Tight Frame Normal Map Compression

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Overview

- Introduction to normal mapping
- Previous work
- Tight Frame Compression
- Evaluation

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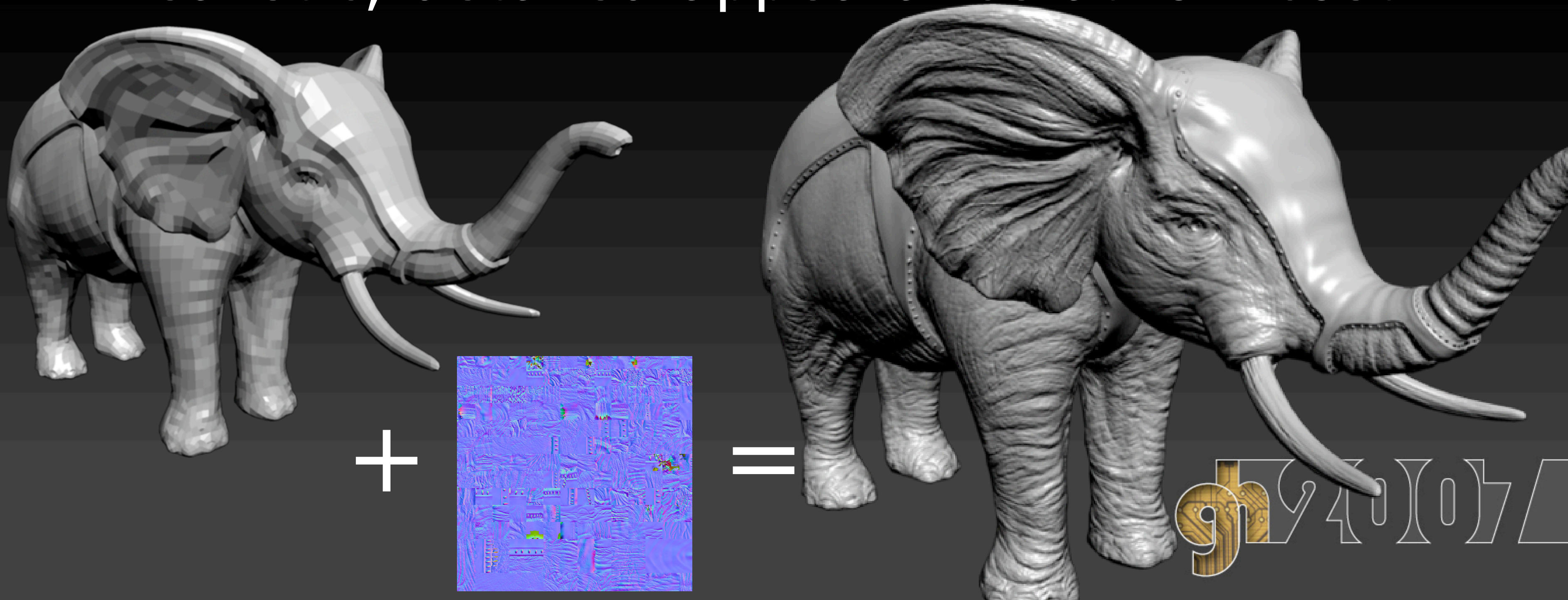
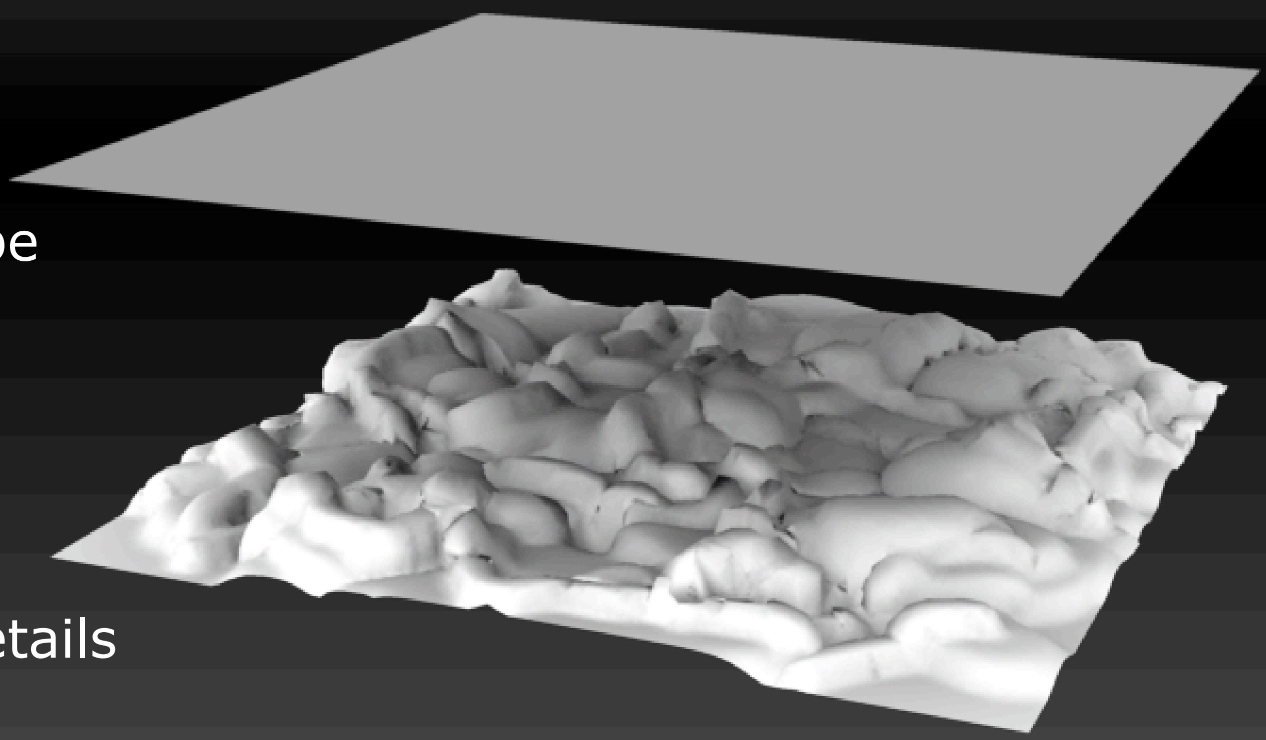
Normal Maps

- Add geometric detail with texture maps
- Store value of the local normal vector
- Realistic, detailed appearance at low cost



Normal Map Generation

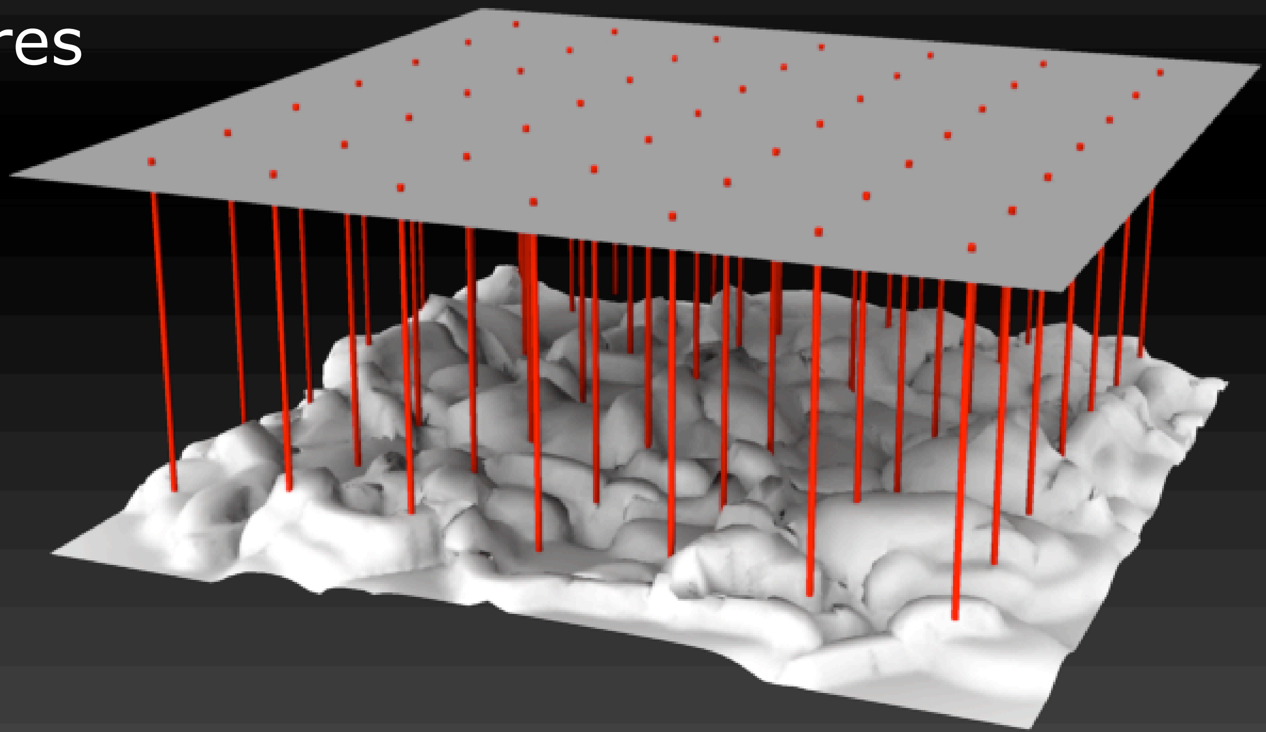
- Create two versions of geometry
  - Lo-res
    - overall shape
  - Hi-res
    - shape + details



