



Adaptive Scalable Texture Compression

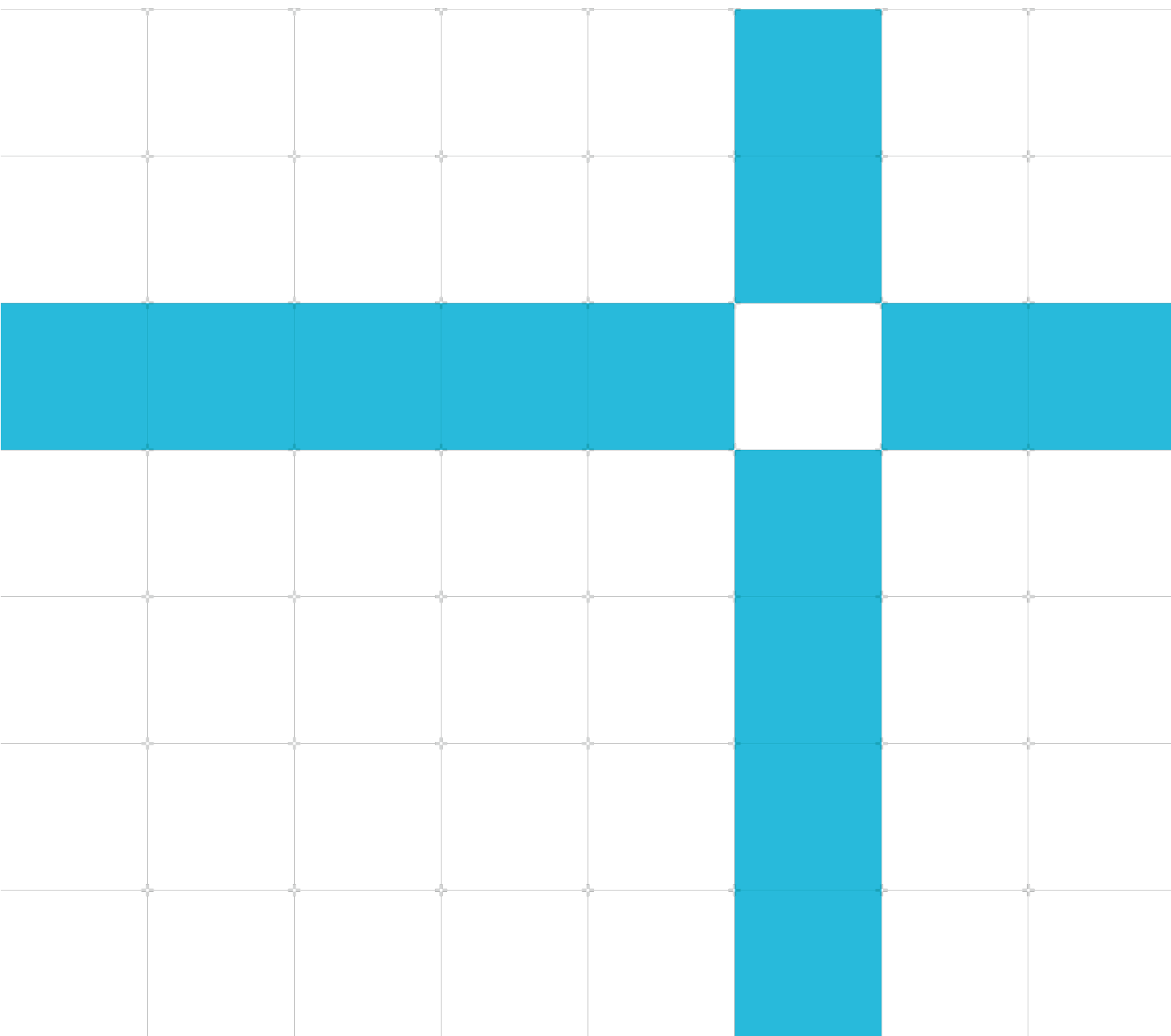
User Guide

Non-Confidential

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Issue 01

102162



Adaptive Scalable Texture Compression

User Guide

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Release information

Document history

Issue	Date	Confidentiality	Change
01	01 July 2020	Non-Confidential	First release

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(LES-PRE-20349)

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1 Overview

Adaptive Scalable Texture Compression (ASTC) is an advanced lossy texture compression technology developed by Arm and AMD.

