SIGGRAPH2011

Per-Face Texture Mapping for Realtime Rendering

“Realtime Ptex”

Quick Note

- For CUDA/Compute folks:
  - Ptex != PTX

Goals

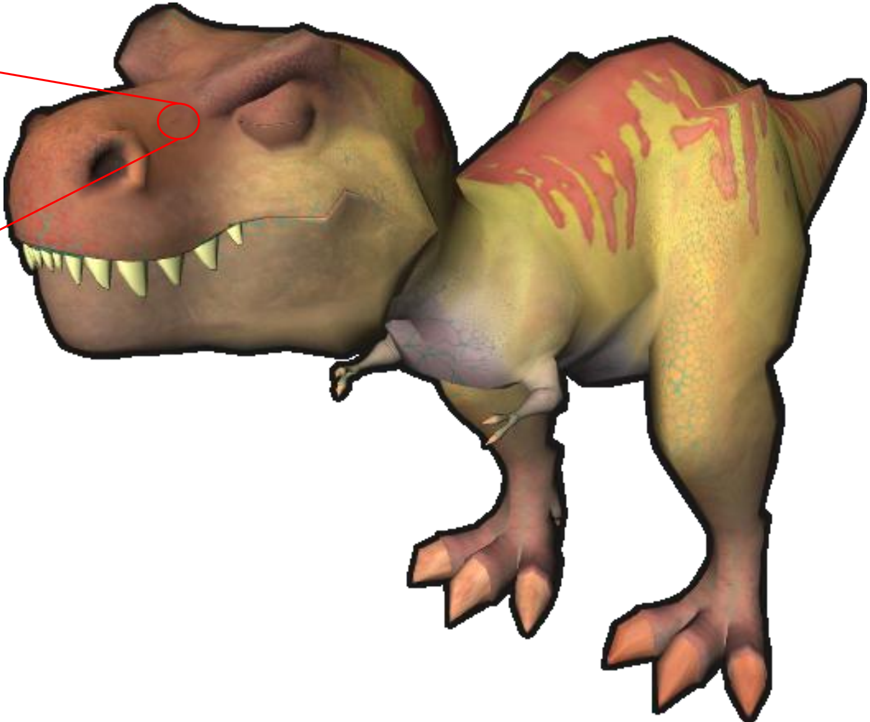
- Render native Ptex datasets in real-time on commodity hardware
- Remove texture seams from textured models
- Remove expensive, manual model unwrap step from art pipeline
- Support arbitrary resolutions on a per-face basis

Video Time!

Video Recap

Stored as 8Kx8K

Rendered as 2Kx2K



Model Statistics

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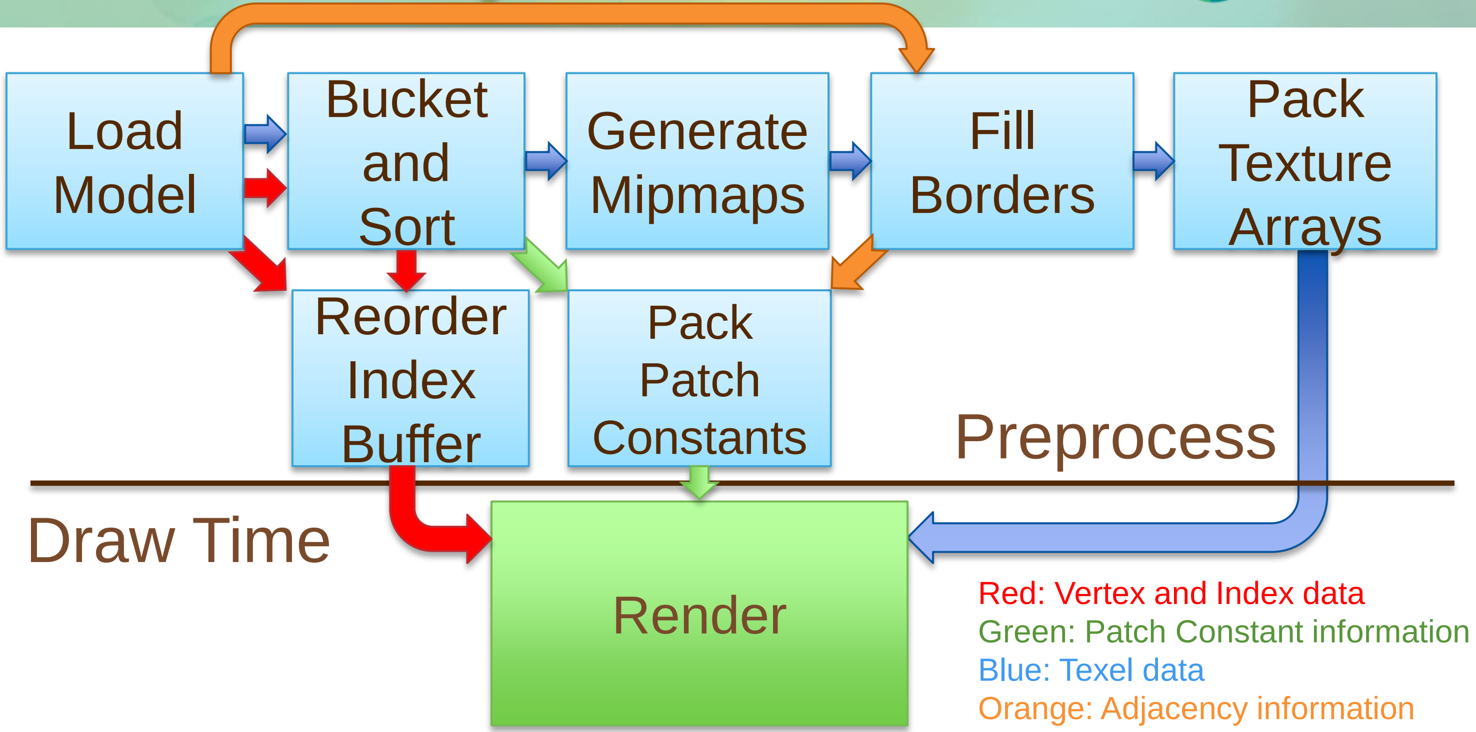
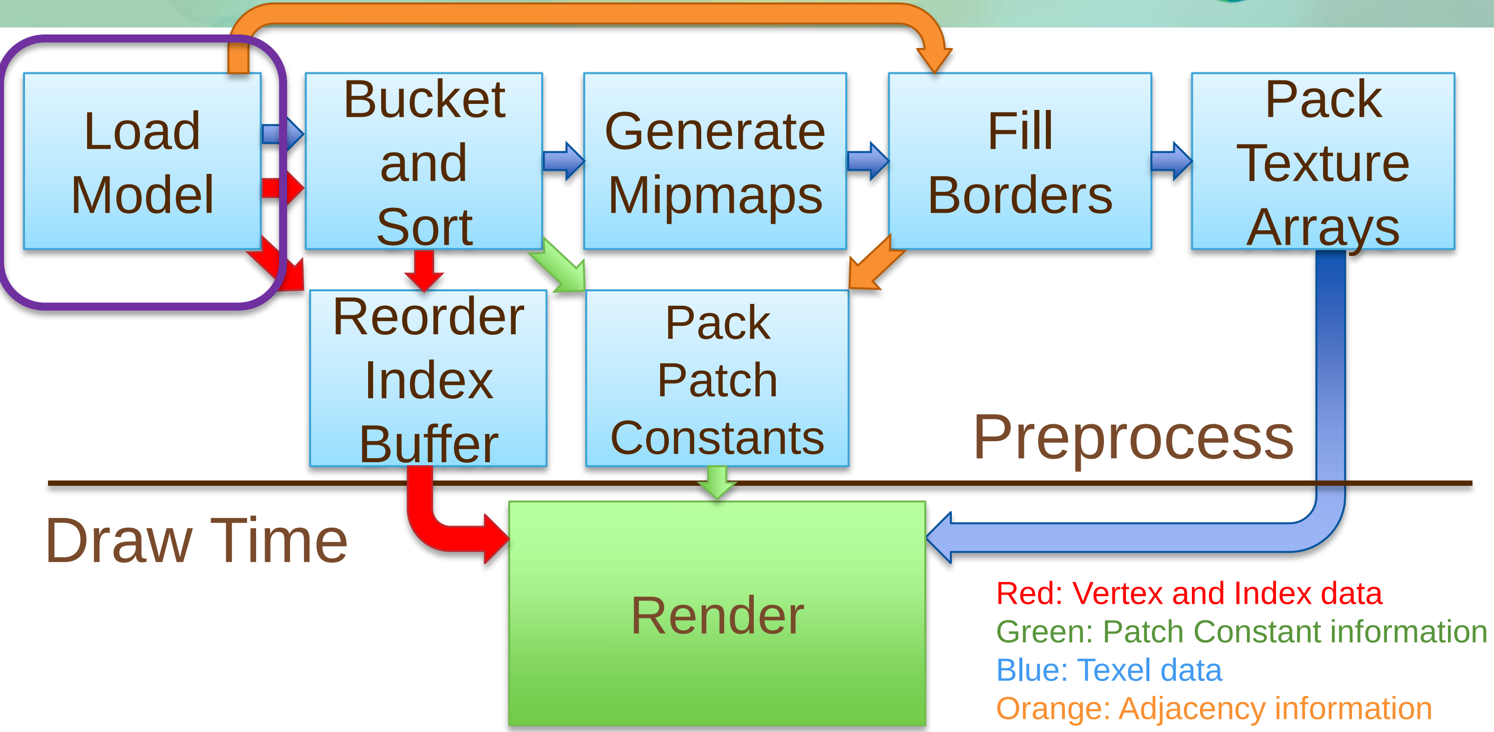
- ~800 FPS on GTX 460 with no optimization
- 278M of Color Texture Data
- 5812 Patches

General Steps



Load Model



Load Model
Bucket and Sort
Generate Mipmaps
Fill Borders
Pack Texture Arrays
Reorder Index Buffer
Pack Patch Constants
Preprocess
Draw Time
Render
Red: Vertex and Index data
Green: Patch Constant information
Blue: Texel data
Orange: Adjacency information