Normal Map Generation

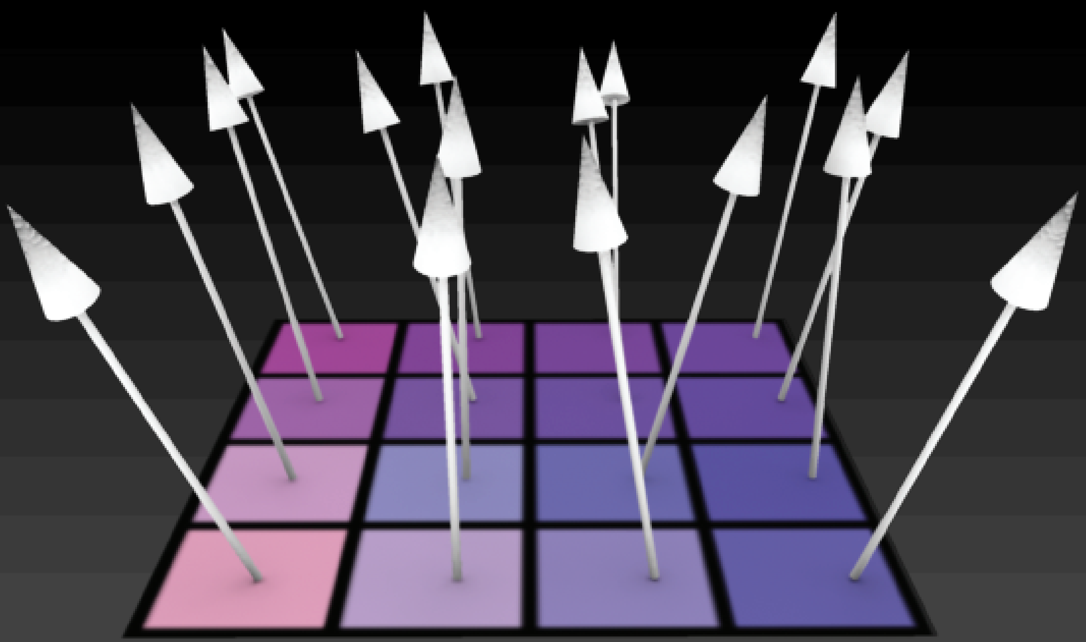
- Shoot rays
  - from the lo-res surface

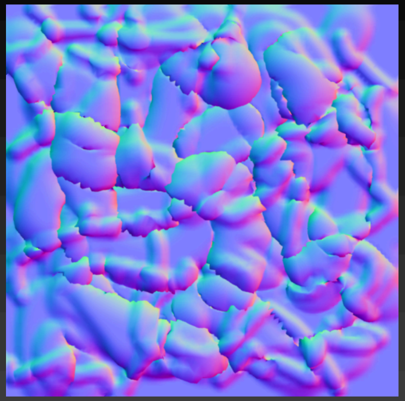
    to the hi-res surface



Normal Map Generation

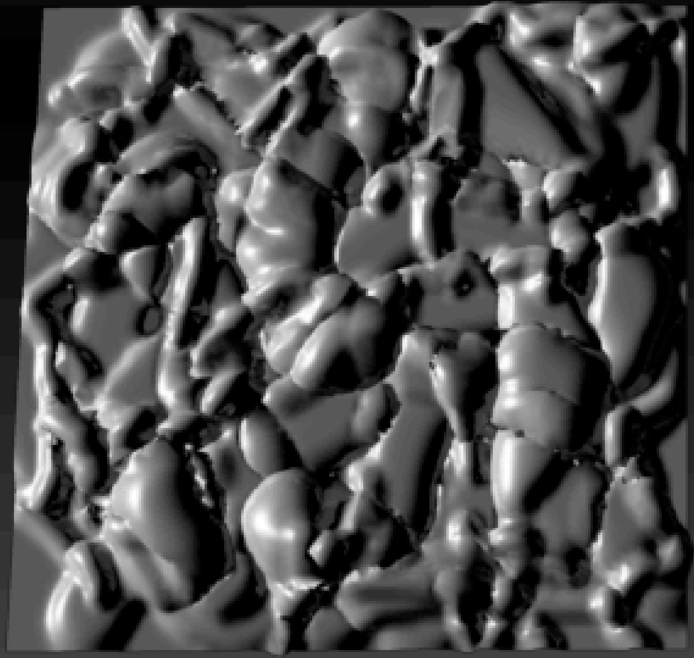
- Store the normal vector from the intersection points in an RGB texture





Normal Map Generation

- Render lo res surface + normal map

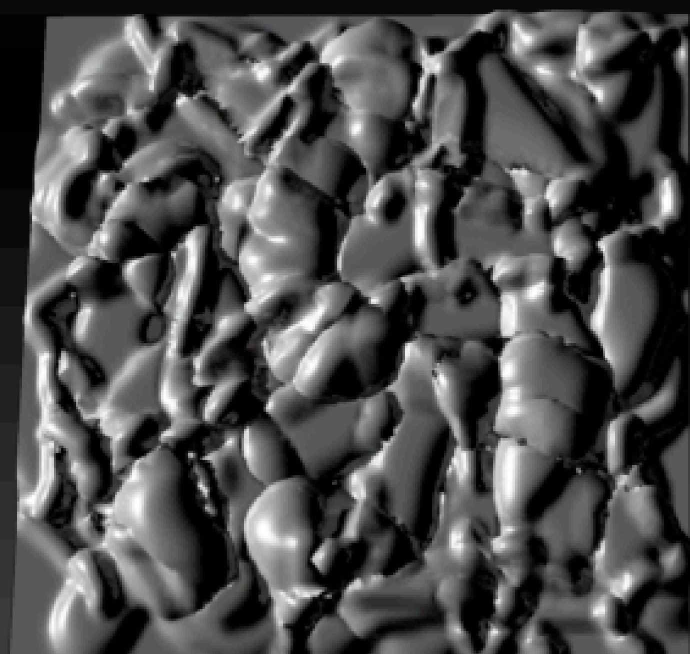


20k triangles

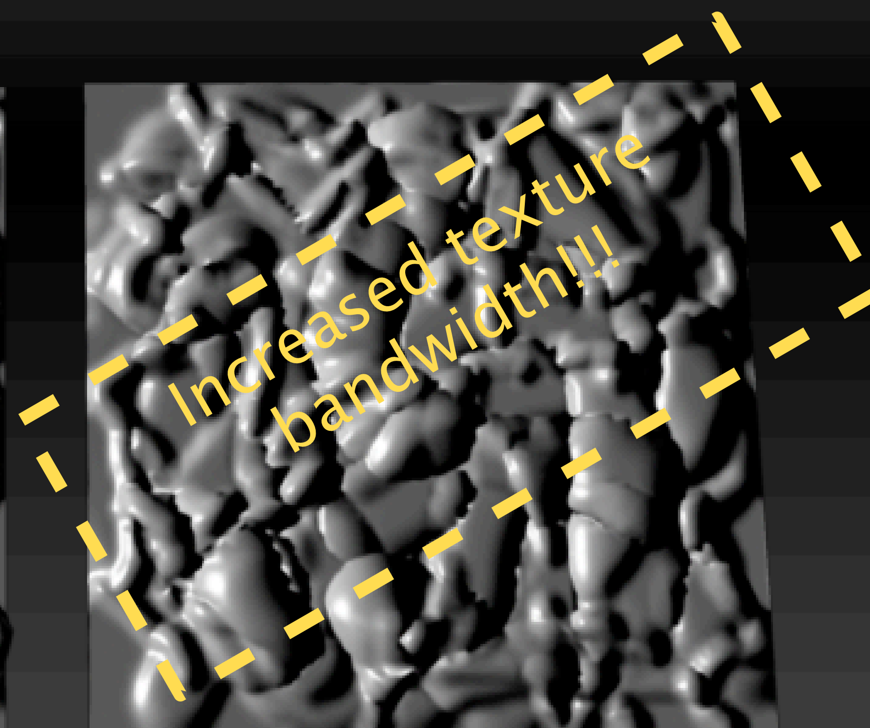
2 triangles + normal map

Motivation

- We need compression!



20k triangles



2 triangles + normal map

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Previous Work

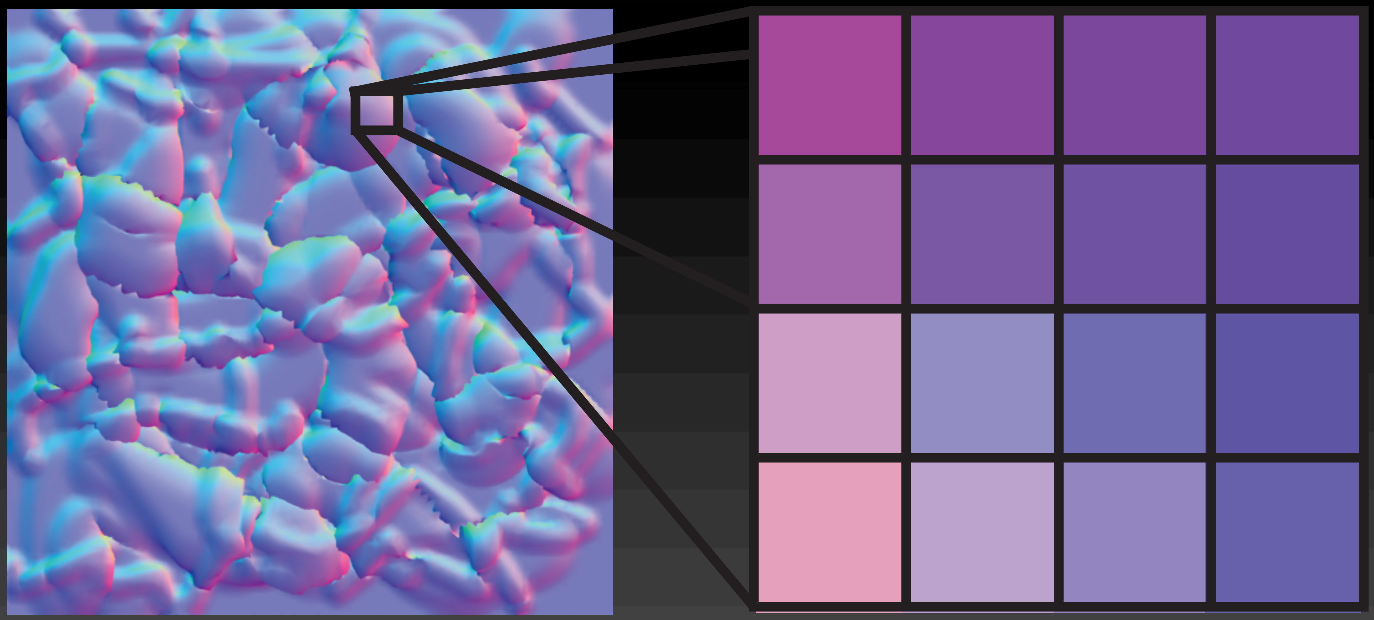
- Surface normal compression [Deering 95]
- S3 Texture Compression/DXTC [Iourcha99]
- 3Dc [ATI05]
  - Dedicated format for normal maps
- e3Dc [Munkberg 06]
  - Enhanced 3Dc with rotations and diff-coding
- Adaptive bit rate [Wong06,Yang06]
- Vector Quantization [Yamakasi et. al 06]

