Advancements in HDR Images & Textures

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What do we do?

- We develop Basis Universal, an open source image/texture compression library
- We take advantage of GPU hardware acceleration to allow image-intensive applications to run more performantly
- When textures use compressed GPU formats, they take up a lot less space in GPU memory
- In real time, we transcode from KTX2 to the correct format that GPU hardware needs
- We contribute to the KTX2 standard so we can design the best format for everyone’s needs
- We partnered with Google to develop this HDR addition
- For HDR, we’re calling our spec revision “UASTC HDR”, building off our high quality UASTC spec for SDR images
SDR Codec Examples

Credit: https://x.com/abwood/status/1384901778173538313
SDR Workflow

Source image (.png) ➔ Encode ➔ KTX2 ➔ Real-time transcode ➔

Mobile
- ETC1
- ETC2
- PVRTC1
- ASTC
- BC1-5
- BC7

Desktop
SDR Codec Examples

Credit: https://blog.playcanvas.com/basis-texture-compression-arrives-in-playcanvas/
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What is HDR?

- HDR stands for “high dynamic range”
- When we go into a dark room, it takes a while for our eyes to adjust. In a light room, it feels too bright to see for a second. There is such a wide range of visible light!
- The real world has all kinds of ranges of colors and light that SDR (standard dynamic range, the most common range we use now) technology doesn’t pick up on
- HDR images are more realistic on HDR monitors, but even on SDR displays using them can expand graphics quality with unique photo editing and graphics engine capabilities
HDR Workflow

Source image (.exr, .hdr, .png) → Encode → KTX2 → Real-time transcoding → ASTC (Mobile HDR) → BC6H (Desktop HDR) → Uncompressed RGB/RGBA (half float)
Overview of UASTC HDR

- 6x compression in both storage size and GPU memory (48 -> 8 bits/pixel)
- One format that works on both HDR desktop and mobile GPUs
- Format is a simple subset of ASTC
- Real time transcoding to BC6H and uncompressed, no transcode process needed for ASTC
- WASM transcoding
- Quality is almost identical to ASTC/BC6H (which are very high quality) in terms of human perception

Next we’ll do a deep-dive into some of the technical details behind the project, and end with benchmarks and images of the codec
Example of minimal quality difference

Original image (desk: Reinhard tonemap, 1.0 intensity scale)  Compressed for mobile GPU (UASTC HDR)  Compressed for desktop GPU (UASTC HDR->BC6H)

More examples/explanation coming later!
UASTC HDR - Technical Details
UASTC HDR: Quick Background

- ASTC=Adaptive Scalable Texture Compression: A flexible, GPU-friendly, fixed-bitrate, fixed block size lossy texture format standard from the Khronos Group.
  - ASTC was developed by visionary engineers at ARM and AMD, supported by many mostly mobile GPU’s.
  - Supports LDR and HDR (half float/FP16/IEEE 754-2008), 4x4-12x12 block sizes, upsampled weight grids, many other features. Notable limitation: unsigned only.
    - See Adaptive Scalable Texture Compression, J. Nystad, A. Lassen, A. Pomianowski, S. Ellis and T. Olson
- On desktop (and many game consoles) the simpler “good enough” alternative from Microsoft is BC6H: “Block Compression” 6H.
  - Always 4x4 block size, 8 bits/texel. Notably: BC6H supports both signed or unsigned FP16 texels.
- To distribute HDR texture content, one of the common solutions is to offline encode twice to ASTC and BC6H, using two different encoders from different authors. Two encoders=≈2x as many bugs, API’s, optimization effort etc. Also distribution complexities, 2x storage cost.
- An alternative solution is to real-time encode on the target (using SIMD or compute), requiring extra power, complexity, potential bugs due to driver interaction (drivers/shader compilers=bugs), pipeline bubbles, quality tradeoffs, encoder licensing/dev costs, SIMD porting cost, etc. (Sometimes this solution is needed.)
- The compressed GPU texture formats are the “black sheep” of the image/texture compression approaches. Few work in this space, but they are crucial to exploit the power of modern GPU’s.
UASTC HDR: A New Alternative