This guide provides information about how you can use ASTC effectively to optimize the performance of your apps. In particular, this guide covers the following subjects:

- What is ASTC and why is it needed?
- Technical details of the ASTC compression algorithm
- How to use tools like Arm ASTC Encoder (astcenc) and Arm Mali Texture Compression Tool to compress game assets
- How to use ASTC with graphics APIs like OpenGL ES and Vulkan
- How to use ASTC with the Unity and Unreal Engine gaming engines

At the end of this guide, you can [check your knowledge](#). You will have learned about the best practices for using ASTC, including the key decisions you must take.

2 Best practices

This guide provides information about what ASTC is, specific technical details about how ASTC works, and guidance on how to use ASTC in your projects.

The guide includes many pieces of advice regarding best practices for using ASTC.

For your convenience, here are links to the sections in the guide that contain this best practice guidance:

- [Using ASTC for game assets](#)
 - [Choosing a suitable bitrate](#)
 - [Normal maps](#)
 - [Masks](#)
 - [sRGB](#)
- [Unity and ASTC](#)
 - [Build settings](#)
 - [Texture-specific settings](#)
 - [Building for different hardware](#)
- [Unreal Engine and ASTC](#)

3 Why treat textures differently?

For most content, texture access is one of the main consumers of memory bandwidth in a system. Textures are usually represented as 2D image data. Over time, textures have become higher resolution, resulting in larger amounts of image data being transferred between the GPU and main memory. This memory bandwidth overhead can slow down GPU performance if we cannot load data fast enough to keep the functional units fully utilized. As well as the bandwidth overhead, moving all this data around uses power which reduces battery life.

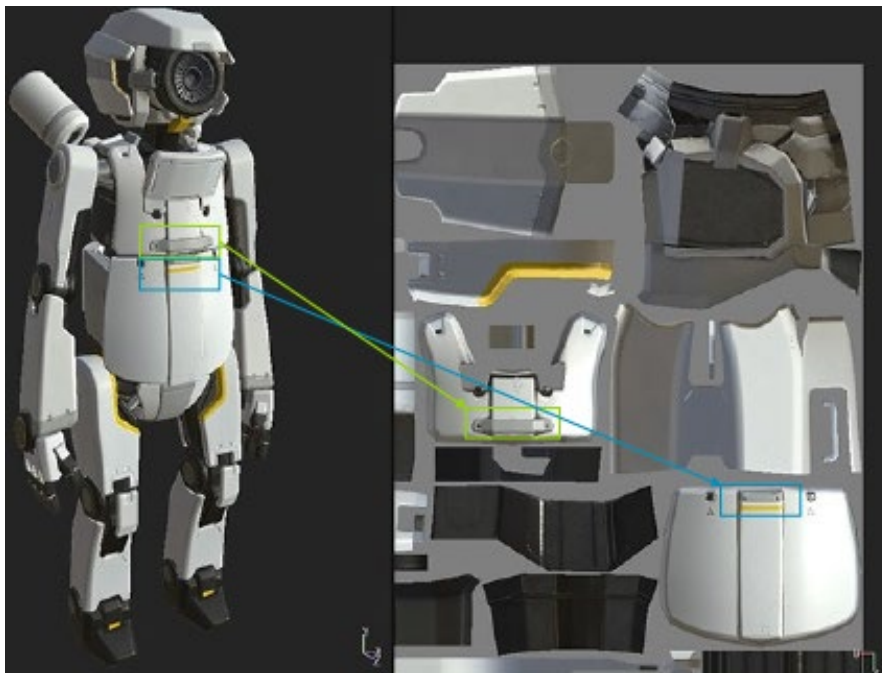
To reduce the impact on performance, we can use specialized compression schemes to reduce the size of texture resources. These real-time compression schemes are significantly different to the more general types of compression, like JPEG or PNG, that you are probably familiar with.