Design choices

- Fixed rate encoding at 8 bpp
  - Fast random access
  - Simple decompressor
  - 4x4 texel blocks
- Use advantages from e3Dc
  - Rotation encoding
  - Differential encoding
  - Variable point distribution
- Exploit coherence between channels

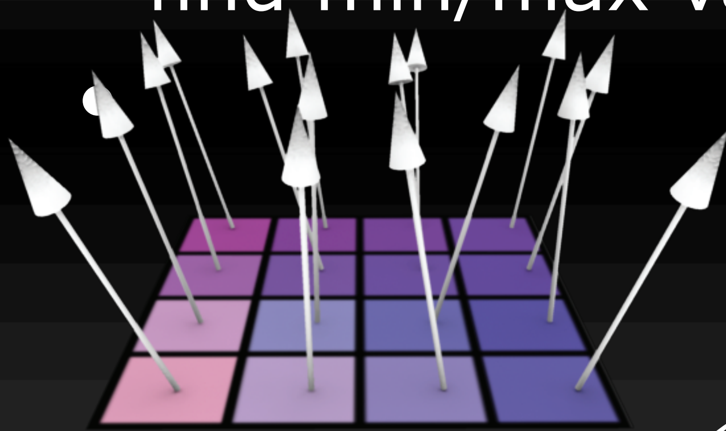
3Dc Overview

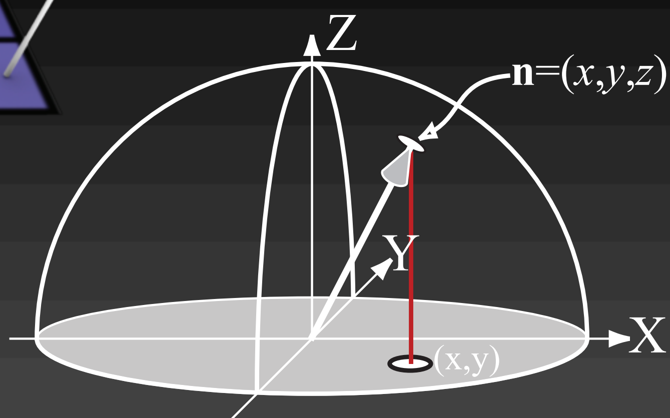
- Divide the input file in 4x4 blocks of texels

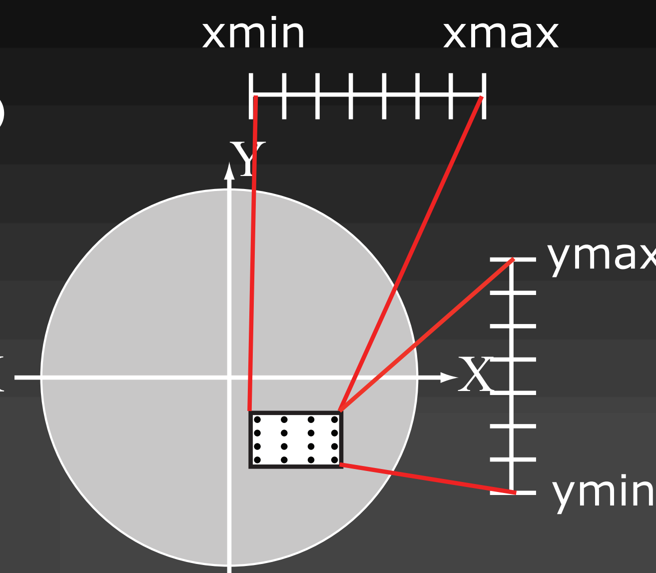


3Dc - Projection

- Project the normals on the xy plane and find min/max values of the bounding box

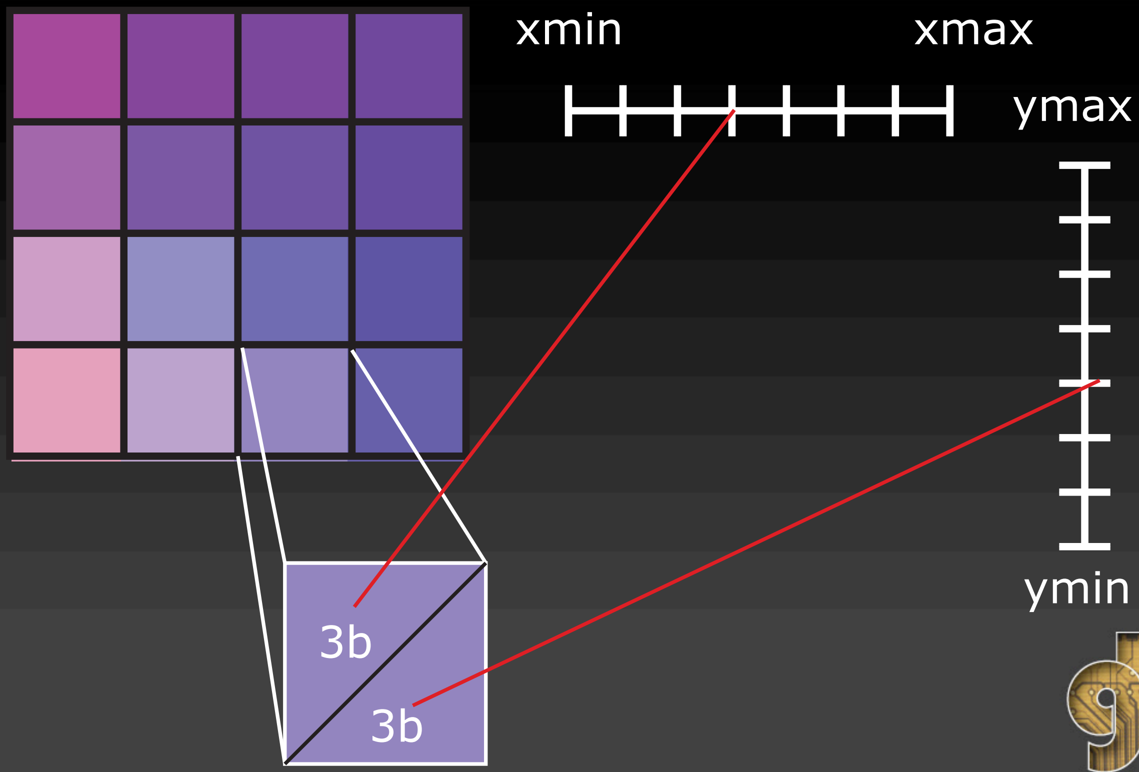






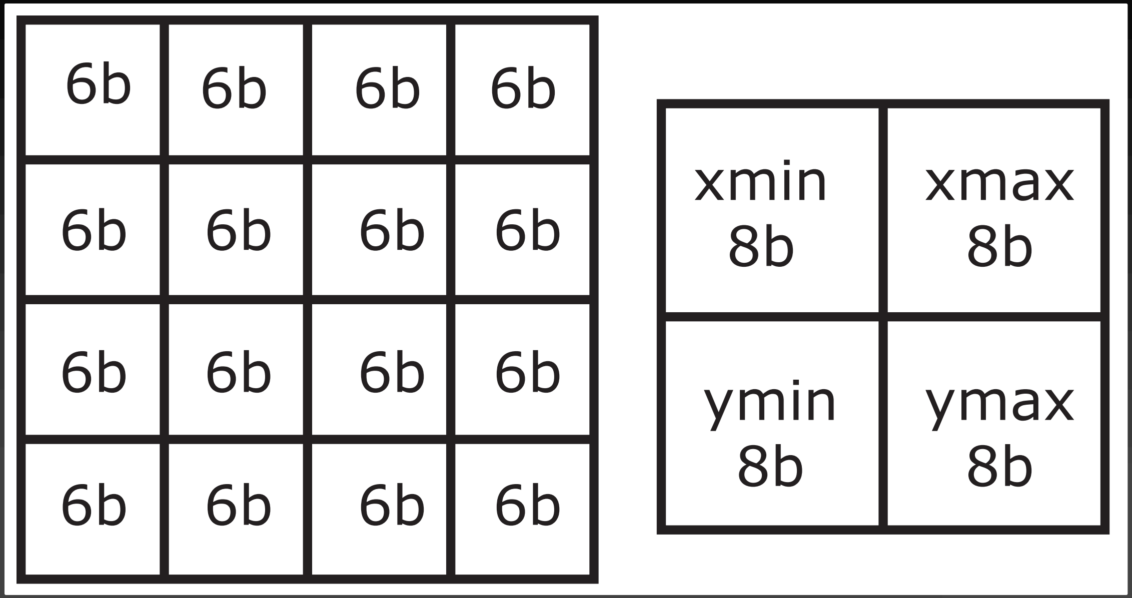
3Dc - Texel Quantization

- Map each texel to a quantized (x,y) value
  - Eight levels in x & y; (3,3) bits to select (x_i,y_i)



3Dc - Compressed Block

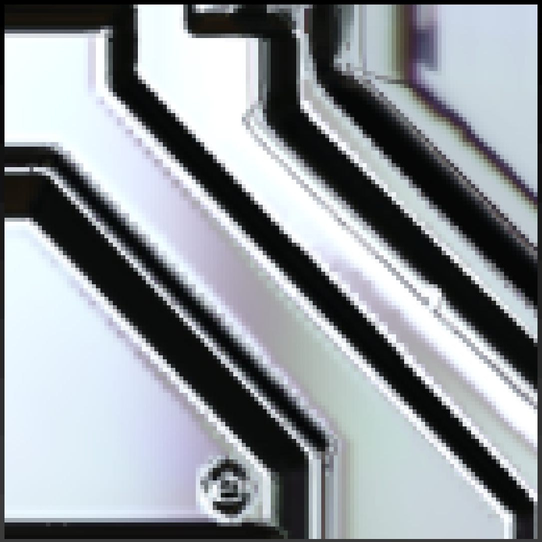
- Compressed form
  - 4x8 bits for x_{min}, x_{max}, y_{min}, y_{max}
  - 6x16 bits for per texel index
  - Total: 128 bits per block : 8 bits per texel