- We encode to a common subset and feature union of both ASTC HDR and BC6H.
- “UASTC” HDR=“Universal” HDR ASTC, a standardized constrained subset of full HDR ASTC.
- Key feature: UASTC HDR is 100% standard ASTC texture data.
  - UASTC HDR data can be provided to the driver or GPU as-is because it follows the ASTC spec (i.e. it’s just ASTC HDR)
  - Existing ASTC decoders (CPU, hardware or compute) already support it right now.
  - Existing ASTC encoders (CPU or compute) can be enhanced to support UASTC HDR.
- UASTC HDR always uses 4x4 blocks and is always 8-bits pixel/texel.
  - Input: 48 bits/pixel (unsigned FP16 RGB), so fixed 6:1 compression.
  - Supports lossless solid color blocks (“void extent”), or lossy 1 subset, or 2 subsets with 27 possible common partition patterns (out of 32 possible for BC6H)
- To transcode to BC6H, the ASTC block configuration is directly converted to BC6H’s block configuration.
  - No expensive per-texel work needed, no expensive partition pattern searching, etc.
  - UASTC HDR’s RGB endpoint pairs (1 or 2 per block) are directly converted to BC6H’s RGB endpoints.
  - UASTC HDR’s 4x4 texel weights are directly translated to BC6H’s - no searching, just simple weight index remapping.
  - ASTC->BC6H is typically lossy, however the error is within a fraction of a dB PSNR in 16-bit half-float space (details/graphs in a bit).
UASTC HDR: Pros & Cons

• Pros:
  - It’s just constrained ASTC, so UASTC HDR data is still “standard”.
  - We can leverage the existing ASTC spec, tooling, infrastructure, knowledge, etc.
  - Simpler than targeting full ASTC HDR, relatively easy compute shader encoding.
  - No transcoding on mobile devices (so no extra power/compute cost); mostly desktop pays the ASTC->BC6H transcode cost. (Desktop has plenty of power, mobile doesn’t.)
  - Encoder can be improved over time without changing spec.

• Cons:
  - Lower quality than max. achievable BC6H/ASTC. (Visually it’s typically imperceptible in our testing, but this is obviously subjective.)
  - No alpha: BC6H doesn’t support alpha, ASTC HDR does.
  - No signed values: ASTC doesn’t support signed values, BC6H does.
  - Our reference encoder is not as fast as ARM’s, but we can catch up.
UASTC HDR: Risks

- Top risk: There may be “outlier blocks” we haven’t found that transcode particularly badly to BC6H.
  - So far the worse ASTC->BC6H artifacts we’ve seen are not objectionable.
  - The ref. encoder tries 100’s or 1,000’s of block configurations and weight utilization constraints in order to maximize BC6H transcoding quality.

- Once we have a spec the BC6H transcoding algorithm is locked in stone.
  - If we discover higher quality ways of converting the endpoints or weights we’ll need an updated spec.
  - However, there is flexibility here. We may only suggest an algorithm, and it can be improved/tuned over time without invalidating existing data/the spec.

- Another risk: The ASTC HDR subset tradeoff may not be strong enough for all users.
  - Do we add upsampled weight grids? (Extra complexity.)
  - Do we support luma-only CEM’s?
UASTC HDR: ASTC Features Supported

- “Void Extent” solid color blocks
  - 3 half float colors (lossless to BC6H). Must be unsigned, not NaN/Inf.

- ASTC (Color Endpoint Mode) CEM 7: 1 or 2 partitions
  - Endpoint ISE ranges 4-20, all endpoint encoding submodes (0-5)

- ASTC CEM 11: 1 or 2 partitions
  - Endpoint ISE ranges 4-20, submodes 0-7 or direct

- ISE texel weight ranges supported:
  - 1 (3 levels), 2 (4 levels), 3 (5 levels), 4 (6 levels), 5 (8 levels), 6 (10 levels), 7 (12 levels), 8 (16 levels)

- 2 partitions: Only supports the 27 partition patterns in common between BC6H and ASTC (out of BC6H’s 32 supported patterns).