Traditional compression schemes like JPG and PNG are designed to compress or decompress an entire image. They can achieve very good compression rates and image quality. However, they are not designed to let you access smaller portions of the full image easily without decompressing the entire image.

When mapping 2D textures onto a model, individual texels might be extracted from the full texture image in an unpredictable order:

- Not all texture elements might be needed. For example, depending on the orientation of the model, and any other objects that might be obscuring parts of it.
- Texels that are rendered next to each other in the final image may originate from different parts of the texture.

The following image shows the arrangement of different texture elements within a texture image, and a model with that texture applied. Notice that adjacent texels in the rendered image are not necessarily adjacent in the texture image.



It is computationally expensive for a GPU to decompress the entire image when it only needs a small portion of the whole. As a result, real-time compression schemes are designed to provide efficient decoding for random sampling of elements within a larger image, when they are used in shaders.

There are various techniques to achieve this result, but most algorithms do the following:

- Compress a fixed size NxM texel input block in isolation from other blocks
- Write this compressed block out into a fixed number of bits.

This allows simple address calculation in the GPU. Because all input and output sizes are fixed, it is a relatively simple pointer offset calculation to calculate a sample address. We therefore only need to access the data for one NxM block to decompress any single texel.

4 ASTC format overview

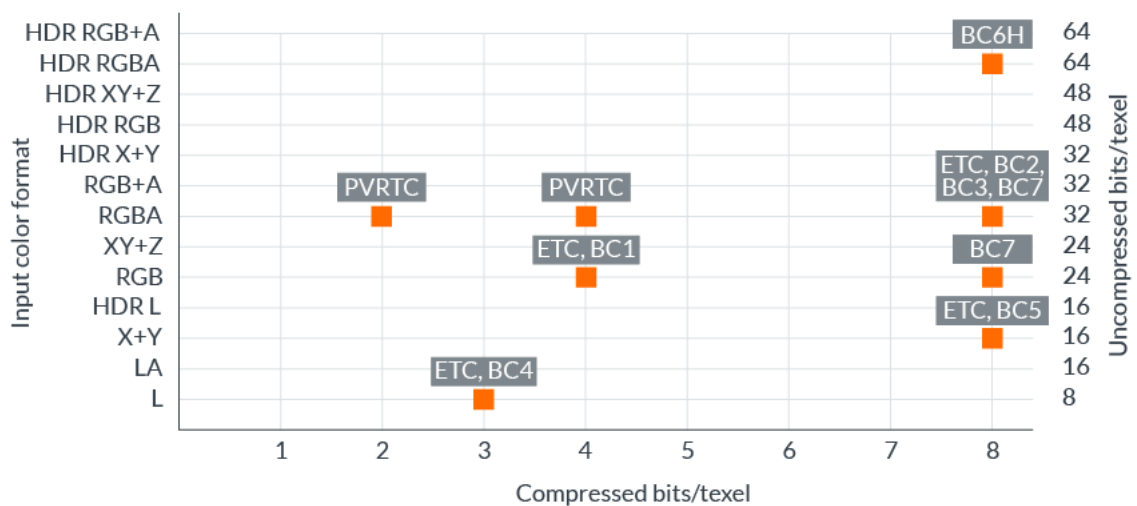
Adaptive Scalable Texture Compression (ASTC) is an advanced lossy texture compression technology developed by Arm and AMD. Khronos has adopted ASTC as an official extension to the OpenGL and OpenGL ES APIs, and as a standard optional feature for the Vulkan API.