Problems with 3Dc

- Difficult scenarios
  - Slow gradients, sharp edges, directed features

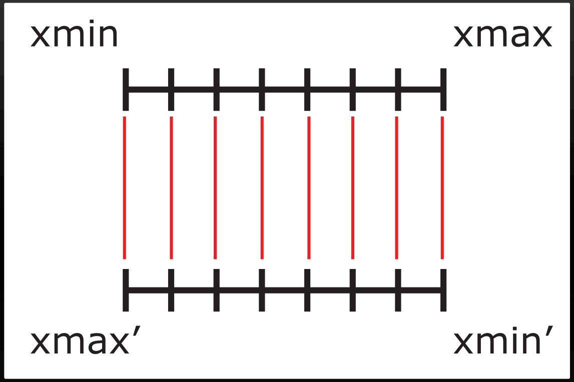
3Dc



Original

3Dc can be improved - e3Dc

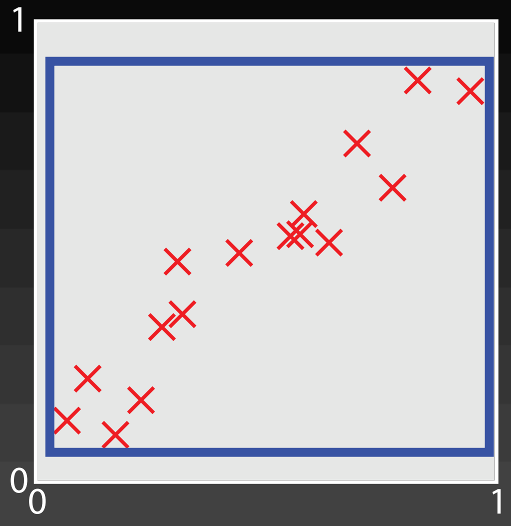
- Observation (used in DXT1)
  - Swap min & max values
    → same reconstruction levels
  - One bit unused per channel!
  - Use these to signal new modes!

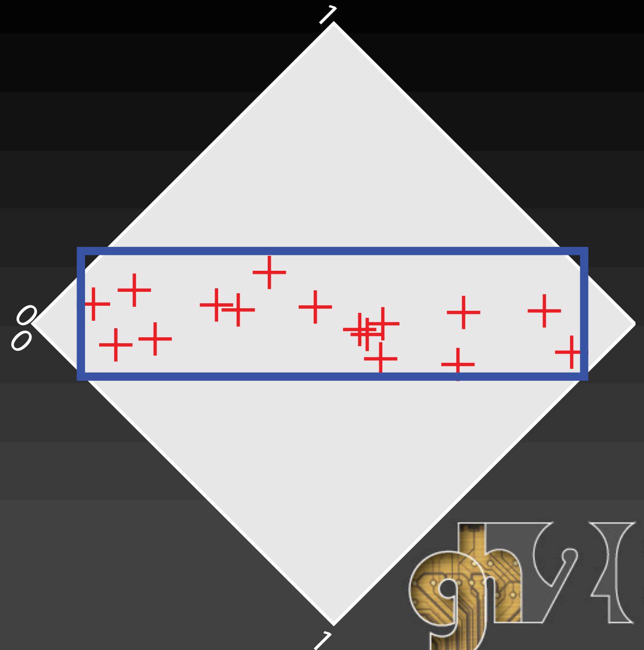


X	Y	mode
$x_{min} < x_{max}$	$y_{min} < y_{max}$	Standard 3Dc
$x_{min} \geq x_{max}$	$y_{min} < y_{max}$	Rotation 30
$x_{min} < x_{max}$	$y_{min} \geq y_{max}$	Rotation 60
$x_{min} \geq x_{max}$	$y_{min} \geq y_{max}$	Differential mode

Rotation Compression

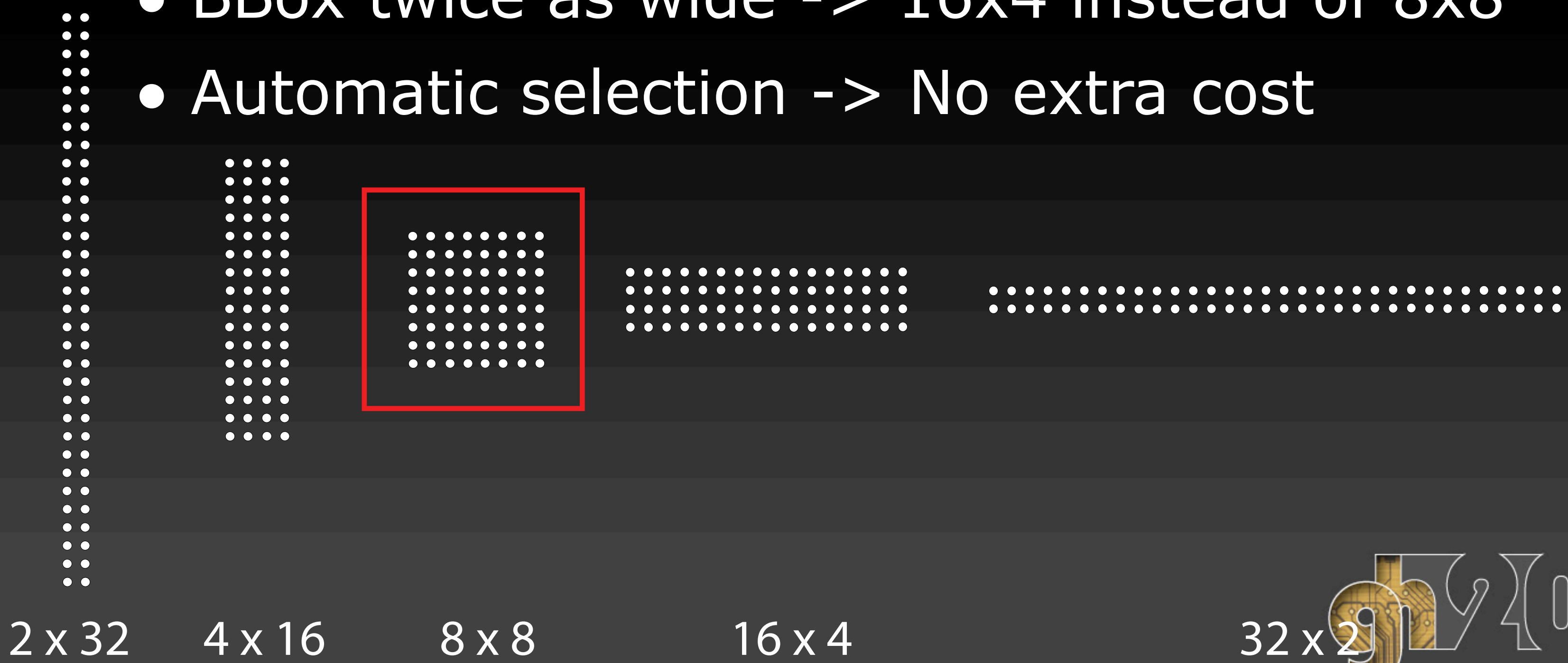
- Rotate coordinate frame for a more compact bounding box
  - e3Dc uses three angles: 0, 30 and 60 degrees



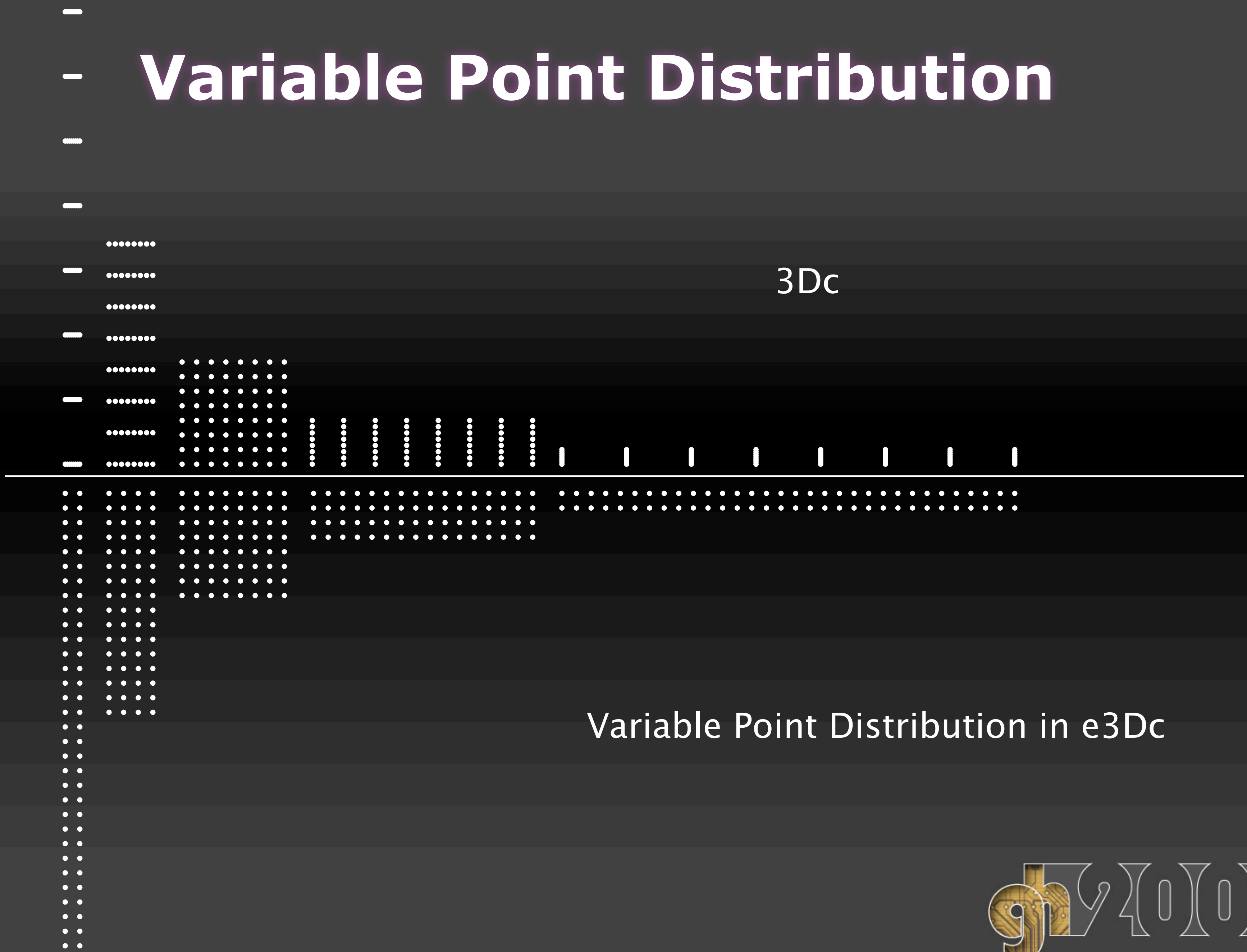


Variable Point Distribution

- 3Dc : points in a 8x8 grid
- Our approach : use aspect ratio of bbox
  - BBox twice as wide -> 16x4 instead of 8x8
  - Automatic selection -> No extra cost

