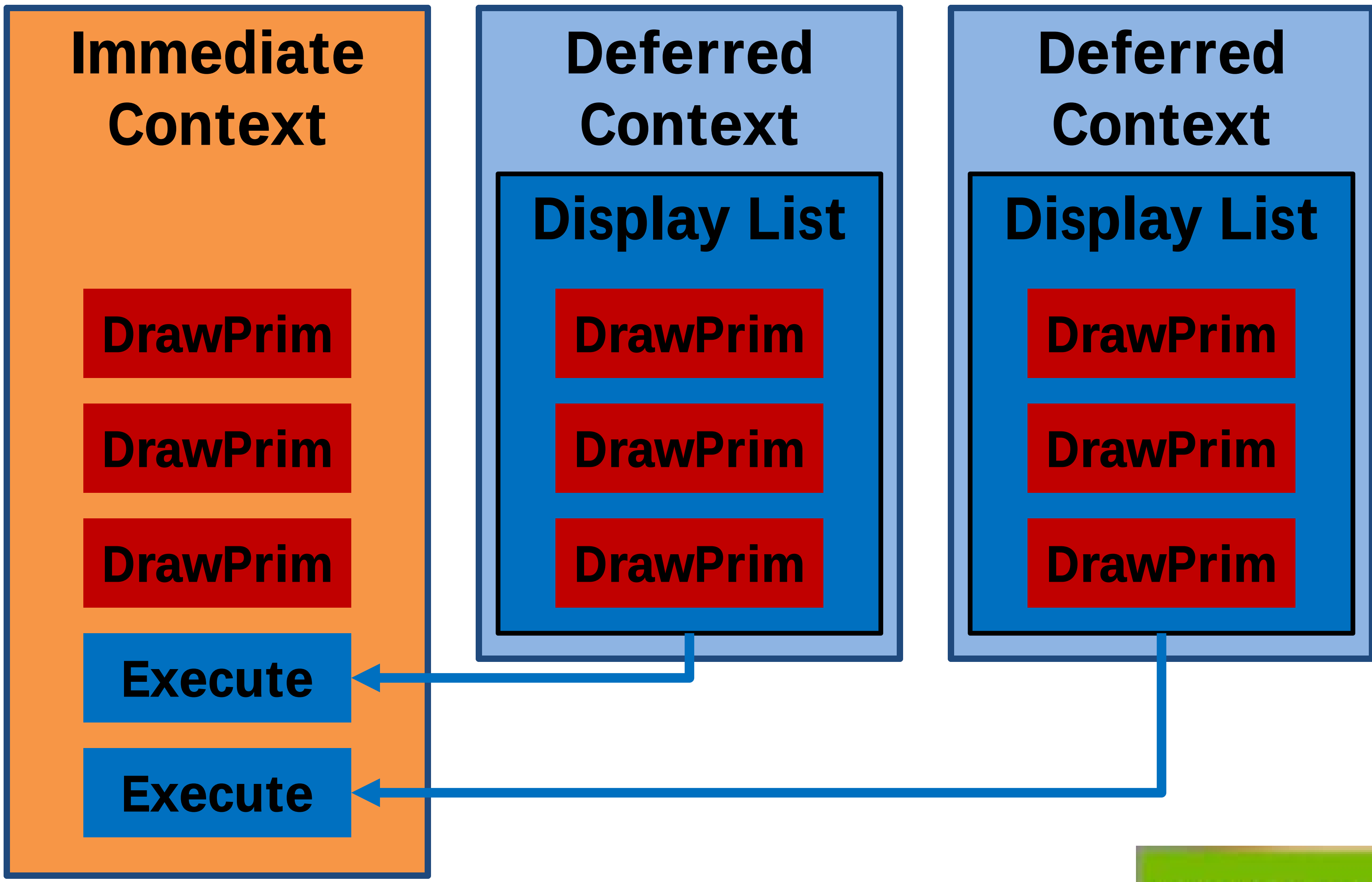
# Async Resources

- Use the Device interface for resource creation
- All functions are free threaded
  - Uses fine-grained sync primitives
- Resource upload and shader compilation can happen concurrently

# State & Draw Submission

- First priority: multithreaded submission
  - Single-use display lists
- Lower priority: per-object display lists
  - Multiple reuse
- D3D11 display lists are immutable

# D3D11 Interfaces

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# Deferred Contexts

- Can create many deferred contexts
  - Each one is single threaded (thread unsafe)
- Deferred context generates a Display List
  - Display List is consumed by Immediate or Deferred contexts
- No read-backs or downloads from the GPU
  - Queries
  - Resource locking
- Lock with DISCARD is supported on deferred contexts

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# D3D11 on D3D10 H/W

- Deferred contexts are implemented at an API-capture level
- Async resource creation uses coarse sync primitives
  - No longer free threaded; thread safe though
- D3D10 drivers can be updated to better support D3D11 features
- Will work on Windows Vista as well as future Windows releases

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# Shader Issues Today

- Shaders getting bigger, more complex
- Shaders need to target wide range of hardware
- Optimization of different shader configurations drives shader specialization

# Options: Über-shader

- Über-shader

```
foo (...) {
    if (m == 1) {
        // do material 1
    } else if (m == 2) {
        // do material 2
    }
    if (l == 1) {
        // do light model 1
    } else if (l == 2) {
        // do light model 2
    }
}
```

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# Options: Über-shader

"One Shader to Rule them All"

- Good:
  - All functionality in one place
  - Reduces state changes at runtime
  - One compile step
  - Seems to be most popular coding method
- Bad:
  - Complex, unorganized shaders
  - Register usage is always worst case path

# Options: Specialization

Multiple specialized shaders for each combination of settings

- Good:
  - Always optimal register usage
  - Easier to target optimizations
- Bad:
  - Huge number of resulting shaders
  - Pain to manage at runtime

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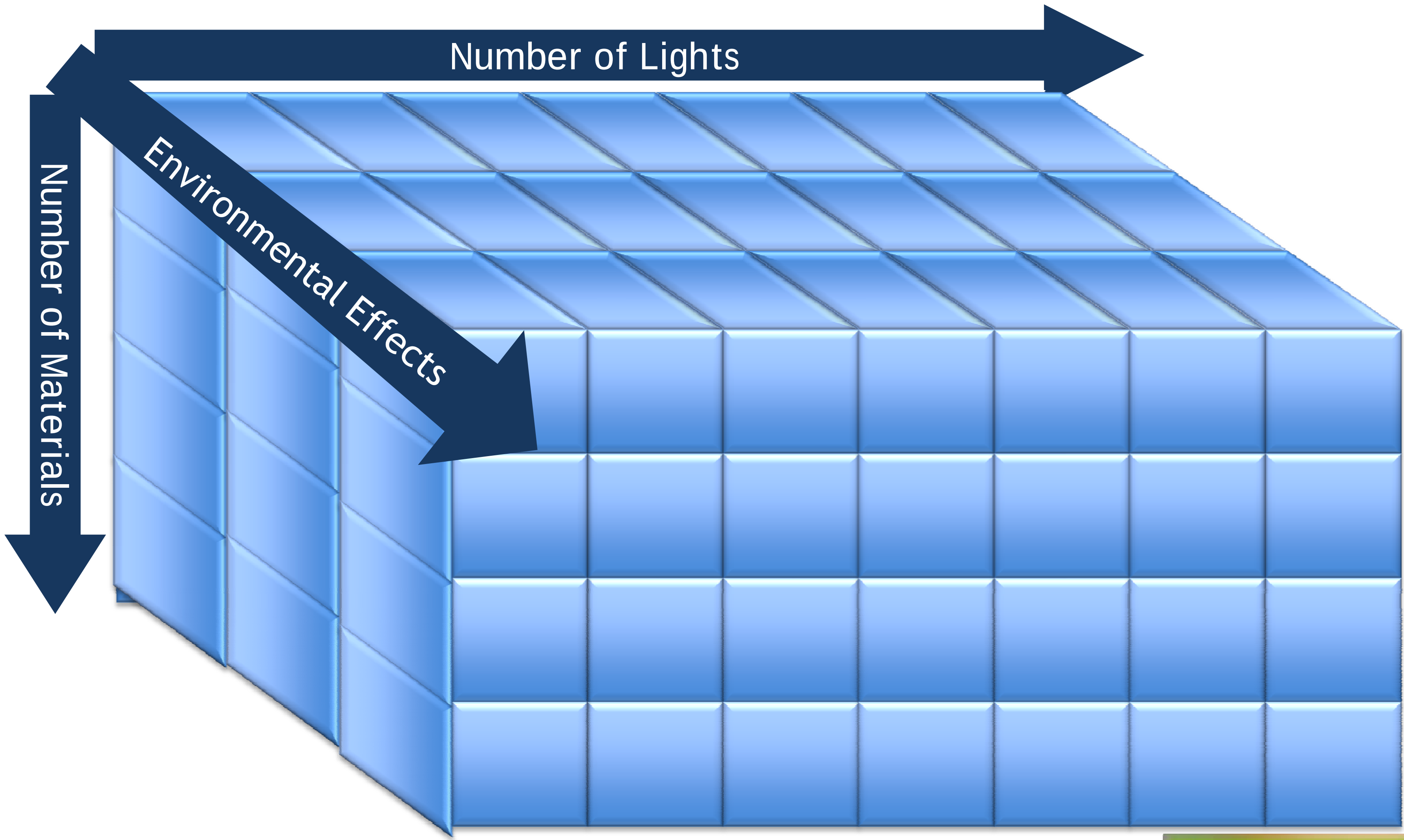
# Combinatorial Explosion

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# Solution: Dynamic Shader Linkage & OOP

- Introducing new OOP features to HLSL
  - Interfaces
  - Classes
- Can be used for static code
- Also used as the mechanism for linking specific functionality at runtime

# Interfaces

```
interface Light
{
      float3 GetDirection(float3 eye);

      float3 GetColor();
};
```

# Classes

```
class DirectionalLight : Light
{
      float3 GetDirection(float3 eye)
      {
            return m_direction;
      }

      float3 GetColor()
      {
            return m_color;
      }

      float3 m_direction;
      float3 m_color;
};
```

# Dynamic Shader Linkage

- Über-shader

```
foo (...) {
    if (m == 1) {
        // do material 1
    } else if (m == 2) {
        // do material 2
    }
    if (l == 1) {
        // do light model 1
    } else if (l == 2) {
        // do light model 2
    }
}
```

- Dynamic Subroutine

```
Material1(...) { ... }
Material2(...) { ... }
Light1(...) { ... }
Light2(...) { ... }

foo(...) {
    myMaterial.Evaluate(...);
    myLight.Evaluate(...);
}
```

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# In the Runtime

- Select specific class instances you want
- Runtime will inline class methods
  - Equivalent register usage to a specialized shader
- Inlining is done in the native assembly
  - Fast operation
- Applies to all subsequent Draw(...) calls

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# Why New Texture Formats?

- Existing block palette interpolations too simple
- Results often rife with blocking artifacts
- No high dynamic range (HDR) support
- NB: All are issues we heard from developers

# Two New BC's for Direct3D11

- BC6 (aka BC6H)
  - High dynamic range
  - 6:1 compression (16 bpc RGB)
  - Targeting high (not lossless) visual quality
- BC7
  - LDR with alpha
  - 3:1 compression for RGB or 4:1 for RGBA
  - High visual quality

# New BC's: Compression

- Block compression (unchanged)
  - Each block independent
  - Fixed compression ratios
- Multiple block types (new)
  - Tailored to different types of content
  - Smooth gradients vs. noisy normal maps
  - Varied alpha vs. constant alpha

| |
|---|
| Also new: decompression results must be bit-accurate with spec |

# Multiple Block Types

- Different numbers of color interpolation lines
  - Less variance in one block means:
    - 1 color line
    - Higher-precision endpoints
  - More variance in one block means:
    - 2 (BC6 & 7) or 3 (BC7 only) color lines
    - Lower-precision endpoints and interpolation bits
- Different numbers of index bits
  - 2 or 3 bits to express position on color line
- Alpha
  - Some blocks have implied 1.0 alpha
  - Others encode alpha