ASTC has the following advantages over older texture compression formats:

- **Format flexibility.** ASTC can compress between one and four channels of data, including one non-correlated channel like RGB+A (correlated RGB, non-correlated alpha).
- **Bit rate flexibility.** ASTC provides a wide choice of bit rates when compressing images, between 0.89 bits and 8 bits per texel (bpt). The bit rate choice is independent of the color format choice.
- **Advanced format support.** ASTC can compress images in either Low Dynamic Range (LDR), LDR sRGB, or High Dynamic Range (HDR) color spaces. ASTC can also compress 3D volumetric textures.
- **Improved image quality.** Despite the high degree of format flexibility, ASTC outperforms nearly all legacy texture compression formats on image quality at equivalent bit rates. Examples of legacy texture compression formats that ASTC outperforms include ETC2, PVRTC, and the BC formats.

Bitrates below 1bpp are achieved by using a system of variable block sizes. Most block-based texture compression methods have a single fixed block size. By contrast, ASTC can store an image with a regular grid of blocks of any size from 4x4 to 12x12, including non-square block sizes. ASTC can also store 3D textures, with block sizes ranging from 3x3x3 to 6x6x6.

Before the creation of ASTC, the available texture compression formats supported relatively few combinations of color format and bit rate, as shown in the following diagram:



The situation is even worse than this diagram shows. Many formats are either proprietary or not available on some operating systems, so any single platform has very limited compression choices.

This situation makes developing content which is portable across multiple platforms difficult. Assets might need to be compressed differently for each platform. Each asset pack might need to use

different levels of compression, and might have no compression on some platforms. This would leave either some image quality, or some memory bandwidth efficiency, untapped.

A better way was needed. The Khronos group requested proposals for a new compression algorithm to be adopted, like the earlier ETC algorithm was adopted for OpenGL ES. ASTC was the result, developed by Arm and AMD, and has been adopted as an official algorithm for OpenGL, OpenGL ES, and Vulkan.

5 The ASTC algorithm

This section of the guide explains how the ASTC algorithm works. We start with a high-level overview of the block compression algorithm and color encoding process, then we examine the technical details.

5.1 Block compression

Compression formats for real-time graphics need the ability to quickly and efficiently make random samples into a texture. This places two technical requirements on any compression format. It must be possible to do the following:

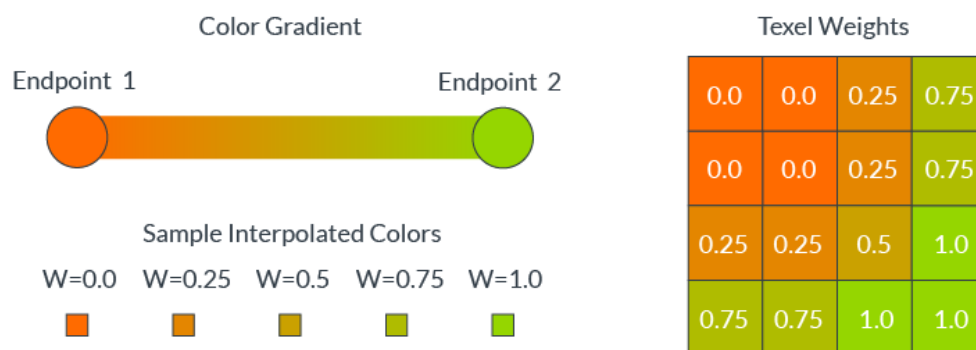
- Compute the address of data in memory given only a sample coordinate.
- Decompress random samples without decompressing too much surrounding data.

The standard solution that all contemporary real-time formats use, including ASTC, is to divide the image into fixed-size blocks of texels. Each block is then compressed into a fixed number of output bits. This feature makes it possible to access texels quickly, in any order, and with a well-bounded decompression cost.