- Weight grid must always be 4x4, i.e. no weight grid upsampling.

- Anything else is not UASTC HDR (i.e. no dual plane, other CEM’s, etc.)
UASTC HDR: BC6H Features Supported

- ASTC HDR->BC6H transcoder supports all BC6H modes:
  - Modes 11-14: 1 subset, 4-bit weights
  - Modes 1-10: 2 subsets, 3-bit weights

- Transcoder uses the highest precision endpoint mode that can delta encode the ASTC HDR endpoints
  - Requires a very simple search.
  - Current transcoder always falls back to trying a lower precision mode if delta encoding fails, may change to a search that minimizes overall error.

- Weight values are translated using fixed 1D lookup tables.
  - We’re going to experiment with many different tables.
  - Some ASTC and BC6H interpolation weights slightly differ, but the encoder can try encodings that don’t utilize these “more lossy” weights and choose the best overall encoding.
How we develop/test for quality

- HDR imaging introduces many new complexities
- BasisU lib now accepts float images (but input must map to pos. FP16)
- Command line tool now accepts .EXR/.HDR files as input
- Main work monitor is a 1000 nits ASUS ProArt, PA27UCX-K 27", 4K HDR Mini LED, 97% DCI-P3 99.5%, Adobe RGB 100% sRGB
  - This monitor still requires tonemapping to display most .EXR/.HDR files
  - Windows 10 HDR setup and finding proper/working HDR image viewers is very tricky
- For debugging/devel, lib can unpack the ASTC/BC6H encodings at dozens of different exposures with a simple Reinhard tone mapper and write PNG’s
- We also use a lossless compressive tonemapper for FP16->16-bit PNG’s
  - Tone mapping is only used for testing/development. The codec itself is full FP16 HDR.
Problem: Which HDR quality metric?

- We need a simple quality metric that works across all supported positive half-float input values and doesn’t assume that the output will be tonemapped or exposed (because: it may not be, we don’t know)
- ARM’s standard “astcenc” encoder reports mPSNR, or “Multi-Exposure Peak-Signal-to-Noise Ratio”
- This approach requires many passes through the image, each pass assumes the output is converted to 2.2 gamma (not sRGB!) and scaled/clamped to [0,255]
- Our needs are different: our encoder works internally in FP16 space (using approx. RMSLE for error), we accept FP16 input, and FP16 output.
- We need/want FP16 PSNR (for positive values).
Half-float PSNR Details

- Jim Blinn’s Corner’s: Notation, Notation, Notation, page 125:
  “If you only deal with positive numbers, the bit pattern of a floating-point number, interpreted as an integer, gives a piecewise linear approximation to the logarithm function.”

- We interpret the FP16 bits as `uint16_t` and generate stock avg. RGB PSNR from that
Some viewers used for testing

- [https://viewer.openhdr.org/](https://viewer.openhdr.org/)
  - Web-based, supports .EXR/.HDR, exposure control, basic
- **Windows: “HDR + WCG Image Viewer” by Simon Tao**
  - Supports HDR mode in Windows (HDR10) with a proper config/monitor/cable
  - [https://github.com/13thsymphony/HDRImageViewer](https://github.com/13thsymphony/HDRImageViewer)
FP16 PSNR on six .EXR/.HDR photos: ARM's astcenc v4.8.0 -thorough vs. UASTC HDR vs. UASTC HDR transcoded to BC6H
sponza: Reinhard tonemapped, $2^{-5}$ intensity scale

Source

UASTC HDR

UASTC HDR->BC6H
desk: Reinhard tonemap, 1.0 intensity scale

Source

UASTC HDR

UASTC HDR->BC6H
Tree, source, Reinhard tonemap
Tree, UASTC HDR, Reinhard tonemap
Tree, UASTC HDR->BC6H, Reinhard tonemap
Thank you!

We are excited to introduce GPU-accelerated, cross platform HDR images to you all!

- Feel free to check out our SDR project here: https://github.com/binomialLLC/basis_universal
- Reach out to us directly: https://binomial.info/contact
- Contribute to the new HDR standard at 3DFormats Khronos meetings
- Public repo coming soon!