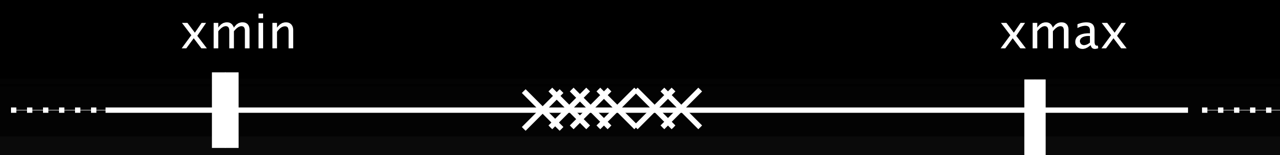


Variable Point Distribution



Differential Encoding

- Slowly varying normals are problematic:
  - Smallest interval is too wide (range/255)



  - The interval cannot be placed accurately enough

Differential Encoding

- Slowly varying normals are problematic:
  - Smallest interval is too wide (range/255)

  - The interval cannot be placed accurately enough

Reinterpret the bits differentially!
(xmin,xmax) → (xmin*, Δx)

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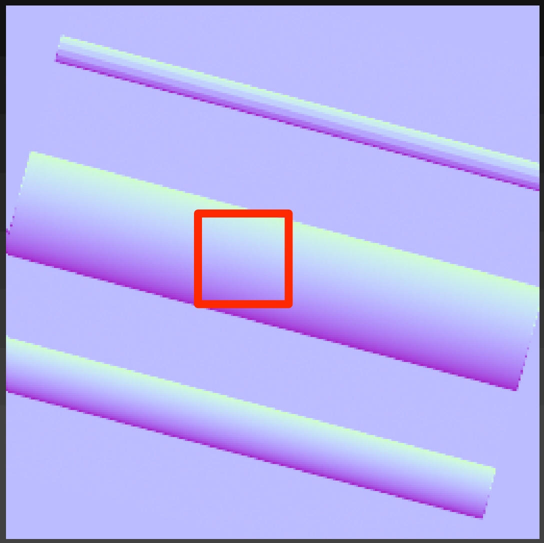
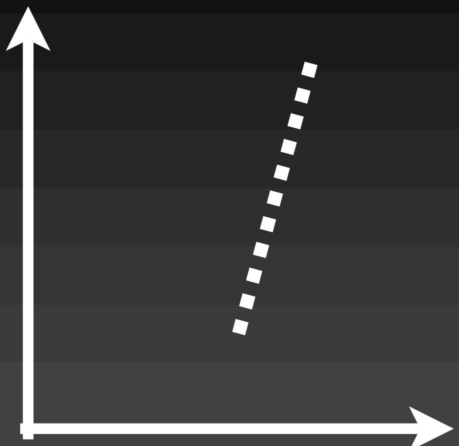
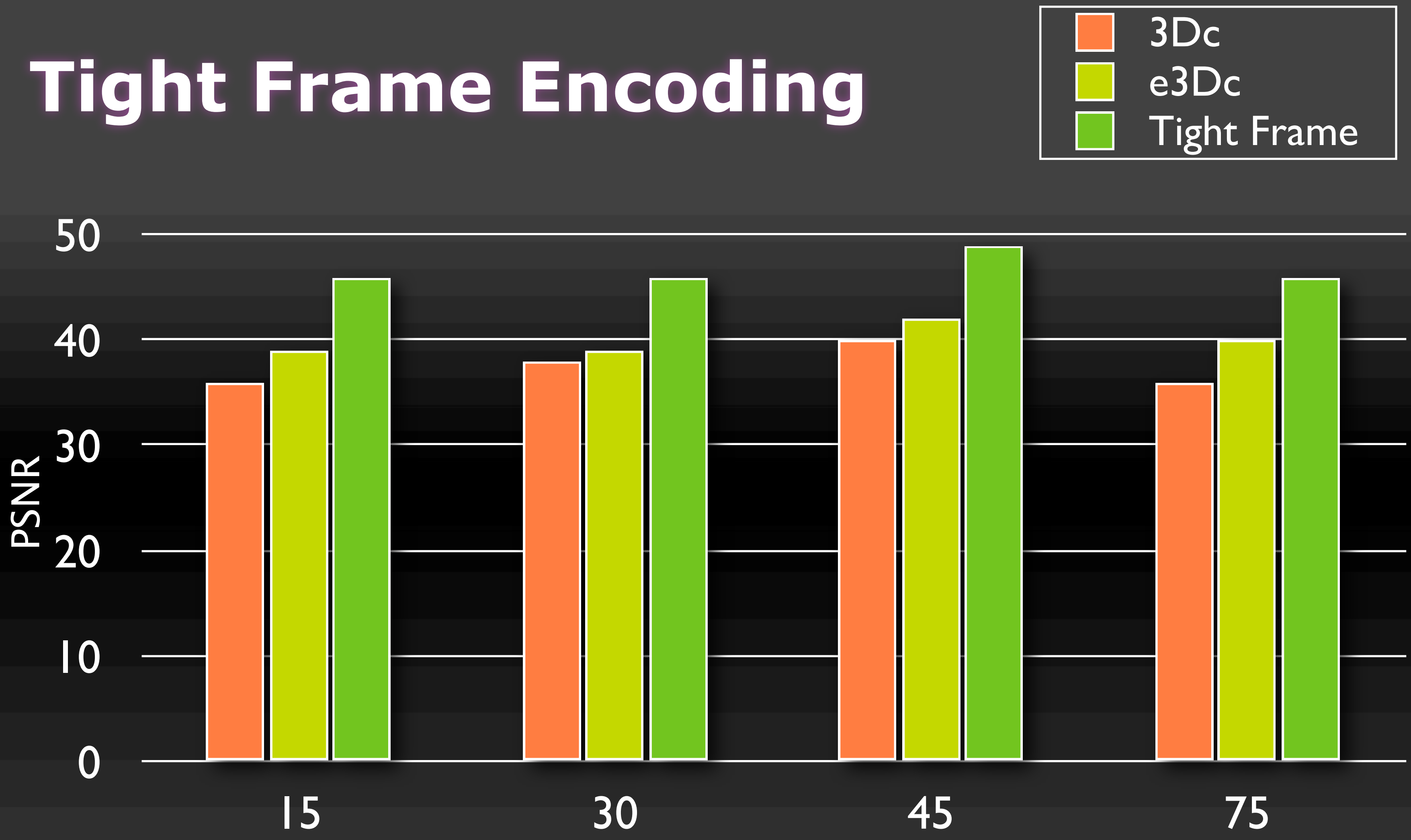
Tight Frame Compression

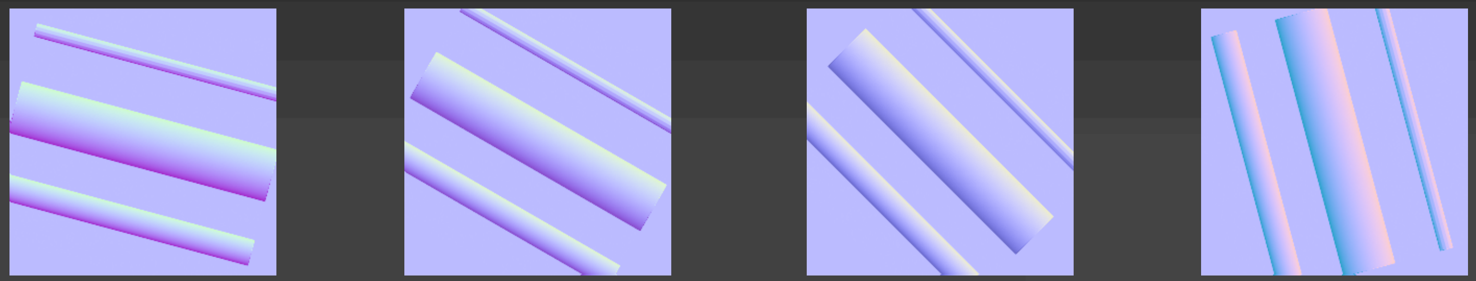
- Example: directed lines
  - coherence between channels!





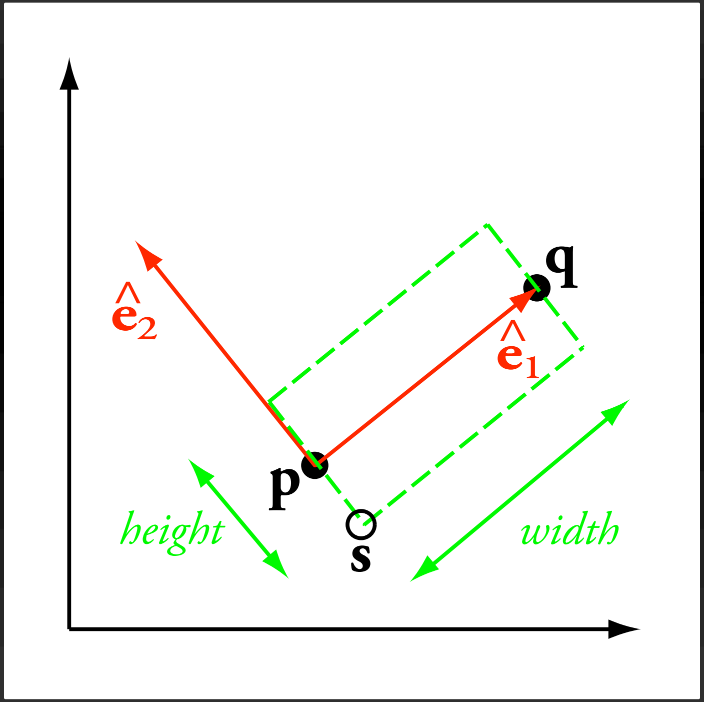
Tight Frame Encoding



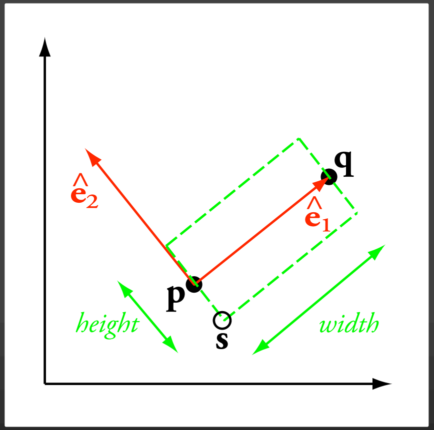


Tight Frame Compression

- OBB is tighter than AABB
- Store two point *p* & *q*
  - Enough to define local coordinate frame e_1, e_2
  - arbitrary rotation
- Store box aspect ratio
  - aspect ratio = height/width
- Variable Point Distribution still works!



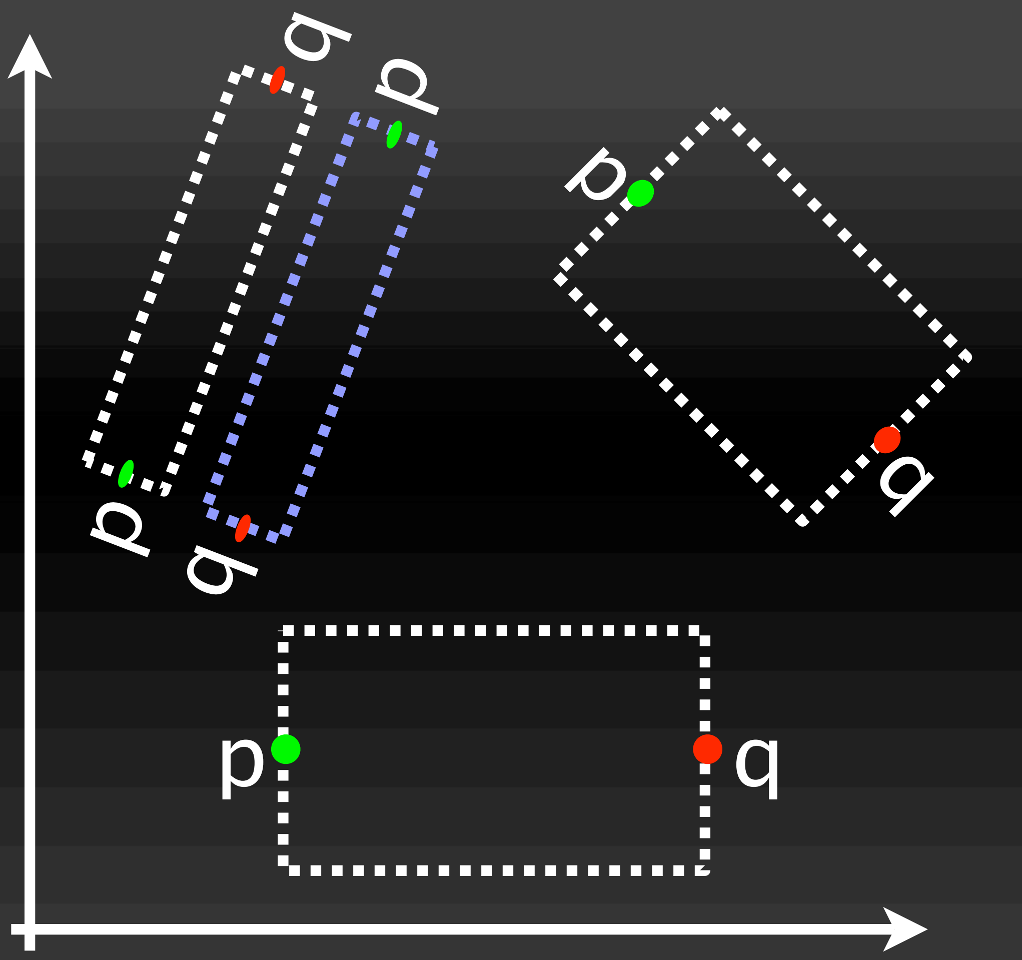
Tight Frame Bit Layout



- Target: 128 bits per block - 8 bpp
- Indices with 6 x 16 bits as before
- 32 bits left for encoding OBB
  - p & q are encoded using 7+7 bits each
  - Four bits for the aspect ratio, a
  - sixteen levels as $a_i = 1/32 + h_i/16$, $i = 0...15$
    Ex:

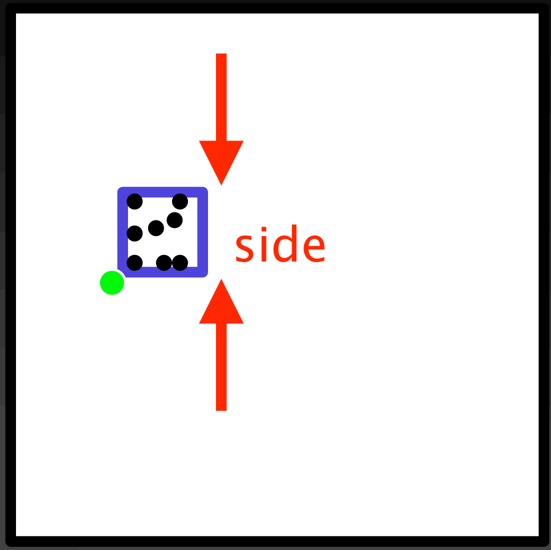
Additional Mode

- Unused bit combinations?
- $p_x >= q_x$ & $p_y >= q_y$
- Use to flag a mode!



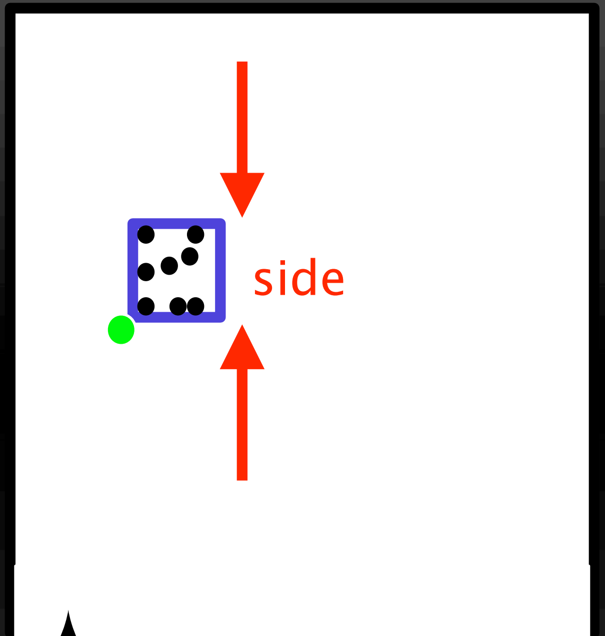
Tight Frame Differential Mode

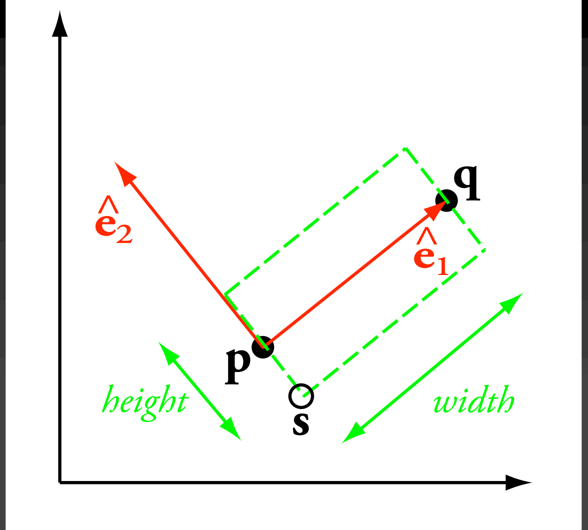
- Trigger when $p_x >= q_x$ and $p_y >= q_y$
- Encode all normals in a small square
  - Limit the square side length
- Compact representation but high resolution!
  - Lower left corner 2x11 bits
  - Side of the square: 8 bits
  - 8x8 grid over the square
  - 6x16 + 2x11 + 8 = 126 bits



Tight Frame Differential Mode

- Differential mode resolution
  - corner 2x11 bits, side: 8 bits,
  - Limit max square side to 1/4
  - min square size = $1/(4*2^8)$ = 1/1024
- Standard mode resolution
  - p and q with (2x7) bits each
  - max size = 1
  - min square size = 1/128





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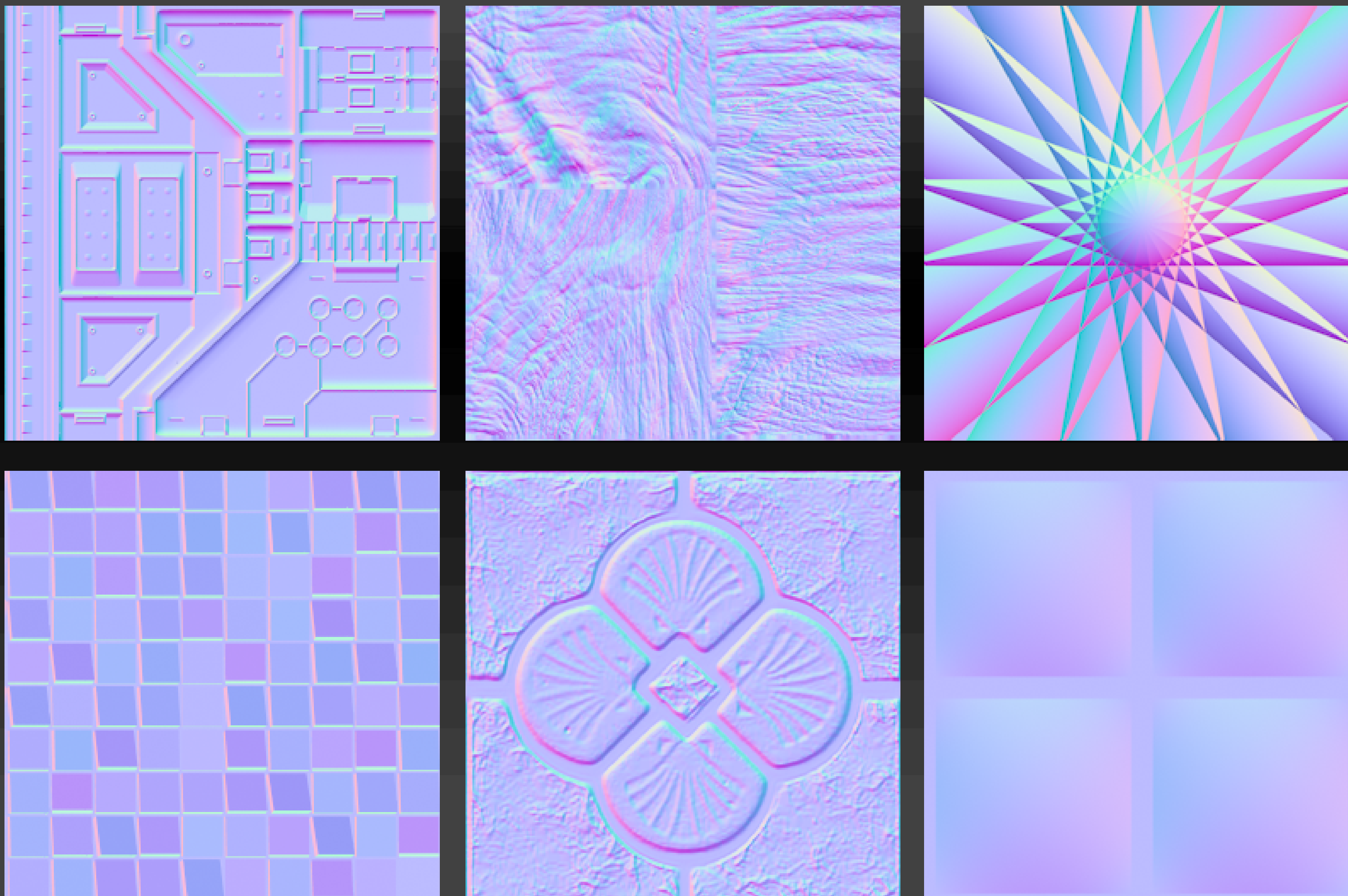
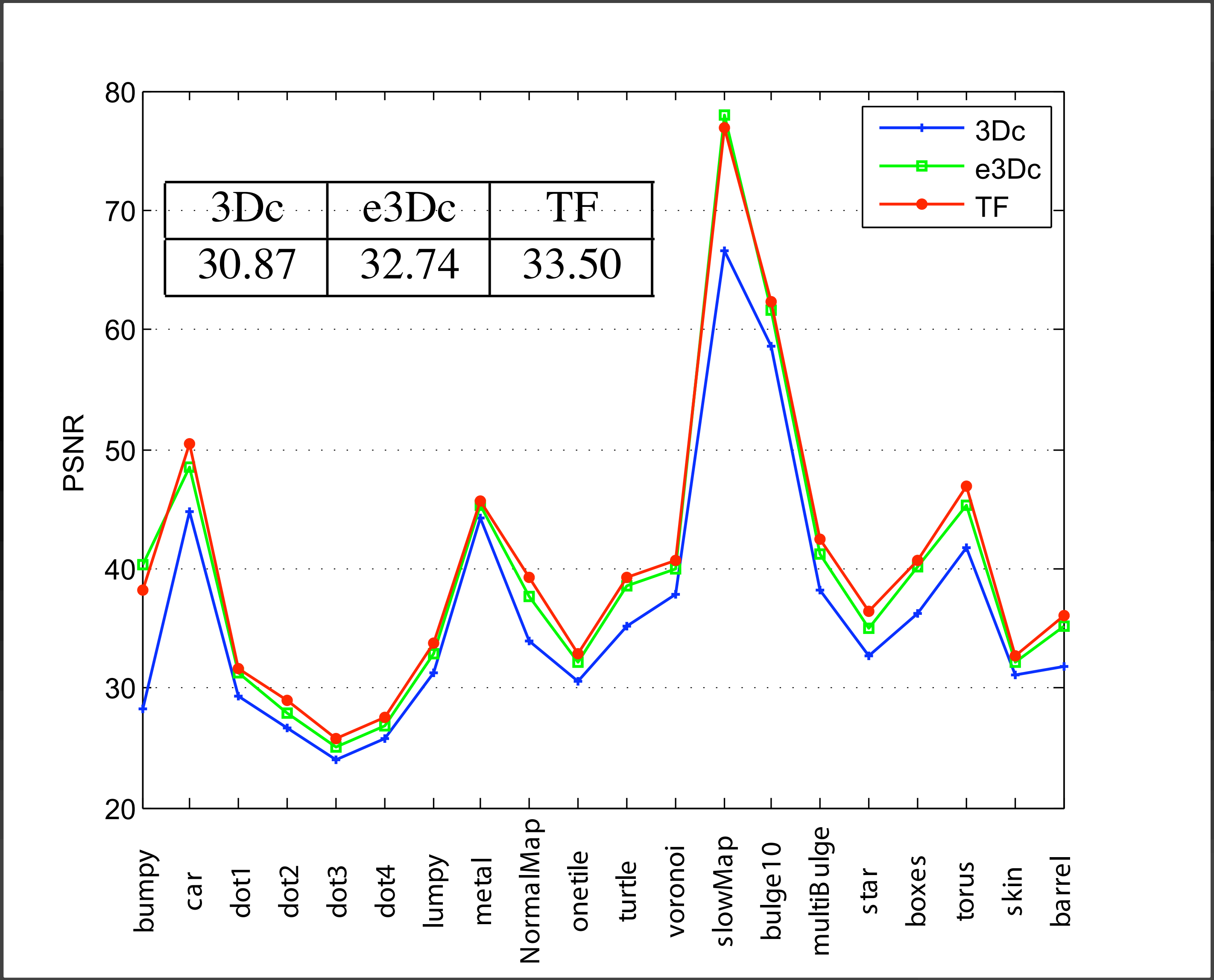
Evaluation

- PSNR
- Max error
  - A few bad normals “cracks” a smooth surface
- Angular deviation [Abate 05]
  - Angle between compressed and original normal
  - Motivation: Even a small error in the specular reflection is visible
  - Presented as a histogram

Test Images

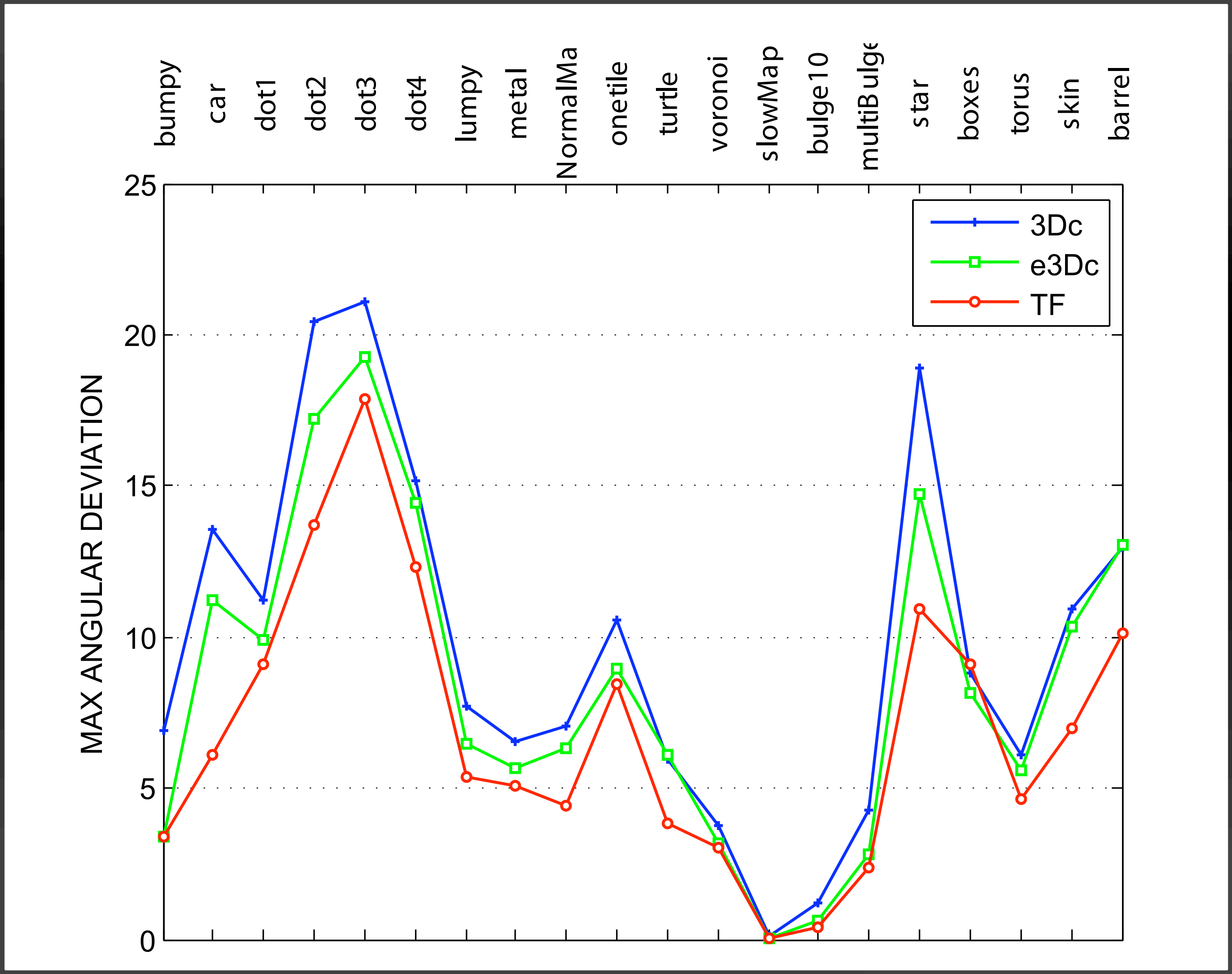


PSNR

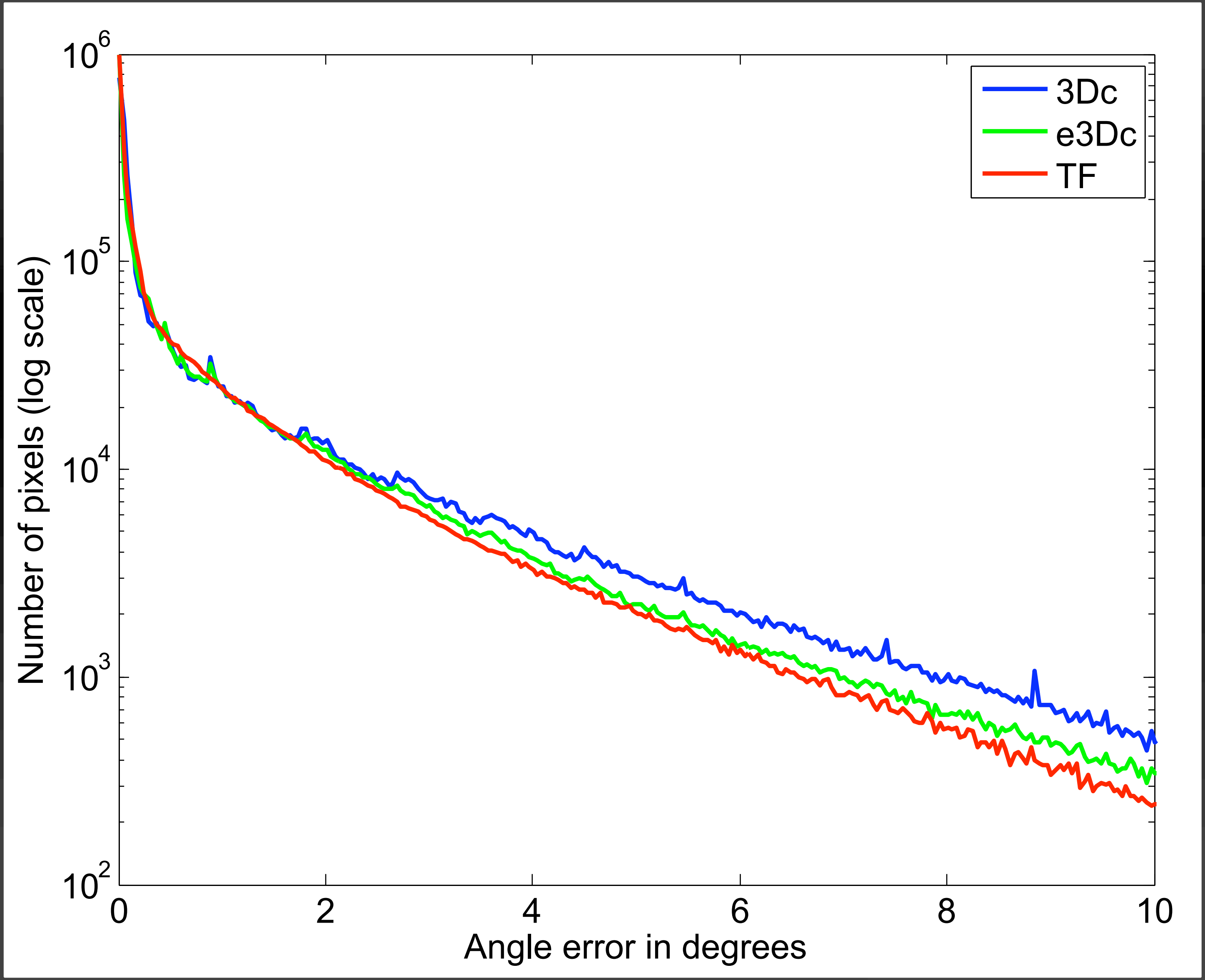


PSNR
3Dc
e3Dc
TF
30.87
32.74
33.50
80
70
60
50
40
30
20
bumpy
car
dot1
dot2
dot3
dot4
lumpy
metal
NormalMap
onetile
turtle
voronoi
slowMap
bulge10
multiBulge
star
boxes
torus
skin
barrel

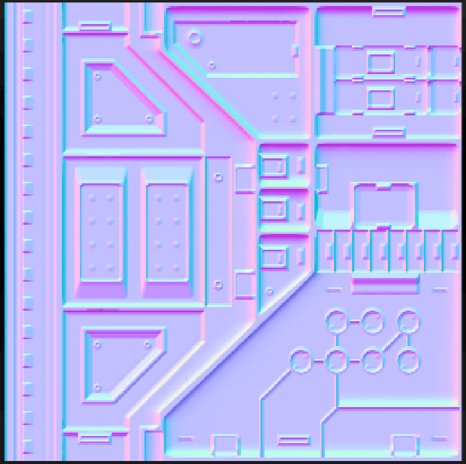
Max angular deviation

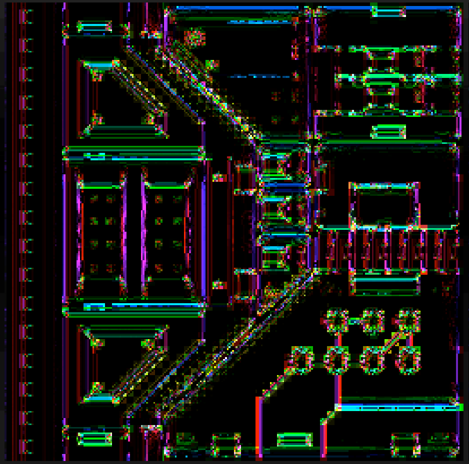


Error distribution

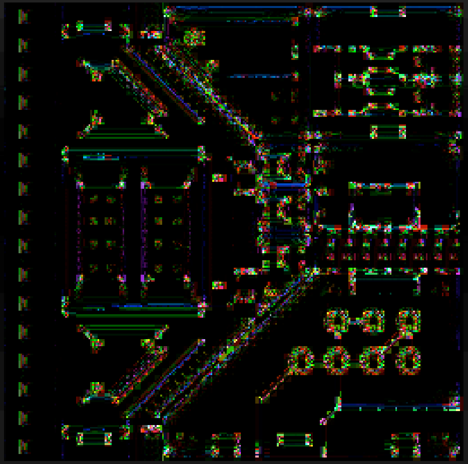


False Color

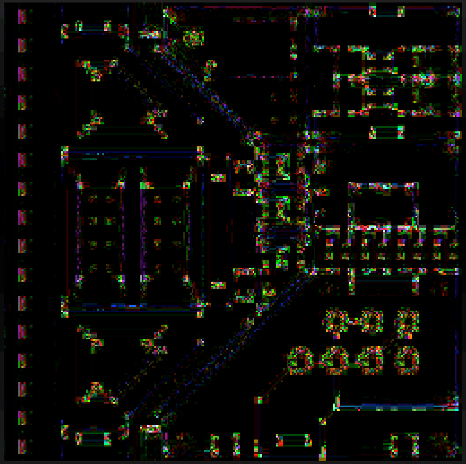




3Dc



e3Dc

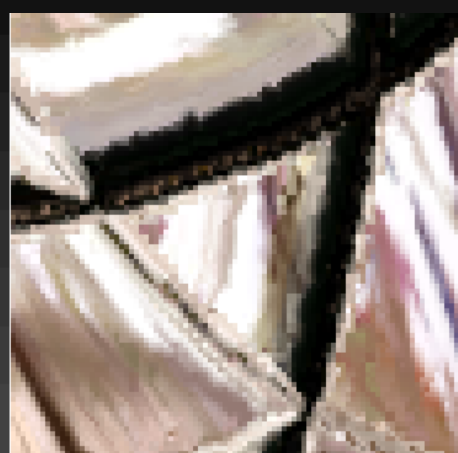


Tight Frame

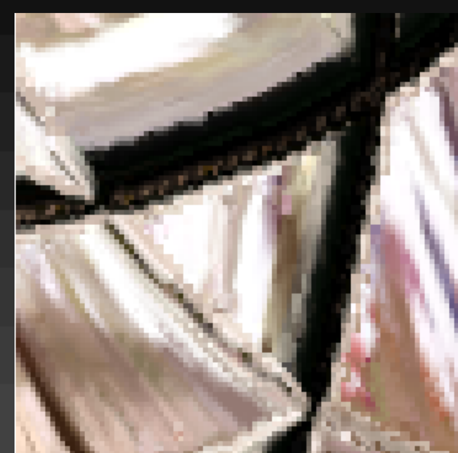
Rendered Quality

SSIM:
structural similarity
image metric

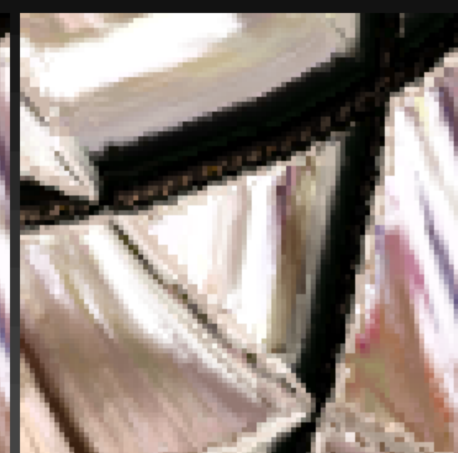
Original
100 %



3Dc
93.3



e3Dc
95.7



Tight Frame
96.3%

Pros & Cons

- Increased hardware cost
  - Twice the number of “multiply and divide” units compared to e3Dc, but still lightweight
- Unlike e3Dc, there is no backward-compatibility with 3Dc
  - The format cannot be used for encoding two 1D signals
  - Not depending on 3Dc patent
- More robust results!

Conclusions

- Higher quality than 3Dc
  - Still at 8 bits per texels
  - More flexibility with OBB, VPD and diff-mode
- Rather modest HW extensions
- API support?
  - Potential candidate for OpenGL ES?

Thank you!

- http://graphics.cs.lth.se