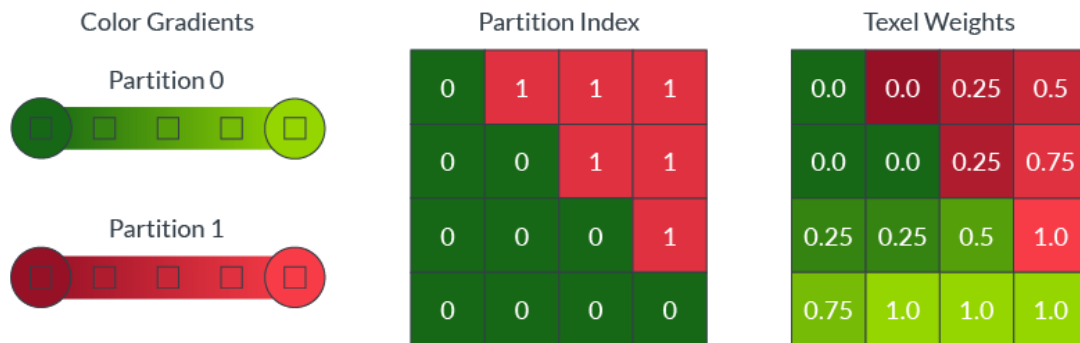
The 2D block footprints in ASTC range from 4x4 texels up to 12x12 texels, which all compress into 128-bit output blocks. By dividing 128 bits by the number of texels in the footprint, we derive the format bit rates. These bit rates range from 8 bpt ($128/(4*4)$) down to 0.89 bpt ($128/(12*12)$).

5.2 Color encoding

ASTC uses gradients to assign the color values of each texel. Each compressed block stores the end-point colors for a gradient, and an interpolation weight for each texel. During decompression, the color value for each texel is generated by interpolating between the two end-point colors, based on the per-texel weight. The following diagram shows this interpolation for a variety of texel weights:



Blocks often contain a complex distribution of colors, for example a red ball sitting on green grass. In these scenarios, a single-color gradient cannot accurately represent all different texel color values. ASTC allows a block to define up to four distinct color gradients, called partitions, and can assign each texel to a single partition. For our example, we require two partitions, one for the red ball texels and one for the green grass texels. The following diagram shows how the partition index specifies which color gradient to use for each texel:



5.3 Integer encoding

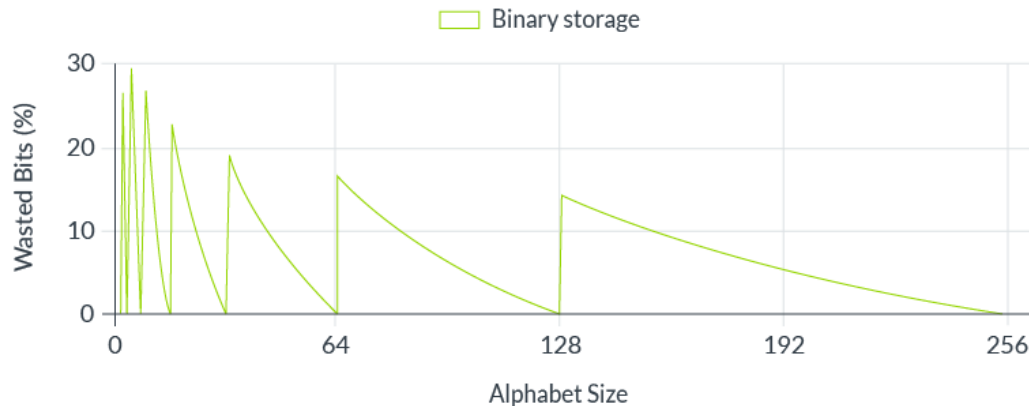
Initially the idea of fractional bits per texel sounds implausible, or even impossible, because we are so used to storing numbers as a whole number of bits. However, it is not quite as strange as it sounds. ASTC uses an encoding technique called Bounded Integer Sequence Encoding (BISE), which stores numbers with a fractional number of bits to pack information more efficiently.