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# Partitions

- When using multiple color lines, each pixel needs to be associated with a color line
  - Individual bits to choose is expensive
- For a 4x4 block with 2 color lines
  - $2^{16}$ possible partition patterns
  - 16 to 64 well-chosen partition patterns give a good approximation of the full set
  - BC6H: 32 partitions
  - BC7: 64 partitions, shares first 32 with BC6H

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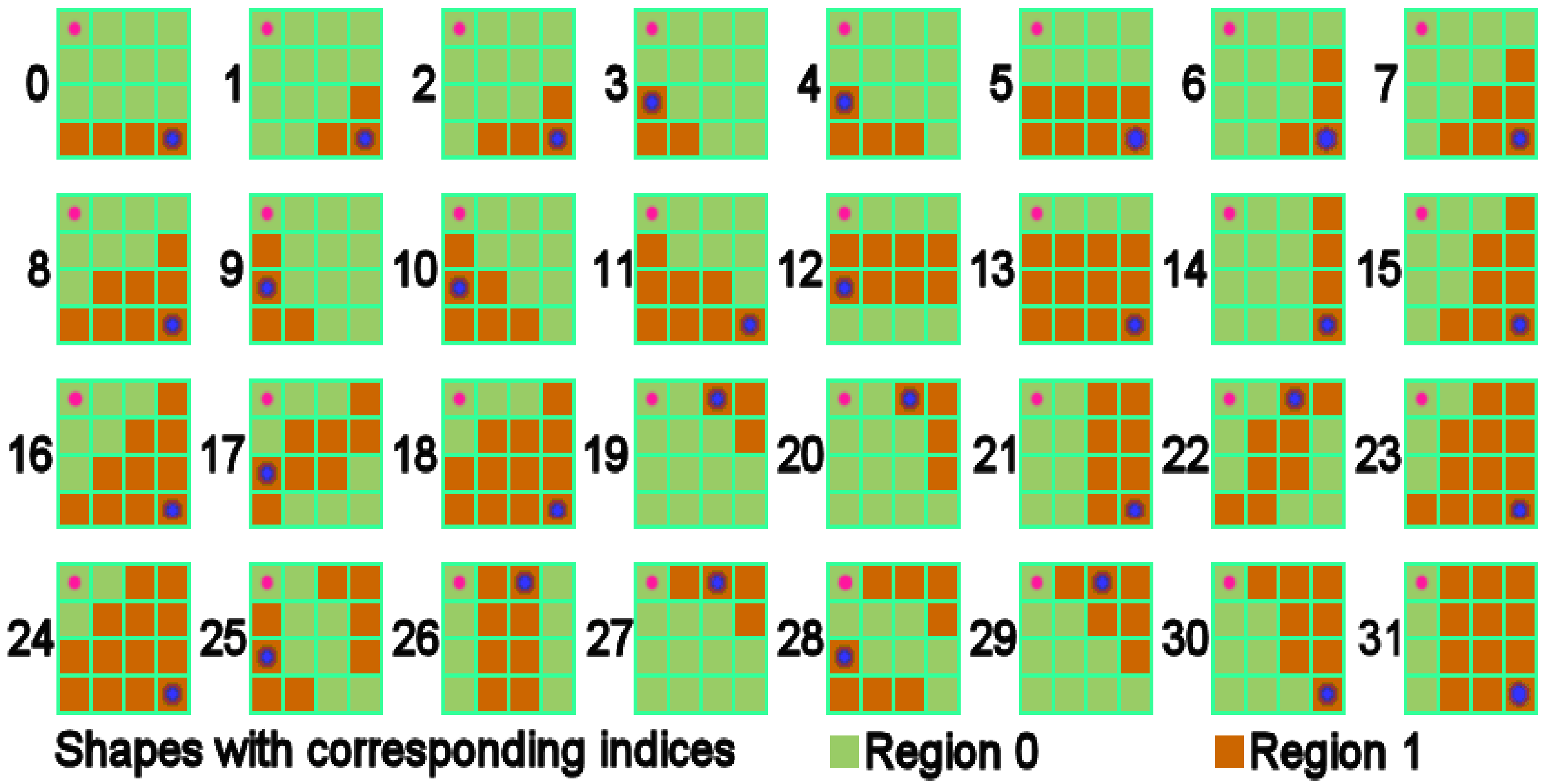
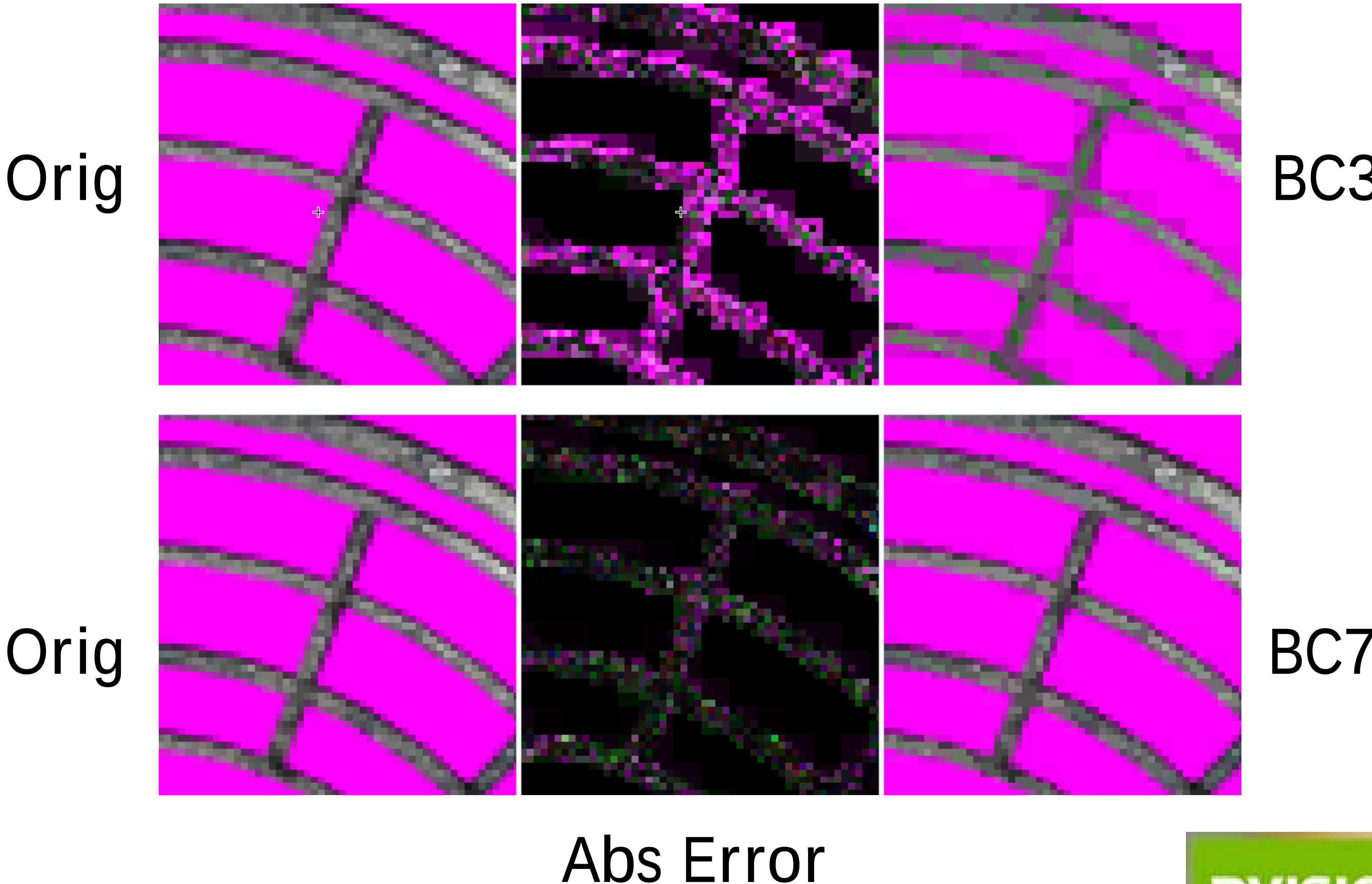
# Example Partition Table

A 32-partition table for 2 color lines



# Comparisons



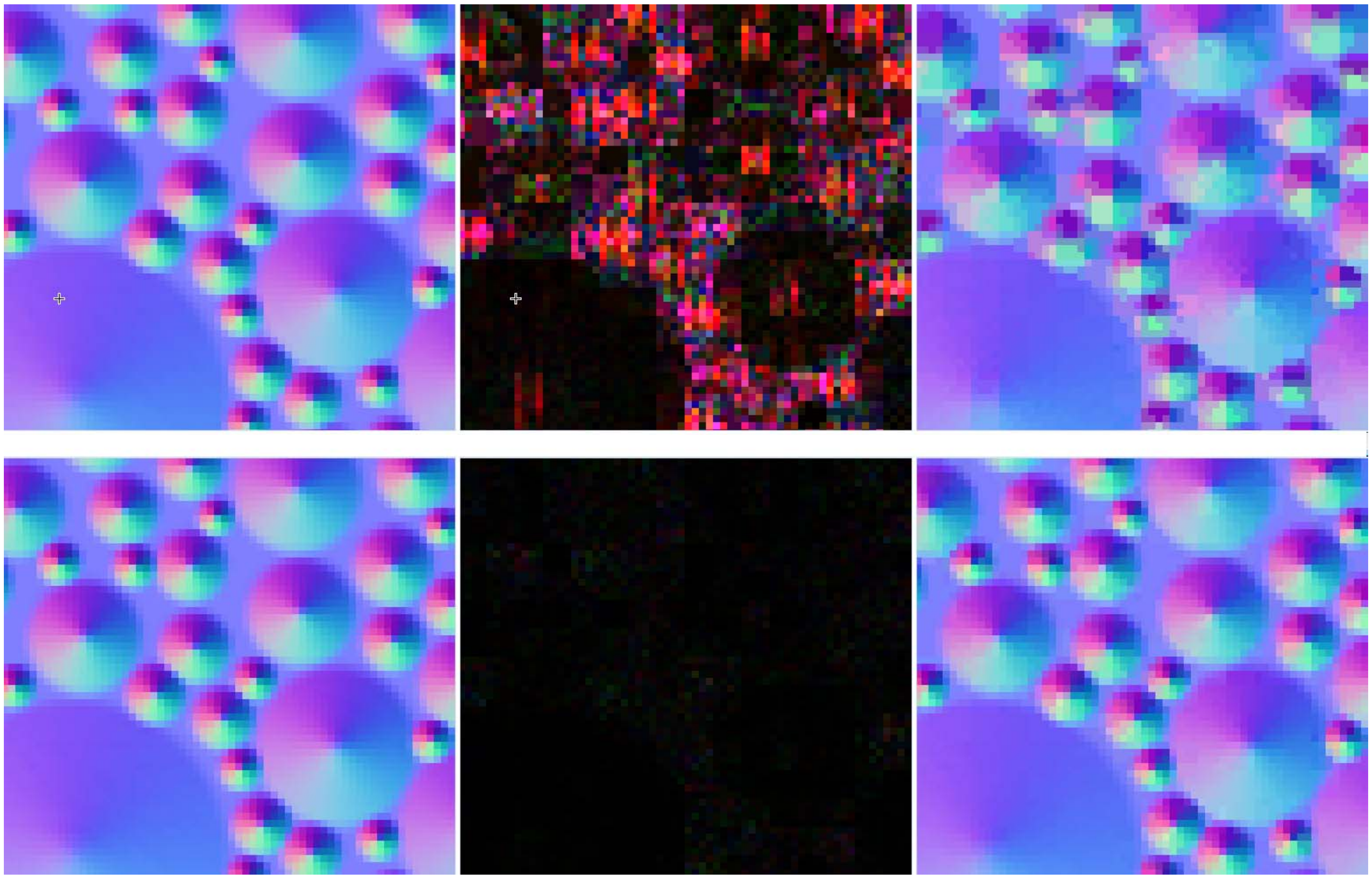
# Comparisons

Orig

BC3

Orig

BC7



Abs Error

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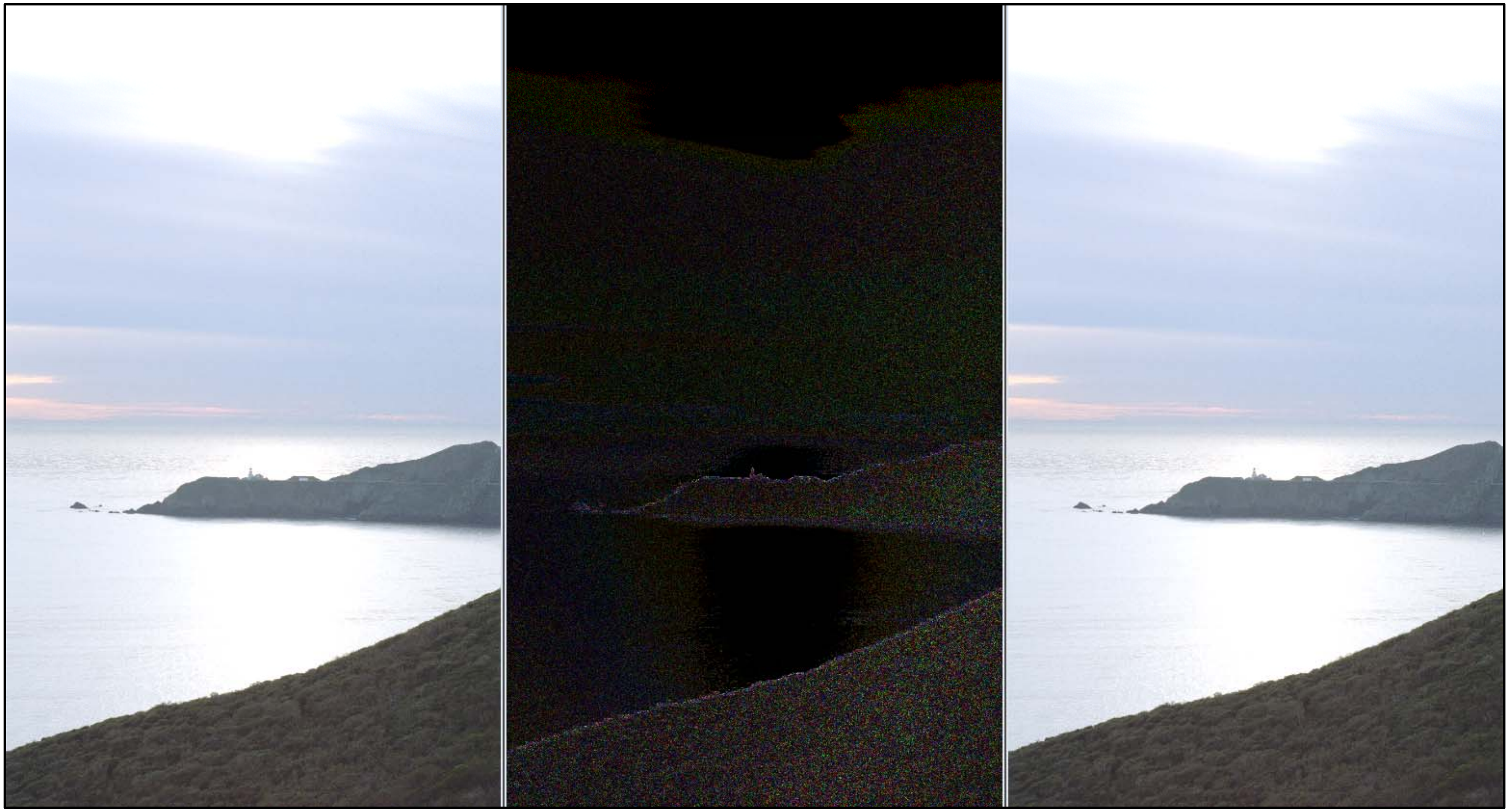
# Comparisons



HDR Original at given exposure | Abs Error | BC6 at given exposure

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# Lots of Other Features

- Addressable Stream Out
- Draw Indirect
- Pull-model attribute eval
- Improved Gather4
- Min-LOD texture clamps
- 16K texture limits
- Required 8-bit subtexel, submip filtering precision
- Conservative oDepth
- 2 GB Resources
- Geometry shader instance programming model
- Optional double support
- Read-only depth or stencil views

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# Questions?

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