Load Model

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- Vertex Data
  - Any geometry arranged as a quad-based mesh
  - Example: Wavefront OBJ
- Patch Texture
  - Power-of-two texture images
- Adjacency Information
  - 4 Neighbors of each quad patch
- Easily load with library available from http://ptex.us/

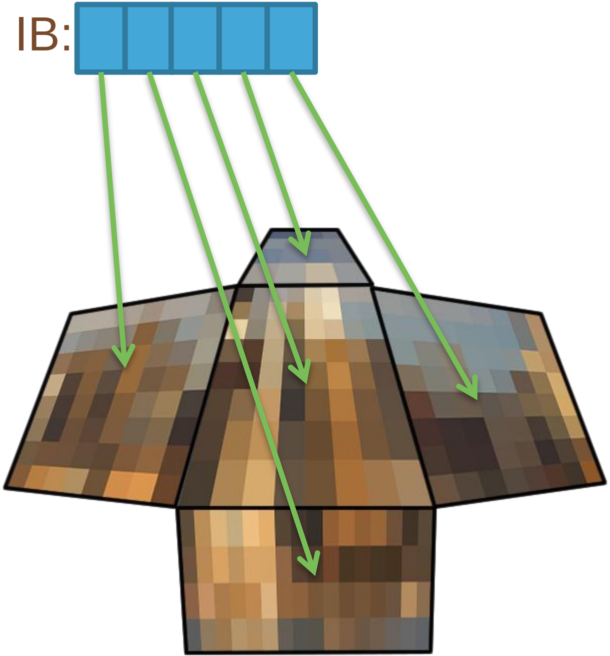
Load Model (cont'd)

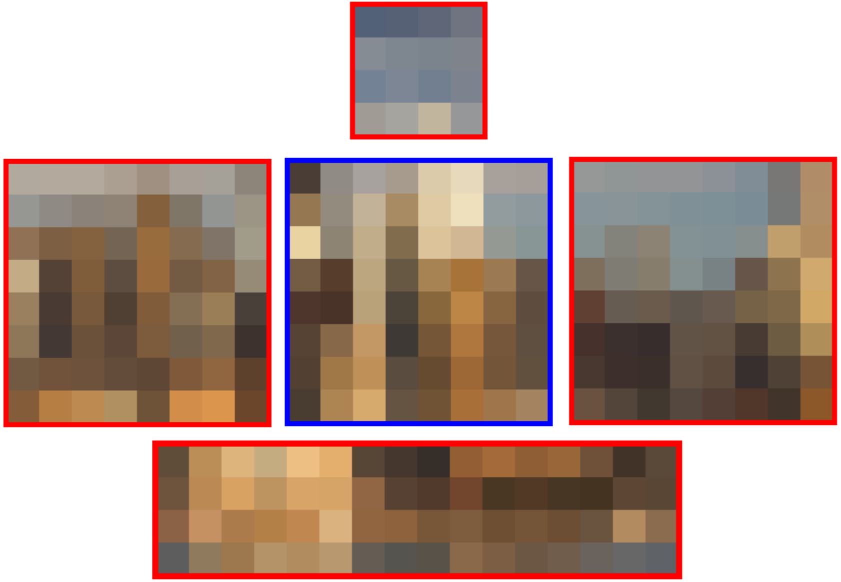
- Texel Data
  - Per face, load the largest available mipmap level from the source files
  - In memory, place the loaded texel data into a memory buffer that has a fixed-size texel border region
  - The borders must be big enough for the largest filter kernel you will support (Border size = ½ filter kernel size)
    - Bilinear (2x2 kernel): 1 pixel border
    - 16x Aniso (16x16 kernel): 8 pixel border

Load Model

VB: ...

IB:

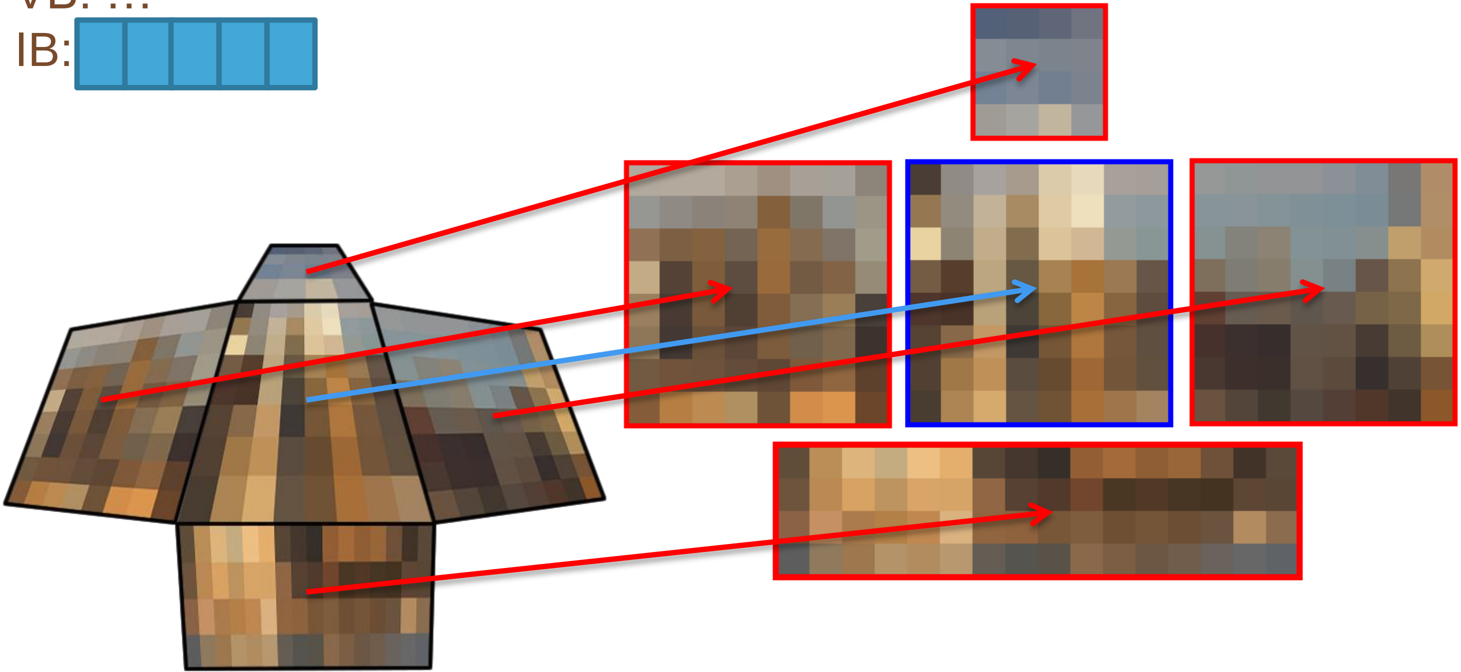




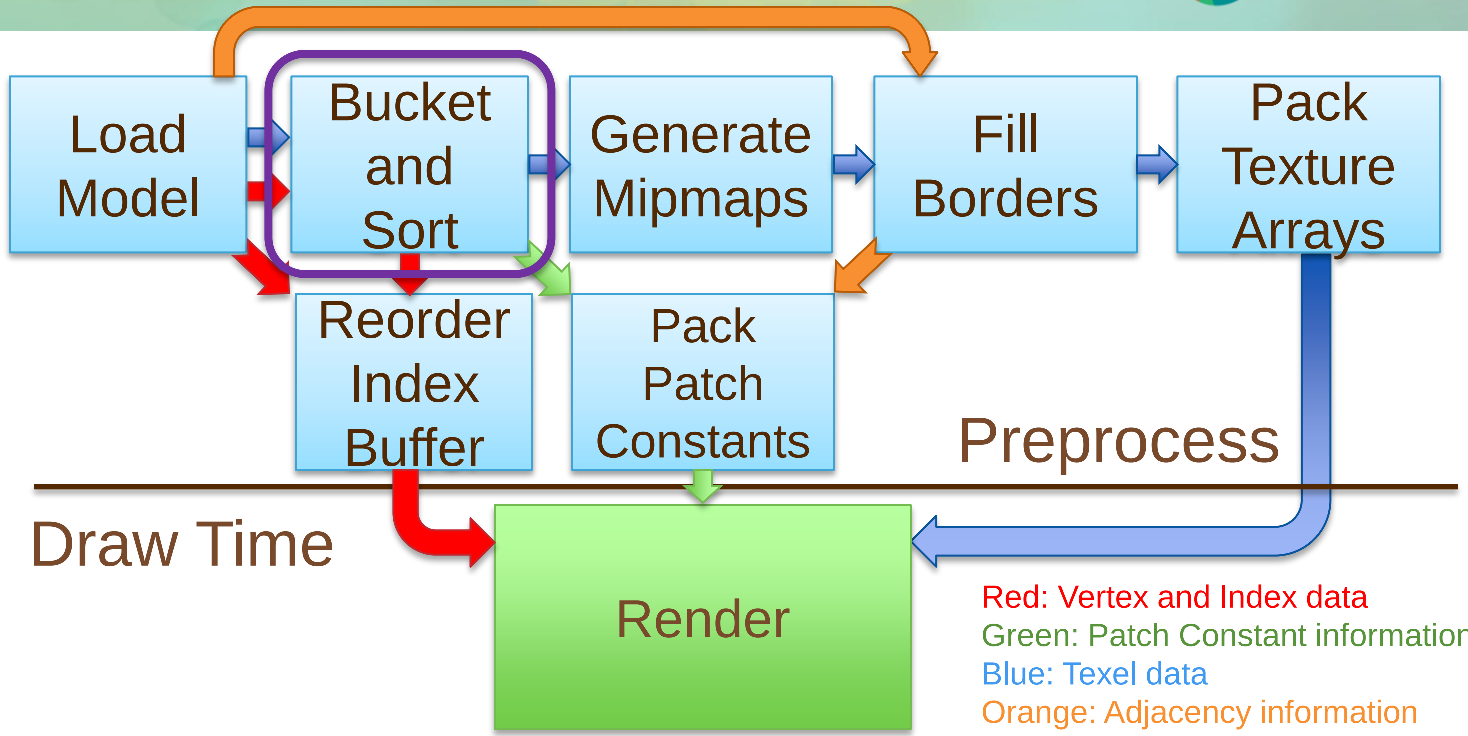
Load Model

VB: …

IB:



Bucket and Sort



Red: Vertex and Index data
Green: Patch Constant information
Blue: Texel data
Orange: Adjacency information

Bucket and Sort

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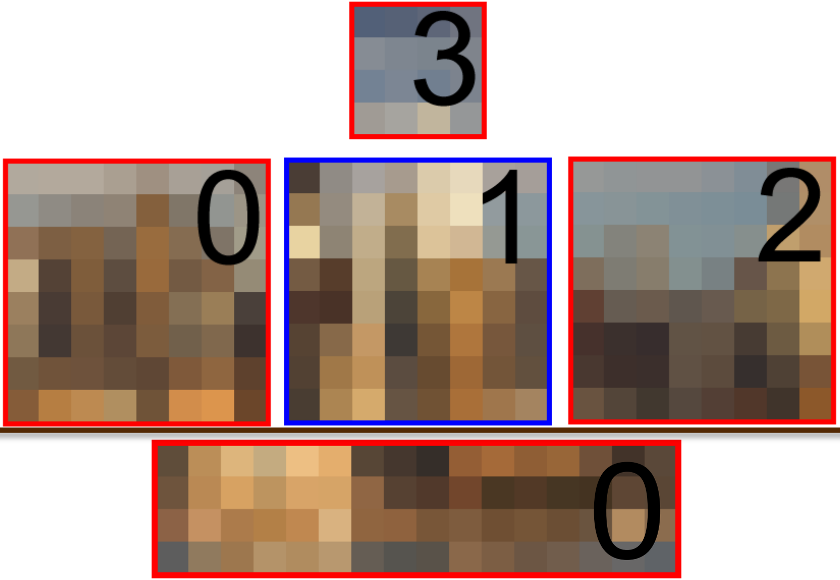
- Bucket ptex surfaces into groups by Aspect Ratio
  - Each Aspect Ratio will be one bucket
  - 1:1 bucket, 2:1 bucket, 4:1 bucket, etc
- Then, within each bucket, sort by decreasing surface size and assign IDs.
  - This allows us to densely pack texture arrays, avoiding “empty” surfaces.

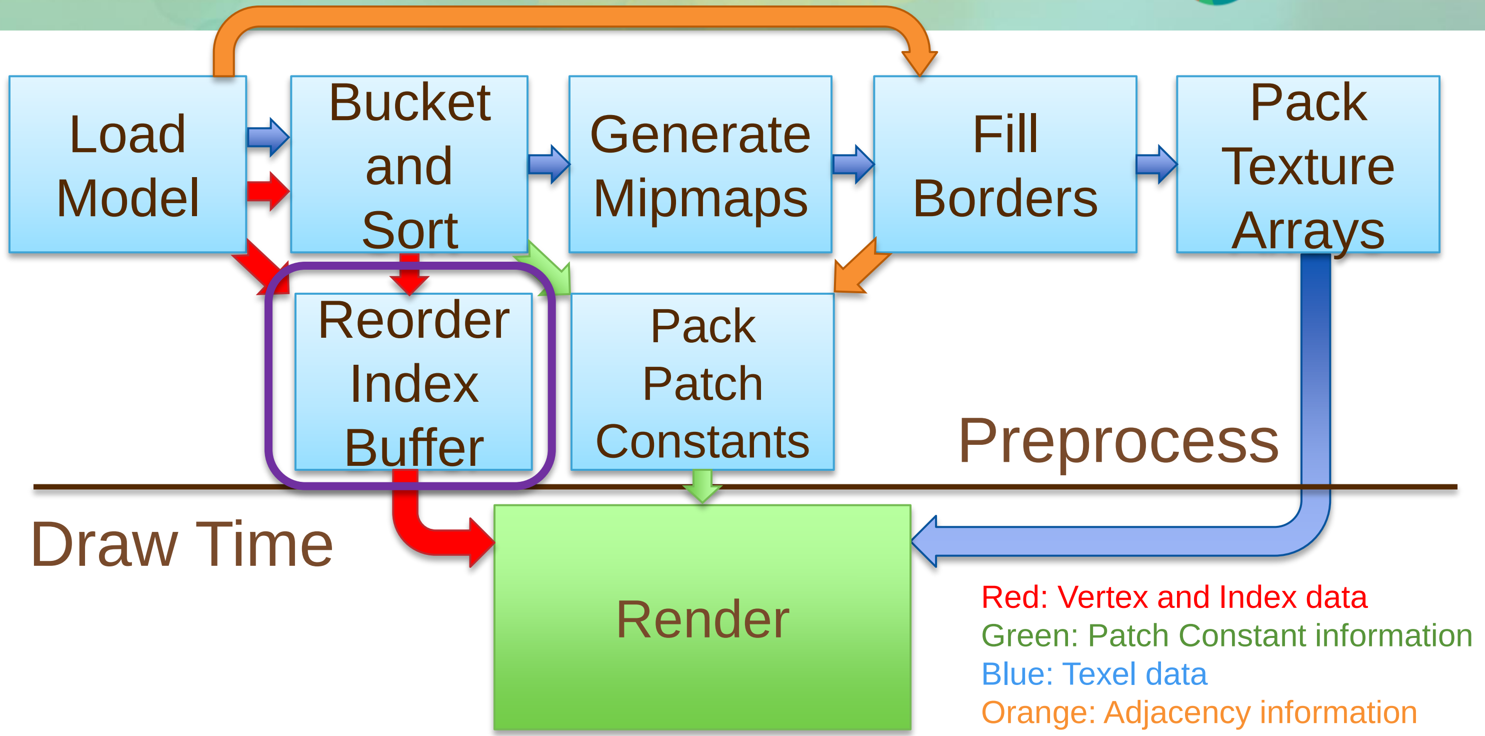
Bucket and Sort



Bucket 1:1

Bucket 4:1

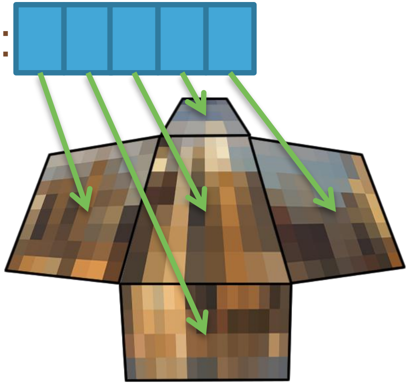
Reorder Index Buffer



Reorder Index Buffer

- Original

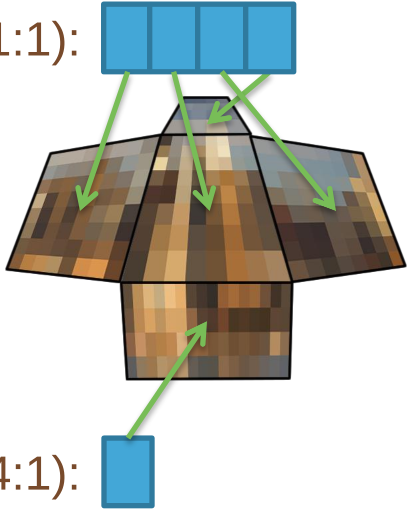
IB:



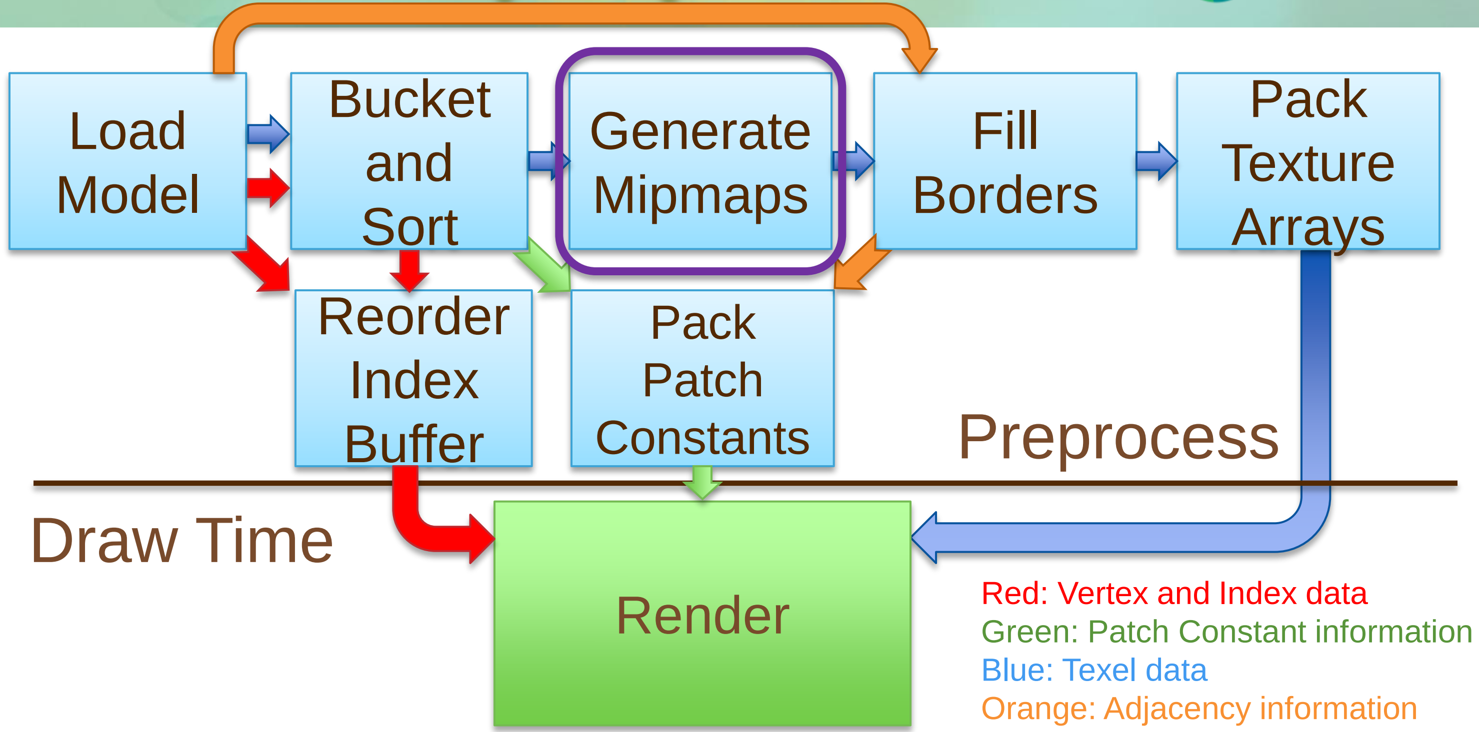
- Post Sort, we have 2!

IB(1:1):

IB(4:1):



Generate Mipmaps



Generate Mipmaps

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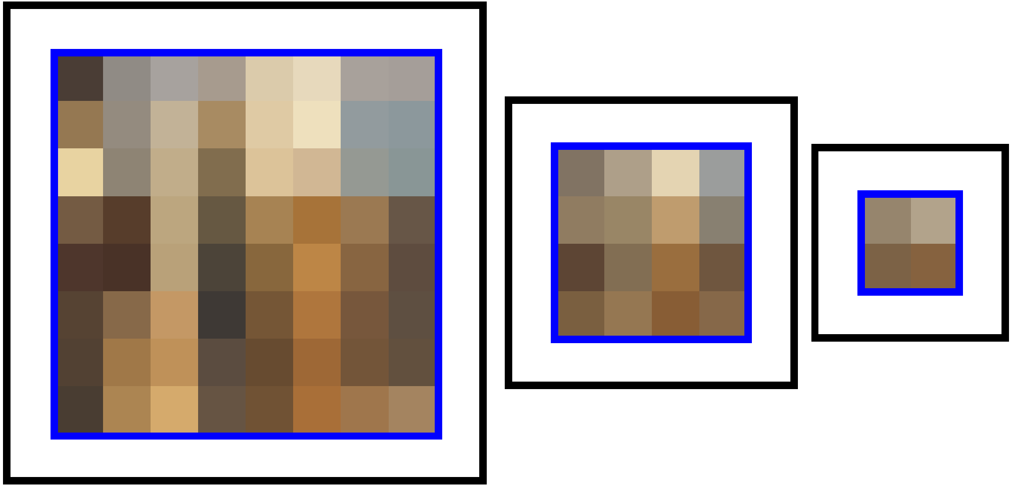
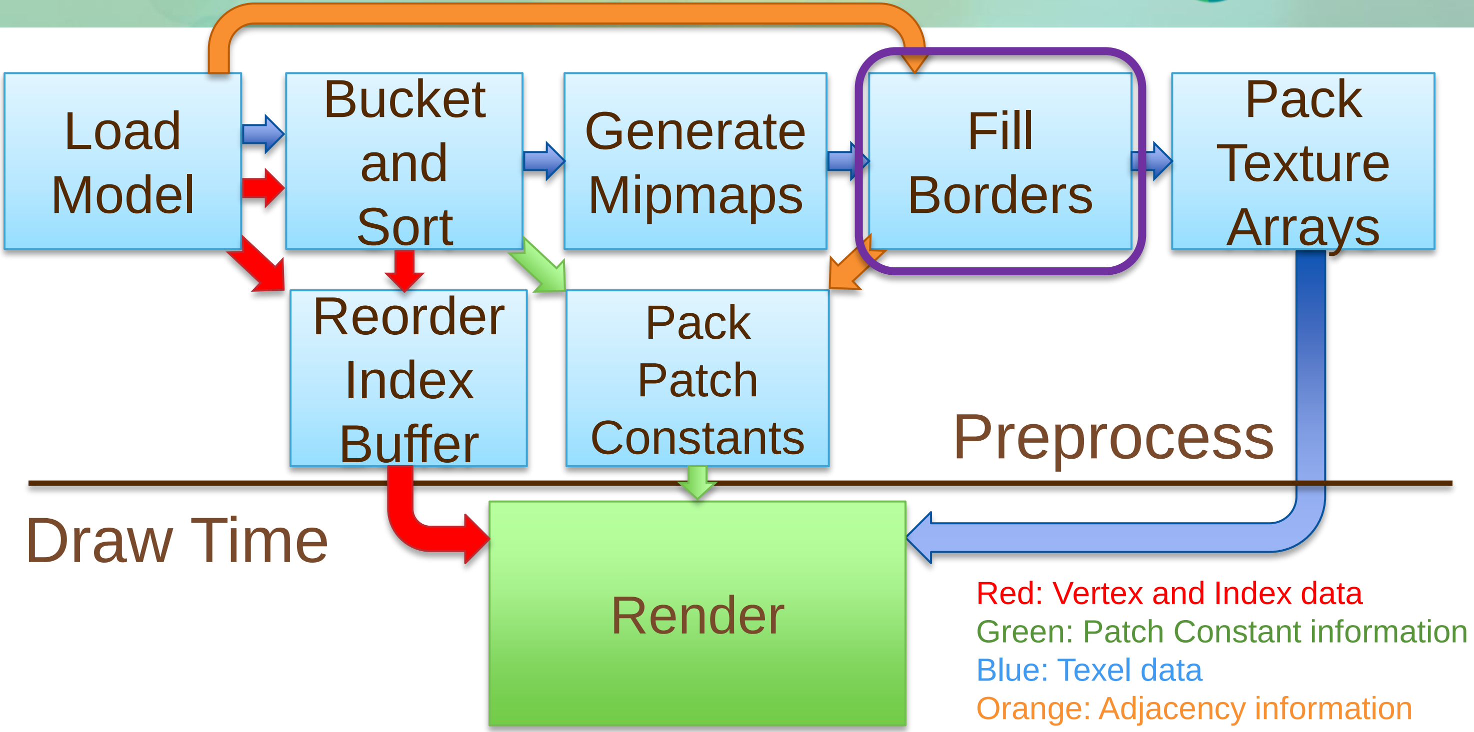
- Walk through surfaces, and generate a mipmap chain from native size to (MinFilterSize x MinFilterSize) for each surface.
  - Bilinear stops at 2x2, 8xAniso stops at 8x8
- Ptex data files do not guarantee complete mipmap chains—although the library can generate all levels for you—with pre-multiplied alpha.
- Mipmap chains stop to allow for unique pinning values in the corners

Generate Mipmaps

- Done for every surface, but only inside the surface—the border is not touched.



Fill Borders



Fill Borders

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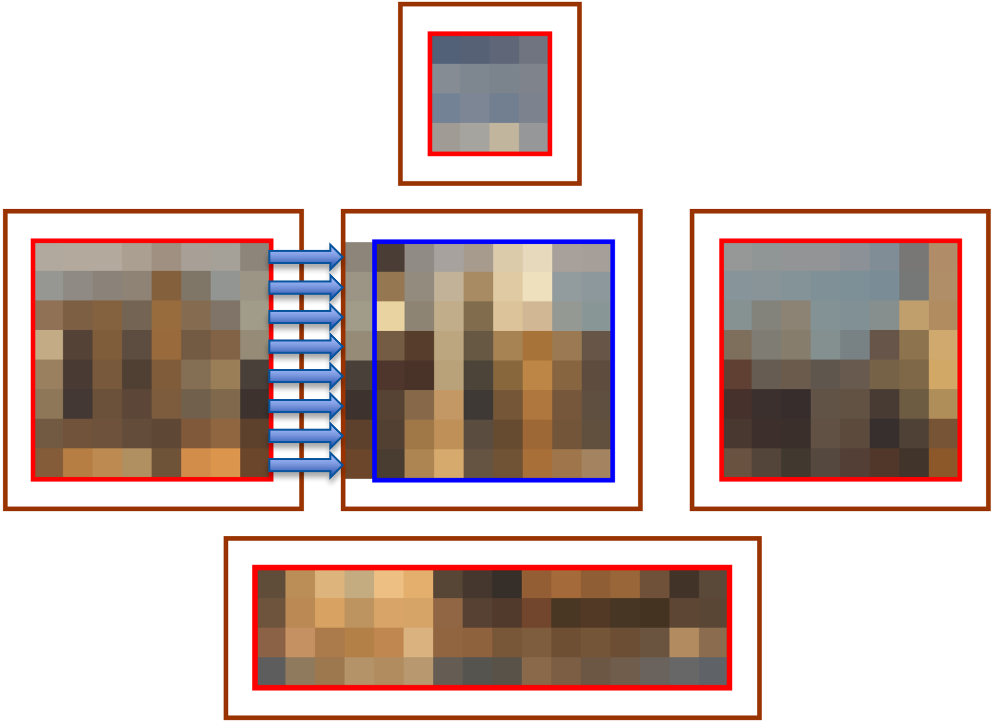
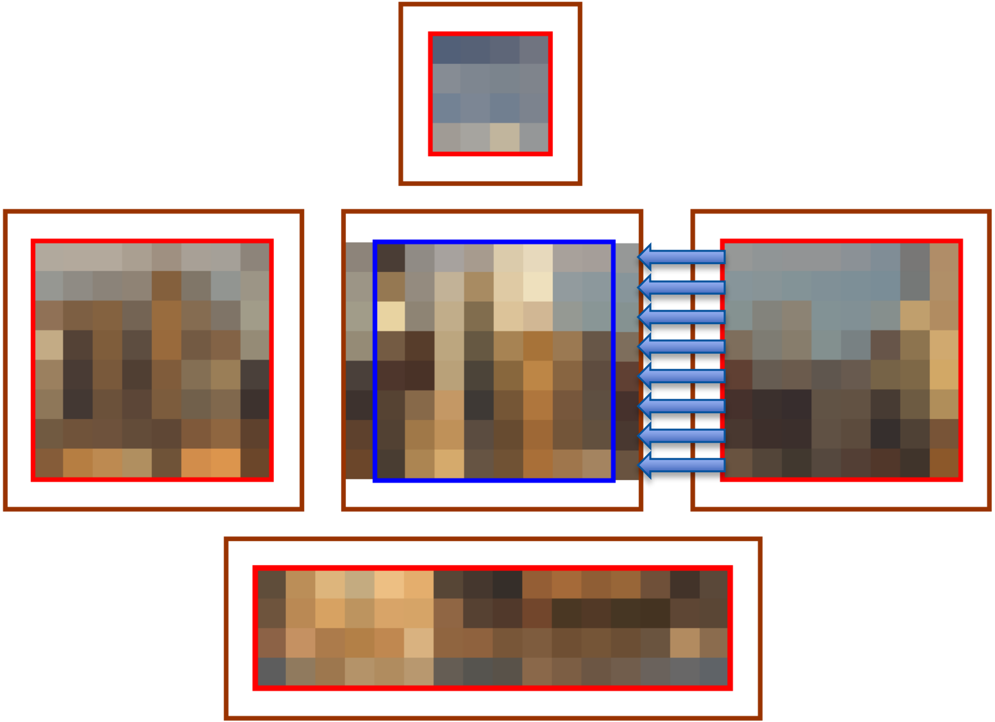
- Copy neighbor texels into border area of this surface's mip level
  - Match source and destination number of pixels when possible
- Bordered textures are the heart of the logical realtime ptex solution
- Allows 1-2 texture lookups per ptex sample request
  - 1 if not performing tween-mip-level interpolation, 2 otherwise

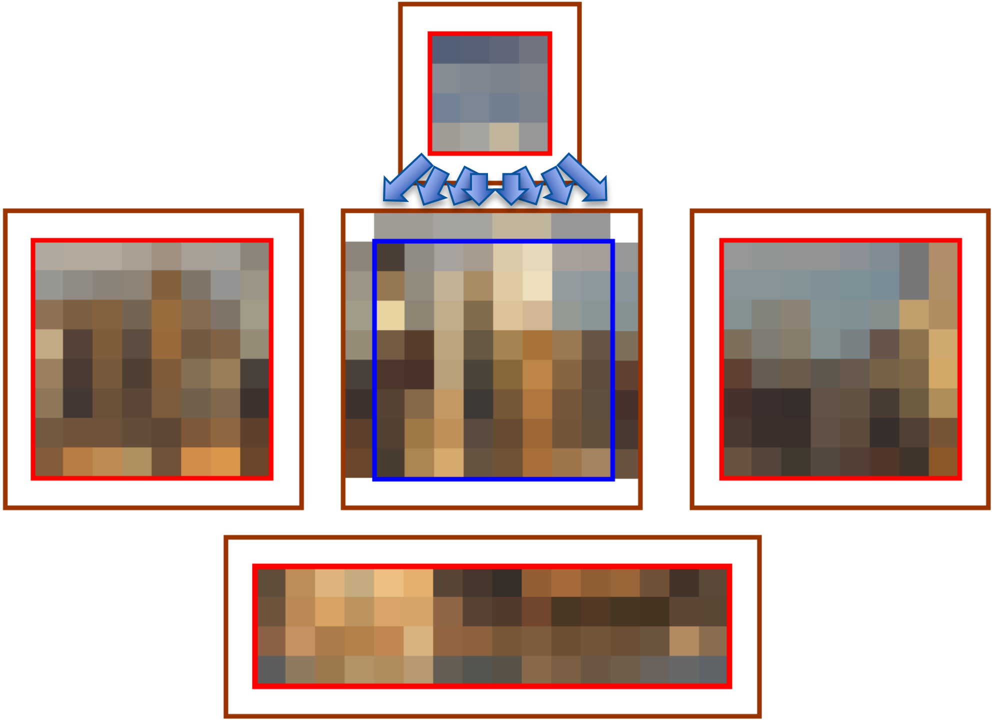
Fill Borders



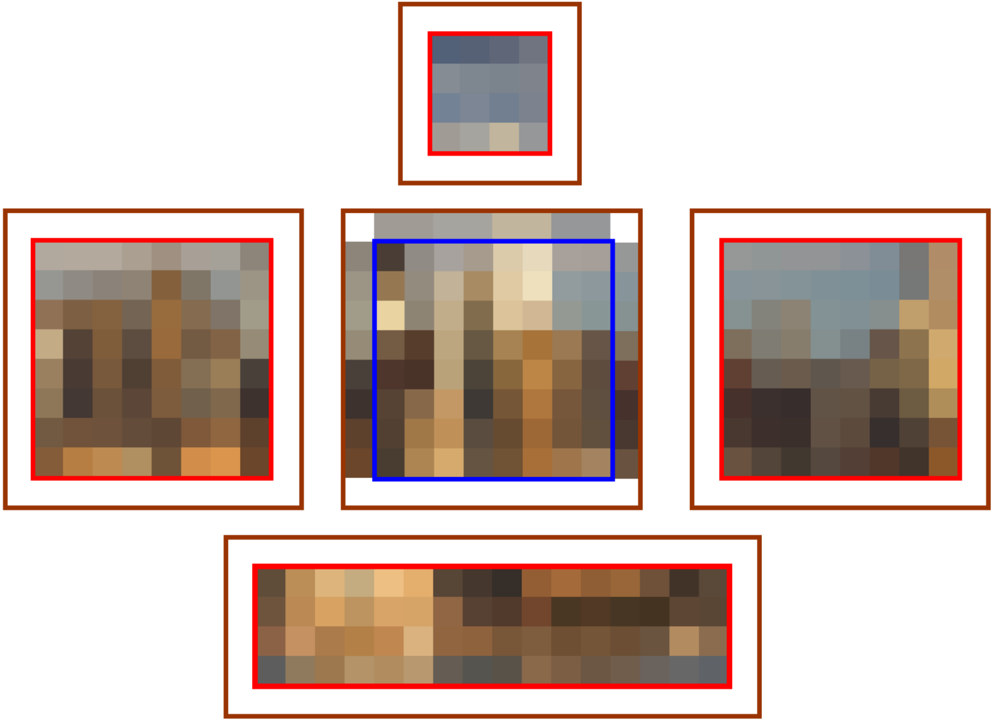
Fill Borders



Fill Borders



Fill Borders



Fill Borders

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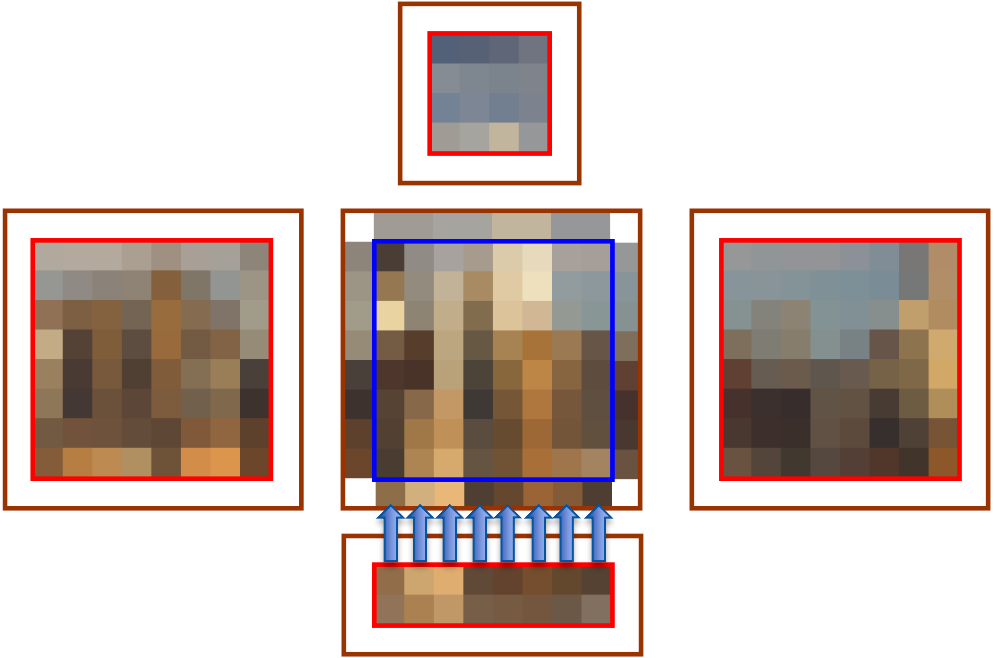

Pack Texture Arrays

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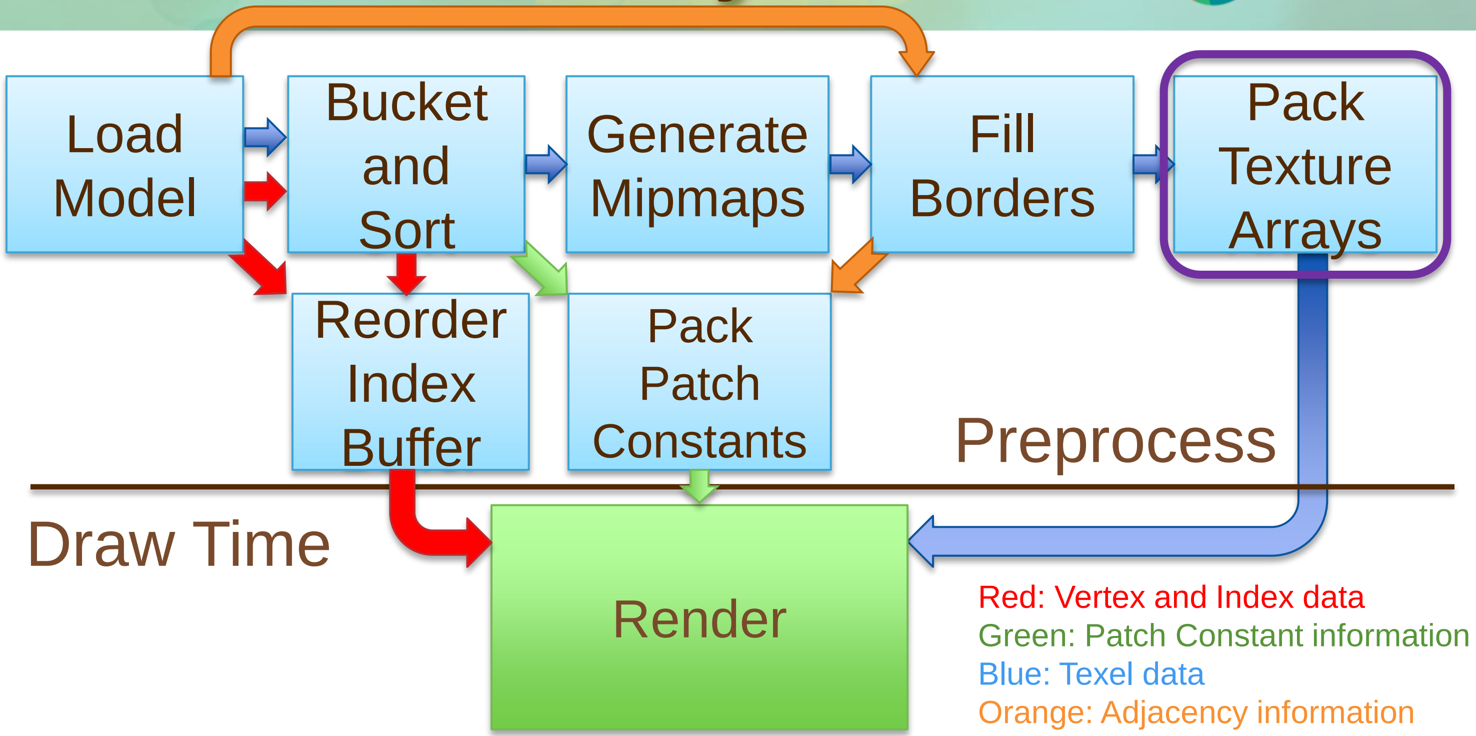

Texture Arrays

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- Like 3D / Volume Textures, except:
  - No filtering between 2D slices
  - Only X and Y decrease with mipmap level (Z doesn't)
  - Z indexed by integer index, not [0,1]
    - E.g. (0.5, 0.5, 4) would be (0.5, 0.5) from the 5th slice
- API Support
  - Direct3D 10+: Texture2DArray
  - OpenGL 3.0+: GL_TEXTURE_2D_ARRAY

Pack Texture Arrays

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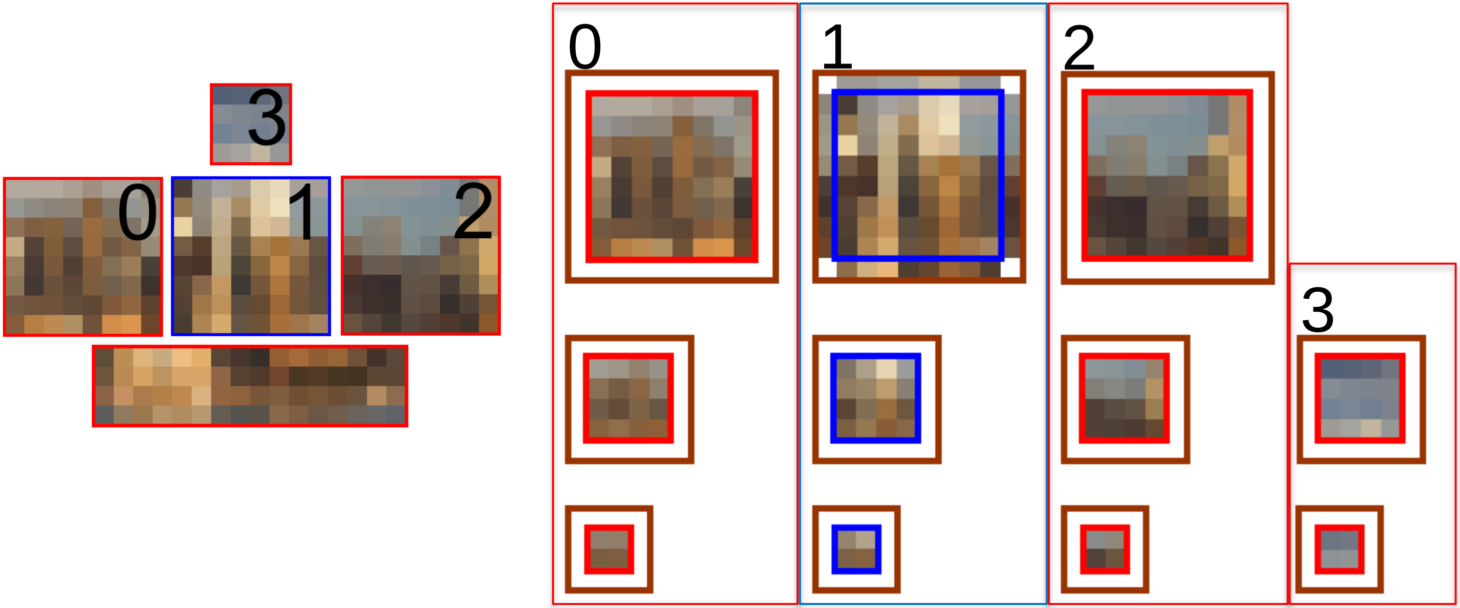
- Copy all generated data into Texture2DArray
- Each Texture2DArray represents a single mipmap level
  - Texture2DArrays present a view of the data that is efficient for GPU layout
  - Logical Textures cut across the same page index of every Texture2DArray

Pack Texture Arrays

Logical Texture Layout



Pack Texture Arrays

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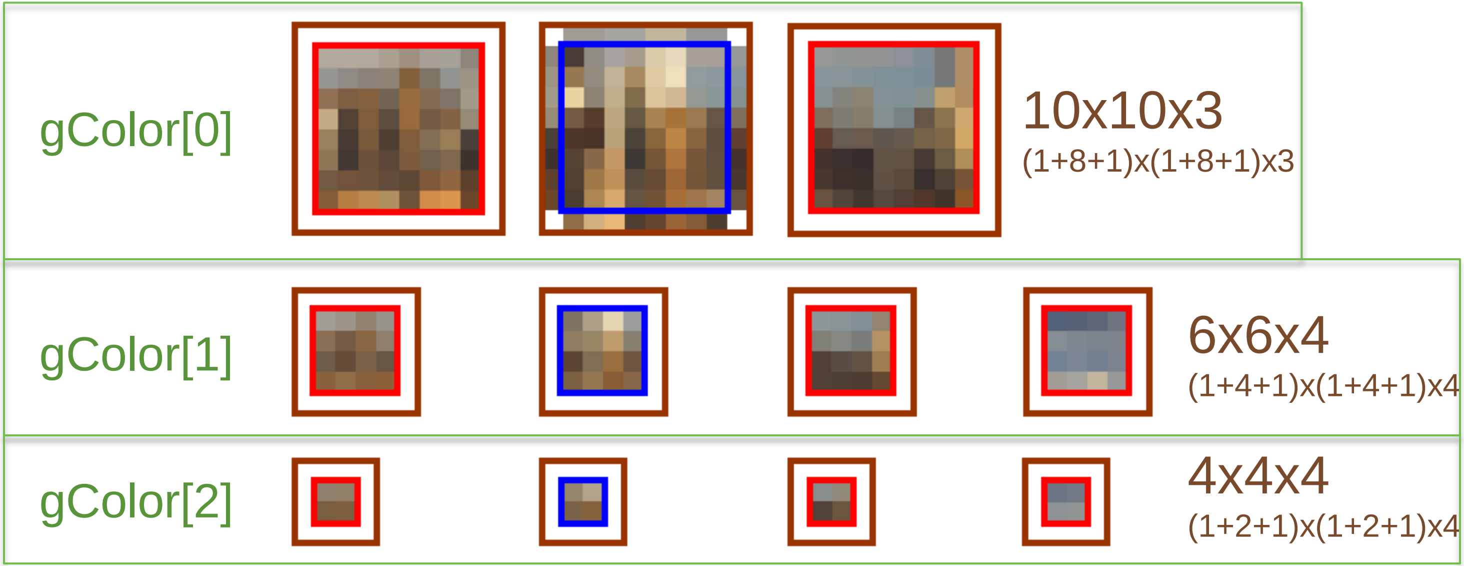
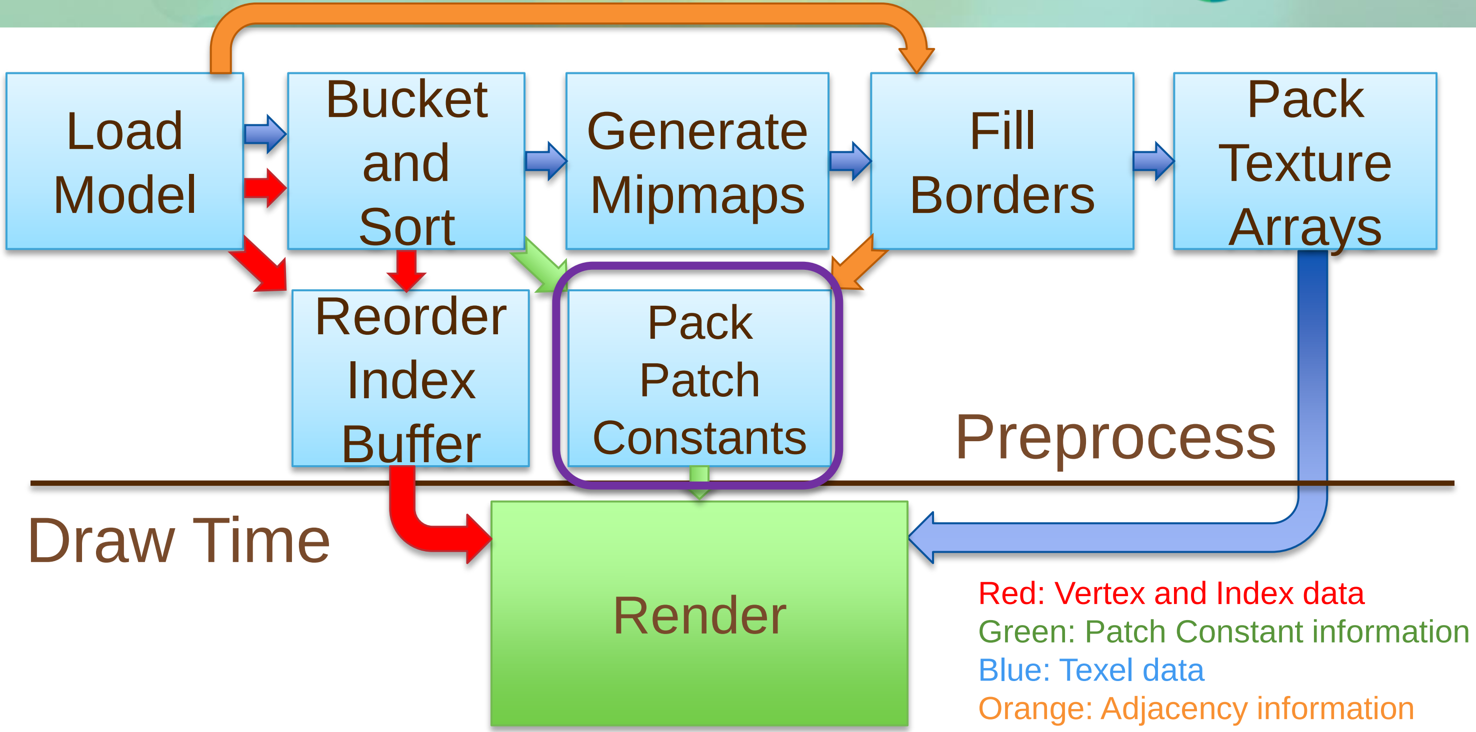
GPU Layout

Texture2DArray



Pack Patch Constants



Pack Patch Constants

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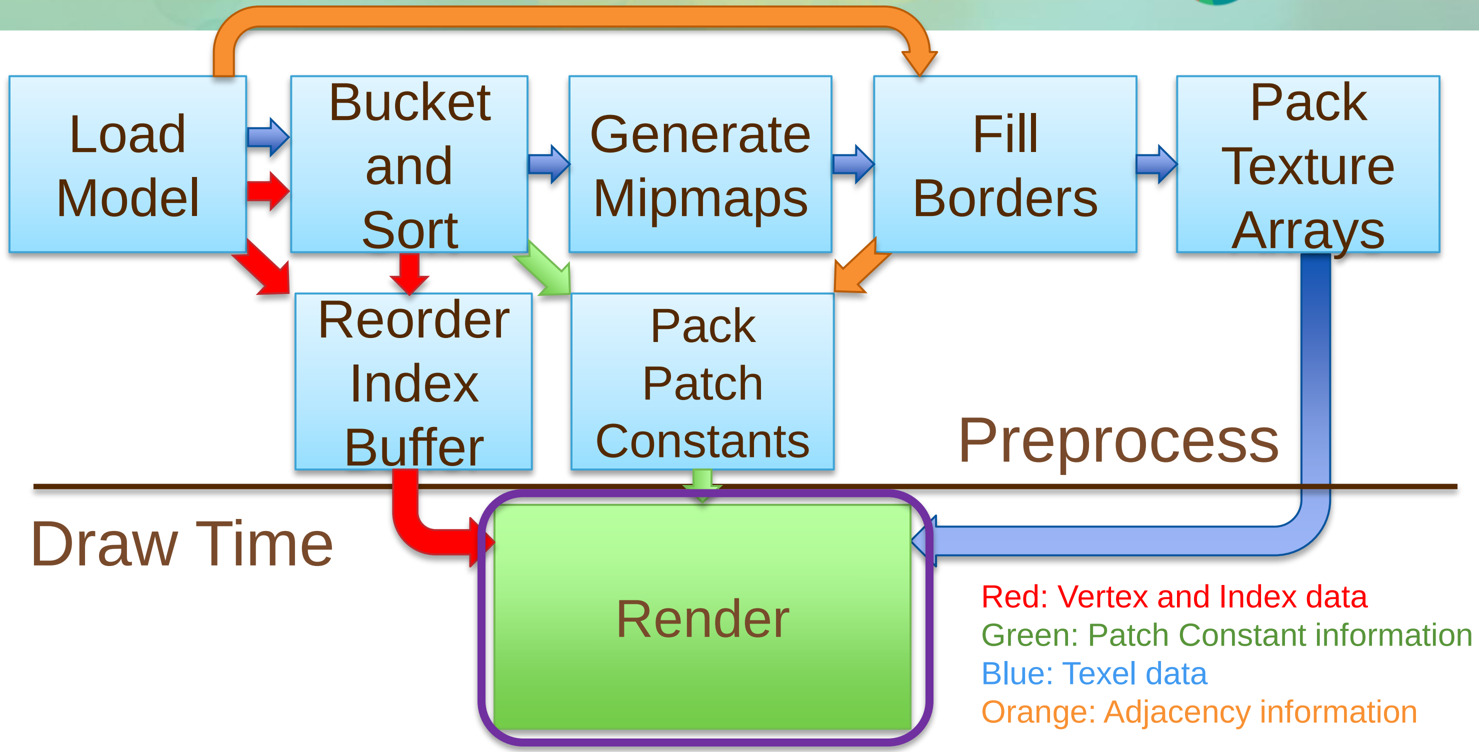
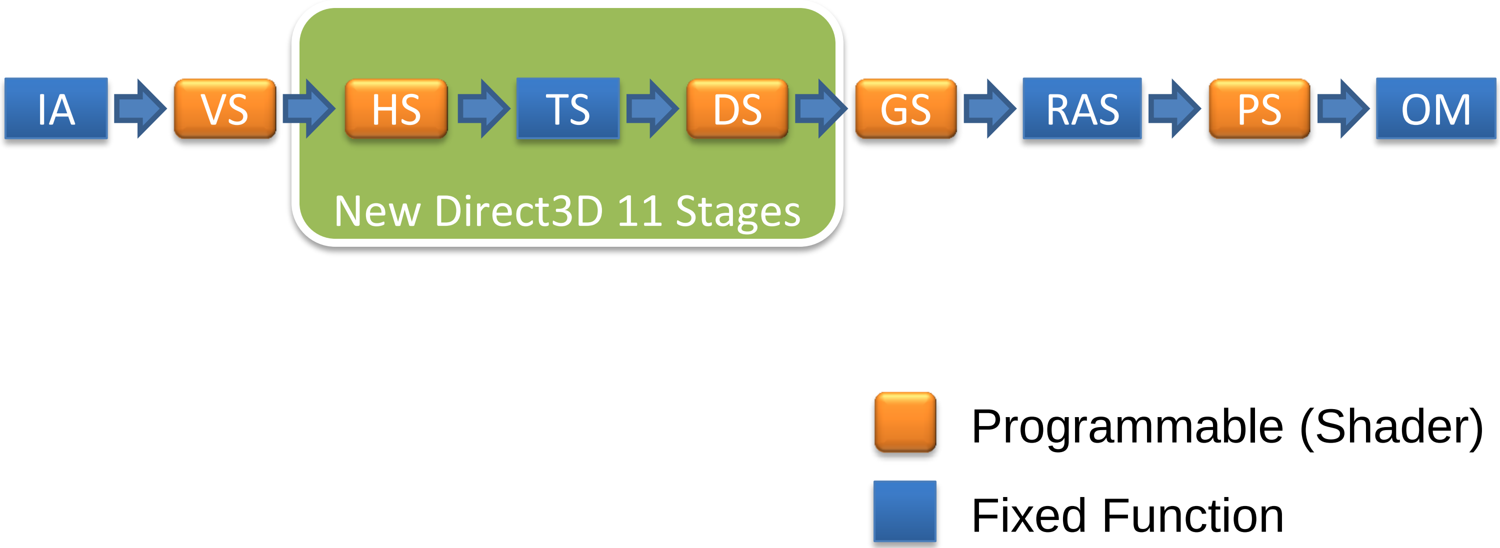
- Each primitive has a “PatchInfo” struct:
  - TextureId – which array slice contains our data
  - TopMipLevel – the index of the top-most mipmap level for this texture
  - FlipUVs – whether or not to flip UVs, allows 1:2 and 2:1 to be grouped into same bucket
  - MaxMipLevels – Maximum mipmap level for each edge

Fill Borders



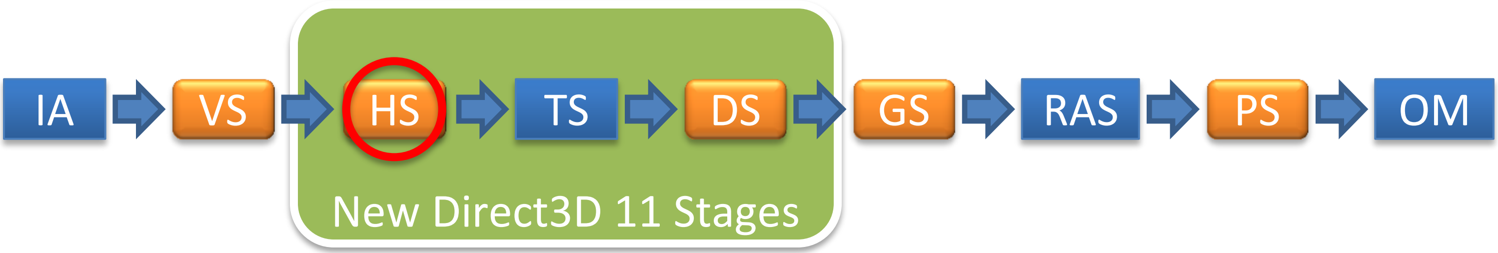
Render

- Brief Recap of D3D11 Pipe stages



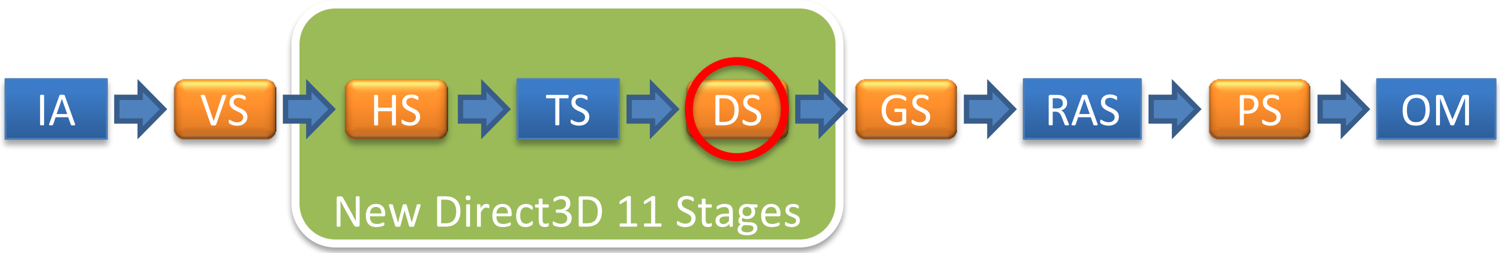
Render

- In the Hull Shader
  - Store pre-expansion PrimitiveID to output control points
  - This is used everywhere to determine which set of Patch Constants are owned by the currently running thread (in Domain, Geometry or Pixel Shaders)



Render

- In the Domain Shader
  - Vertices belonging to a quad meshes are evaluated with a domain location, which is (0,0)-(1,1) for each patch
  - Use this value to store our UV location



Render

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- Texture lookups in Domain or Pixel Shader are replaced with a “ptex” sample function.
  - Determines which logical texture to work from
  - Compute mipmap level(s) to access
  - Scale and bias computed (u,v) by mipmap size
  - Lookup texels, return weighted average

Texture Lookup Shader Code

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- Traditional (D3D11)

```
return
   gTxDiffuse.Sample(
          gSampler,
          I.fTextureUV );
```

- Ptex

```
return
  ptex( gTxDiffuse,
        gSampler,
        I.uPrimitiveId,
        I.fTextureUV );
```

Complex logic hidden in single function call

Questions?

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- jmcdonald at nvidia dot com
- Brent dot Burley at disneyanimation dot com
- http://ptex.us/
- http://groups.google.com/group/ptex
- Or visit our studio session
  - Monday, 8 August @ 4:30 PM – 5:00 PM
  - The Studio / West Building, Ballroom A

Additional Considerations

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- Filtering across edges with differing numbers of pixels
- Filtering across corners

Filtering across edges

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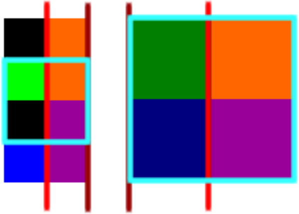
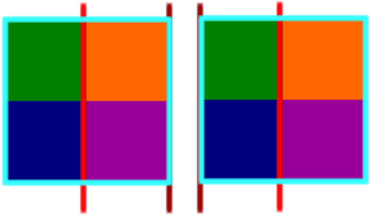
Filtering across edges

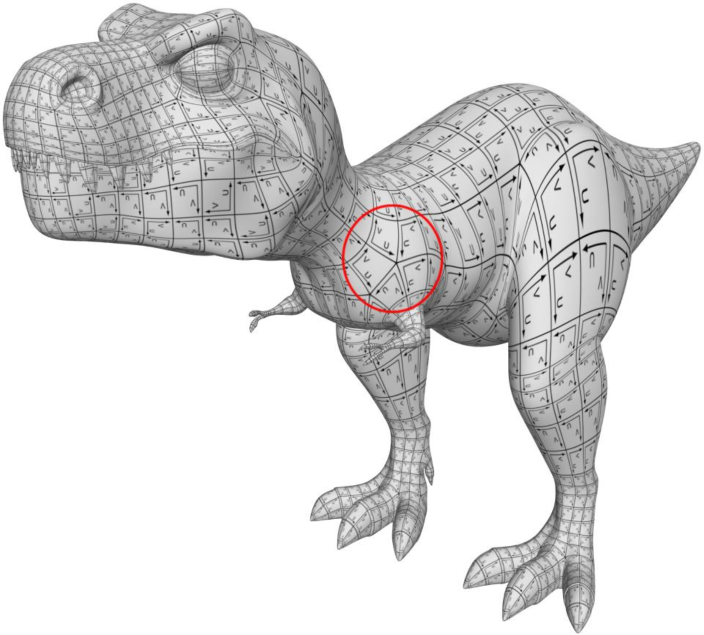


Filtering across edges



Filtering across corners

- Corners with valence > 4 cannot be exactly matched with a bilerp (4 samples)



Filtering across corners

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- The solution is a bit more involved.
  - First, walk the mesh and determine which corners are shared
  - For each shared group, determine the correct value for when we’re exactly at that corner. E.g. Simple Average.
  - Then, modify every mipmap level of every surface of that group s.t. the shared corner has the same value
  - When you’re in the corner, everyone will perform the same lookup—regardless of mipmap level—and continuity prevails

Filtering across corners

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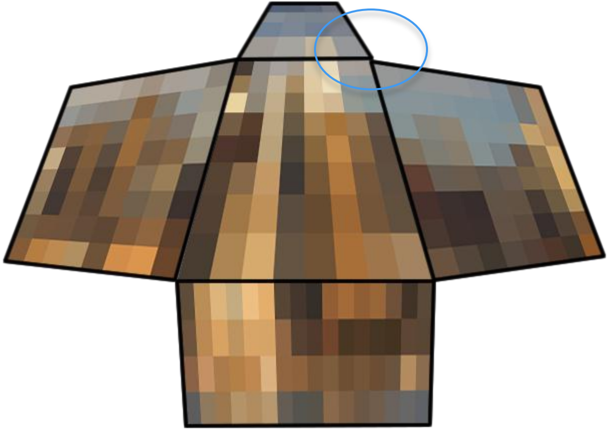
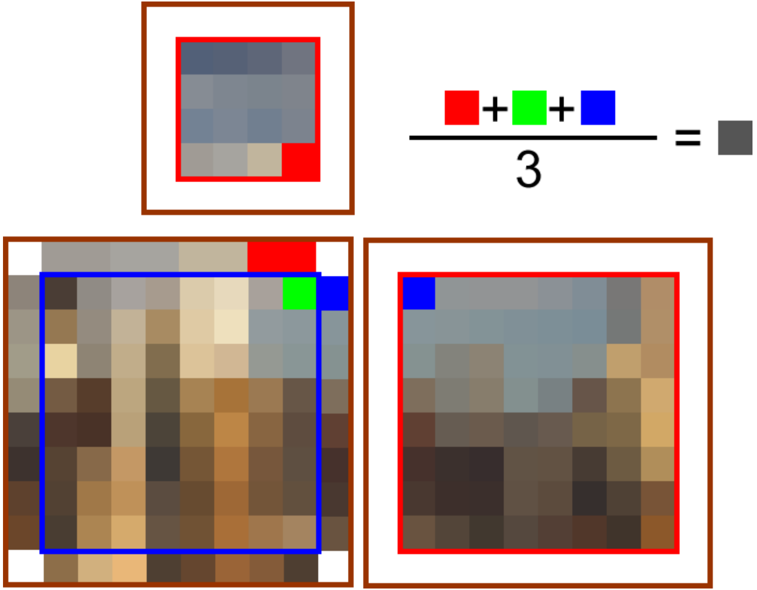
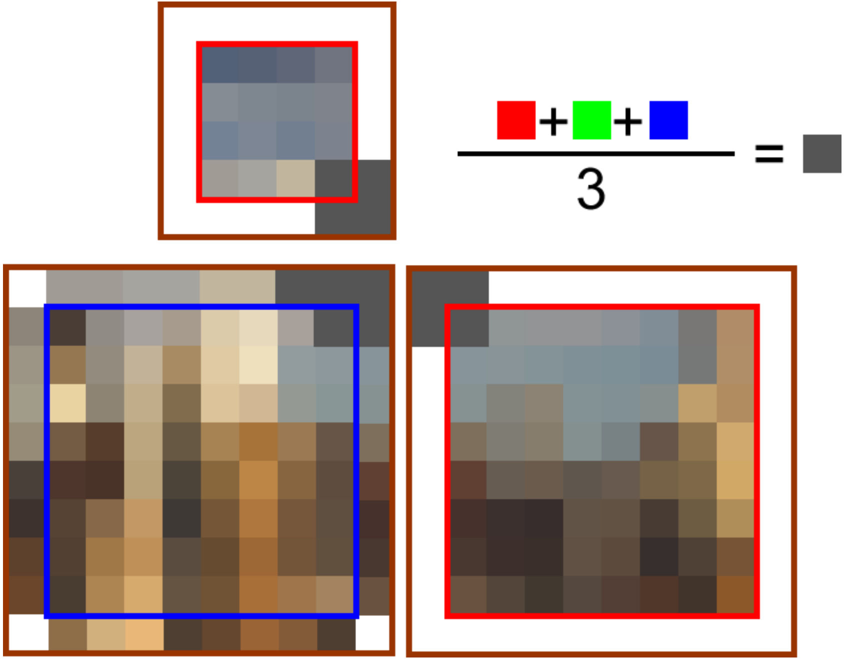
- For Realtime Ptex, we apply pinning to all corners, regardless of valence.





Pinned Corners



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