5.4 Storing alphabets

Even though color and weight values per texel are notionally floating-point values, we have too few bits available to directly store the actual values. To reduce the storage size, these values must be quantized during compression. For example, if we have a floating-point weight for each texel in the range 0.0 to 1.0, we could choose to quantize to five values: 0.0, 0.25, 0.5, 0.75, and 1.0. We can then represent these five quantized values in storage using the integer values 0-4.

In the general case, if we choose to quantize N levels, we need to be able to efficiently store characters of an alphabet containing N symbols. An N symbol alphabet contains $\log_2(N)$ bits of information per character. If we have an alphabet of five possible symbols, then each character contains ~ 2.32 bits of information, but simple binary storage would require us to round up to three bits. This wastes 22.3% of our storage capacity.

The following chart shows the percentage of the bit-space that would be wasted using simple binary encoding to store an arbitrary N symbol alphabet:



This chart shows that for most alphabet sizes, using an integer number of bits per character wastes a lot of storage capacity. Efficiency is critically important to a compression format, so this is an area that ASTC needed to address.

One solution is to round the quantization level up to the next power of two, so that rather than being wasted the extra bits are used. However, this solution forces the encoder to spend bits which could be used elsewhere for a bigger benefit, so it reduces image quality and is a suboptimal solution.

5.5 Quints and trits

Instead of rounding up a five-symbol alphabet, called a quint, to three bits, a more efficient solution is to pack three quint characters together. Three characters in a five-symbol alphabet have 5^3 (125) combinations, and contain 6.97 bits of information. We can store these three quint characters in seven bits and have a storage waste of only 0.5%.

We can similarly construct a three-symbol alphabet, called a trit, and pack trit characters in groups of five. Each character group has 3^5 (243) combinations, and contains 7.92 bits of information. We can store these five trit characters in eight bits and have a storage waste of only 1%.

5.6 Bounded Integer Sequence Encoding

The Bounded Integer Sequence Encoding (BISE), that ASTC uses, allows storage of character sequences using arbitrary alphabets of up to 256 symbols. Each alphabet size is encoded in the most space-efficient choice of bits, trits, and quints.

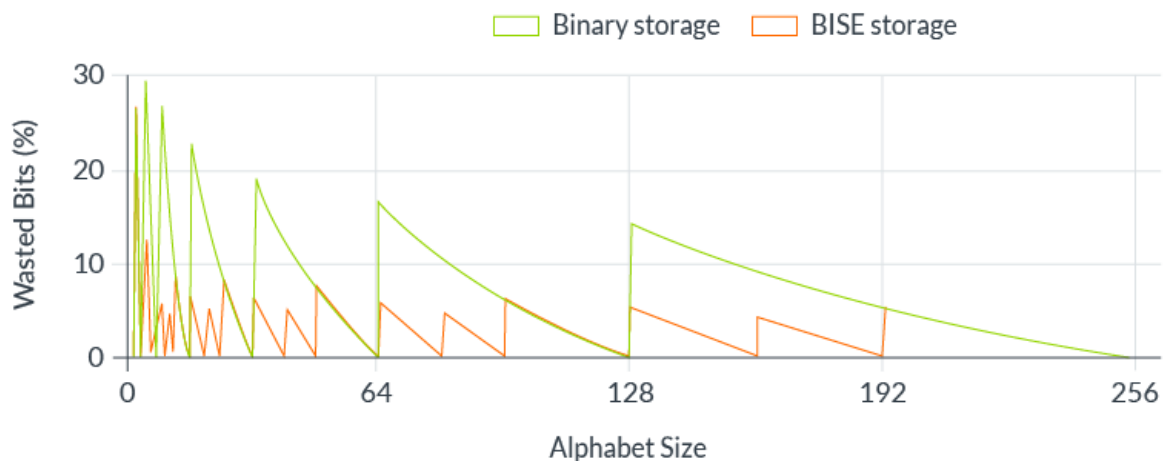
- Alphabets with up to $(2^n - 1)$ symbols can be encoded using n bits per character.
- