ATI Radeon HyperZ Technology

Steve Morein

Radeon

- 0.18u CMOS
- 30 M transistors

Radeon Features

- 3D
  - Charisma Engine
    - Transform, Clipping, and Lighting
    - Key frame Interpolation, multi-matrix skinning
  - Pixel Tapestry
    - 3 texture multi-texture
    - 3D volume texture, 2D cube texture
    - Dot Product per pixel
    - Dependent texture lookup for environment bump mapping
- Elsewhere
    - HDTV decoding
    - Adaptive de-interlacing

The Memory Bottleneck

- 3D is memory bandwidth intensive
  - Pixel Operations
    - Texture Read (TR)
    - Z-Buffer Read (RZ)
    - Z-Buffer Write (WZ)
    - Color Read (RC)
    - Color Write (WC)
  - Common Color/Z depth is 32-bits (4 bytes)
  - Texture Bandwidth
    - Multitexture, Resolution, Texture Compression
    - Net assumption: 32-bits (4 bytes) per pixel

The Memory Bottleneck

Worst case pixel

- RZ + WZ + RC + WC + TR = 20 bytes/pixel
- 40% of bandwidth (8/20 bytes) used for Z data

Common case pixel

- RZ + WZ + WC + TR = 16 bytes/pixel
- 50% of bandwidth (8/16 bytes) used for Z data

Best case pixel (fails Z test)

- RZ = 4 bytes/pixel
- 100% of bandwidth (4/4 bytes) used for Z data
  - But likely to be forced to read texture and color

The Memory Bottleneck

Radeon Fill Rate

- 2 pipes @200MHz = 400 Mpixels/Sec

Memory Bandwidth Need (common pixel case)

- 400 Mpixels/Sec * 16 bytes/pixel = 6.4 GBytes/Sec
  - We'll ignore bandwidth needed to refresh the display

Available Bandwidth (common memory system)

- 166MHz, 128-bit DDR SGRAM
- 166MHz * 2 (DDR) * 16 bytes = 5.3 GBytes/Sec
  - Efficiency, of course, is much worse than 100%

Bandwidth need exceeds available, big problem!

The Memory Bottleneck

- Typical application today
  - 60% pixels pass z test
- Z is largest user of bandwidth
  - It would be nice to find a way to reduce it
- Overdraw (pixels drawn/pixels per frame)
  - Typically around 3
    - One of every 4 pixels drawn is for clearing the Z buffer
- Not bandwidth limited when drawing pixels that fail Z test
  - But why waste clock cycles to draw hidden pixels?

HyperZ

- Silly marketing name
- What it is:
  - Lossless compression of Z buffer
  - “Fast” Z buffer clear
  - Hierarchical Z buffer
- What it does:
  - Reduce Memory Bandwidth
  - Reduce number of pixels drawn

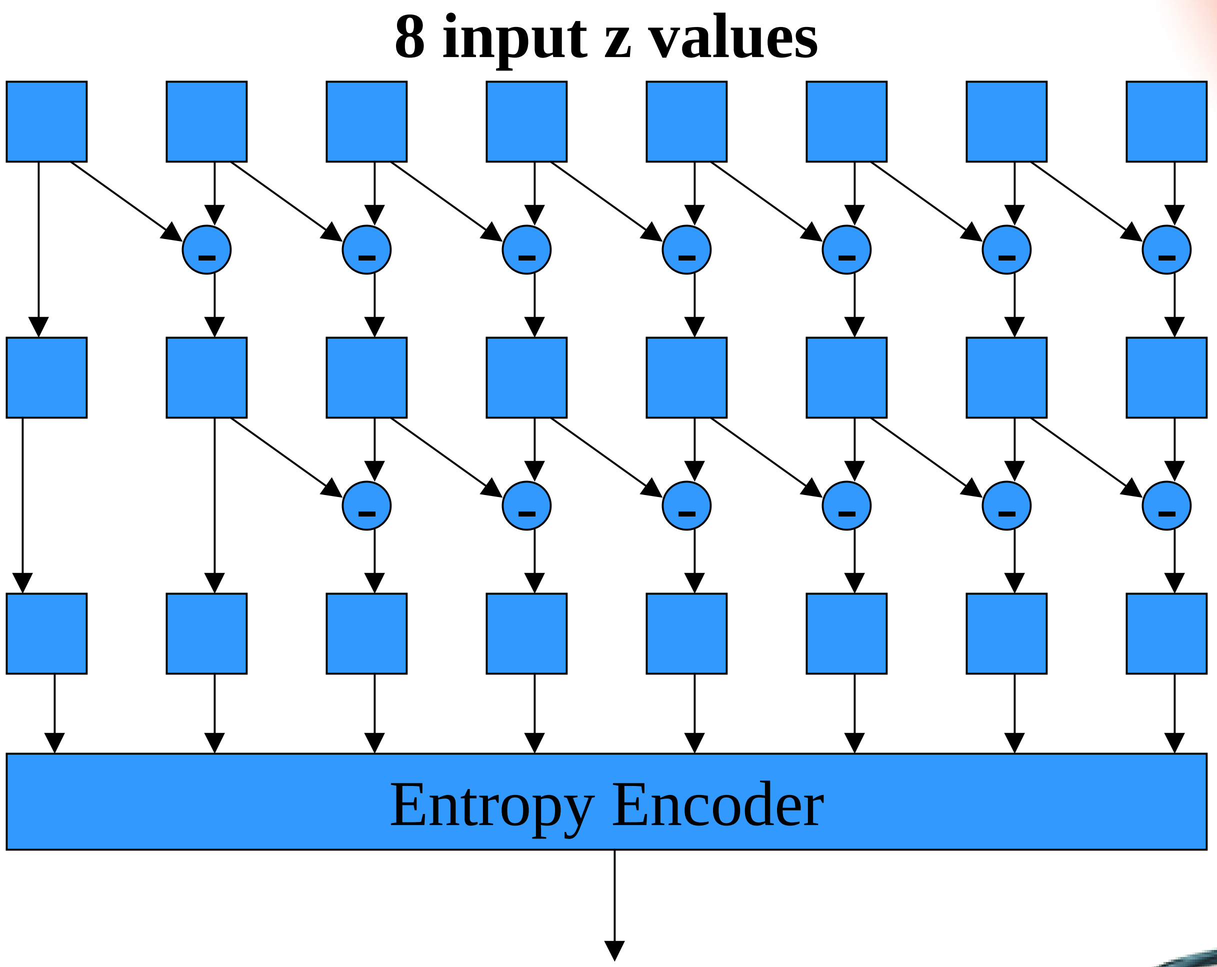
Z Compression Summary

- Lossless
- Not Application Visible
- Variable Length
  - – Block can be uncompressed
    - Required since this is a lossless algorithm
- Reduces Z bandwidth by 50%

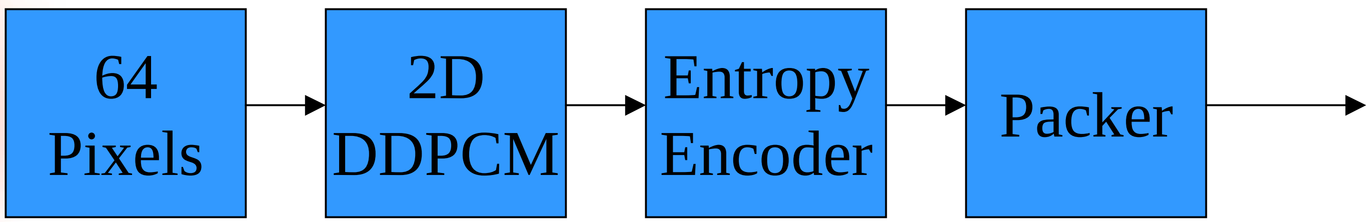
Compression Scheme

- 8x8 pixel cache line size
- Can be compressed to:
  - ½ of original size, "poorly compressed"
  - ¼ of original size, "well compressed"
- Basic algorithm is "DDPCM"
  - Differential differential pulse code modulation

1D Z Compression

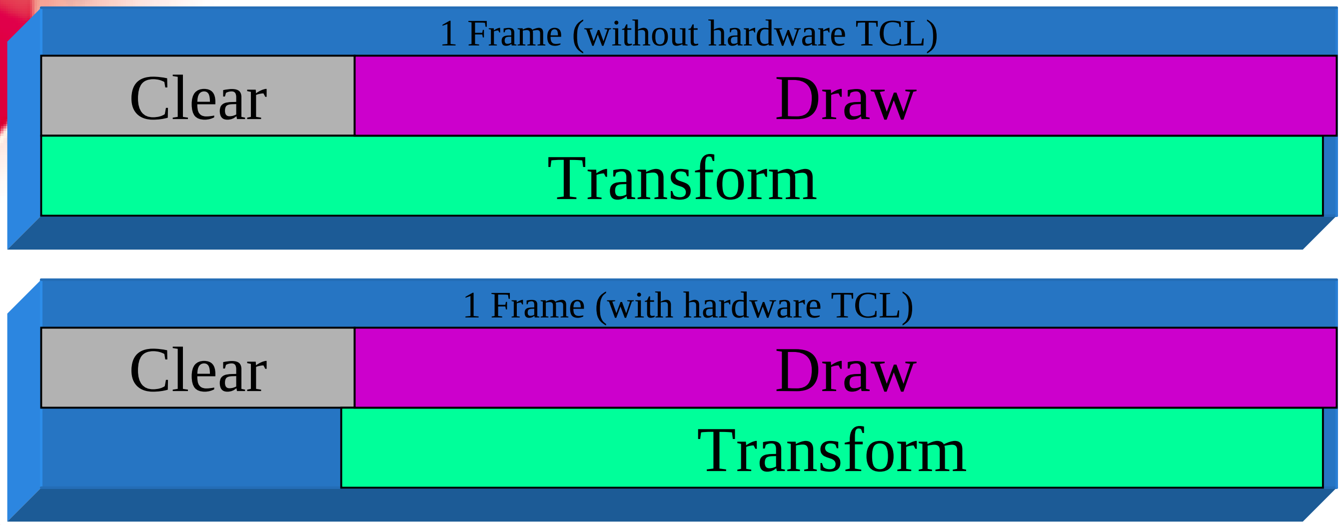


2D Z Compression



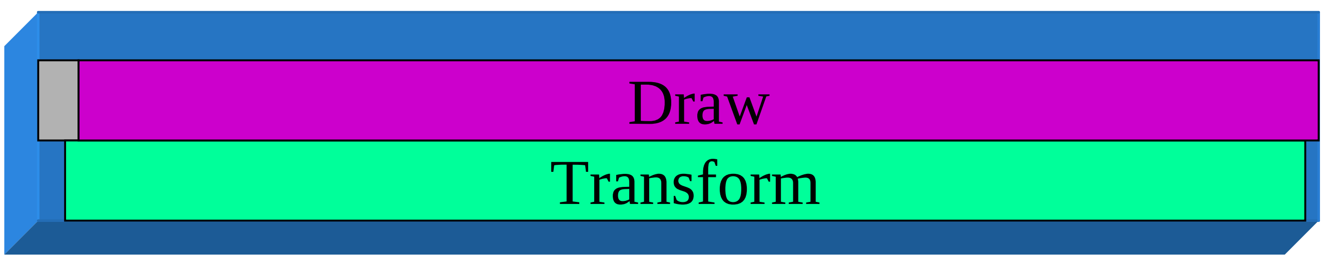
Fast Z Buffer Clear

- Most real-time 3D applications:
  - Clear the Z buffer
  - Do not clear the color buffer
  - Draw all pixels on the screen at least once
- Clear also hurts current PC hardware TCL



Fast Z Buffer Clear

- Avoid clear
- Avoid first read
- A block in memory can be:
  - Compressed
  - Uncompressed
  - Cleared
- Not application visible

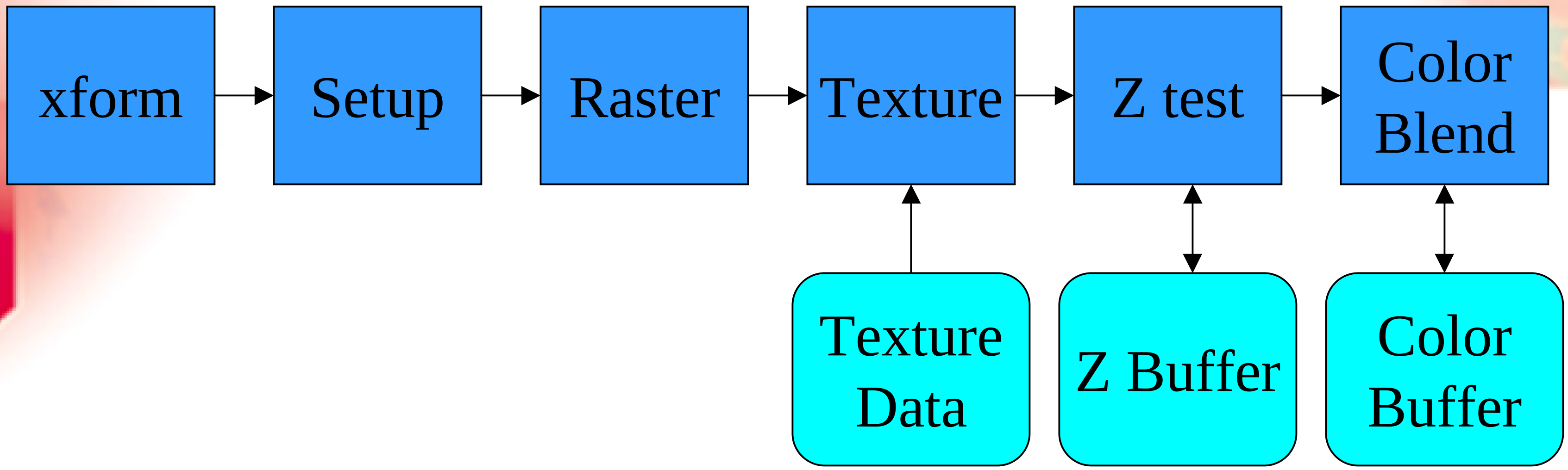


Fast Z Clear and Z Compression

Application	%Increase in fps (166 Mhz core/166 DDR memory)
3D Winbench (total)	29%
Quake	24%
3D Mark (adventure)	24%

Hierarchical Z Buffer

- A Quick 3D pipe review



Hierarchical Z Buffer

Goal

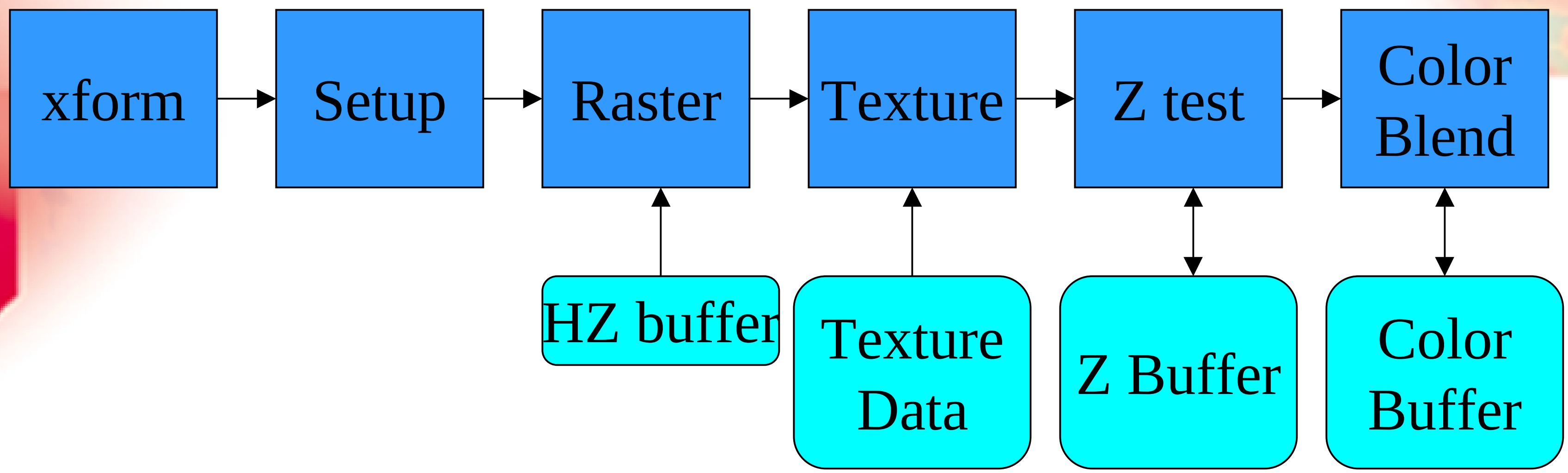
- Remove pixels failing Z test as early in the pipeline as possible
- Remove pixels failing Z test as quickly as possible

Implementation

- Keep reduced resolution Z buffer on chip
- Test pixels early against on chip Z buffer
- Discard pixels before texturing
- Discard at a fast rate (> 8 pixels/clock)

Hierarchical Z Buffer

- 3D pipeline with Hierarchical Z buffer



Hierarchical Z Buffer

- Occluder merging
  - In many cases the occluding object is made of a large number of small triangles, none of which completely occlude the hidden object
- Texture Cache
  - Doing the conservative Z test early prevents the loading of textures used by the hidden object into the texture cache
- “Harder” pixels
  - The pixels that pass the Hierarchical Z test are harder to render; more pass the final Z test.
- Not visible to application
  - Like all of the Hyper Z features, the application does not need to be modified to get a performance boost.

Hierarchical Z Buffer Results

- Application dependent
  - Drawing front to back will optimize performance
  - Some applications already do
  - Benefit even if graphics card does not have Hierarchical Z

Application	% pixels fail Z test	% of failing pixels caught by hierarchical Z
3D Winbench (4)	49%	65%
3D Winbench (9)	24%	93%
Quake	19%	51%
3D Mark (cityl)	22%	44%

Future Work

- Some things worked very well
- Some can be further improved
- Extending this to application level culling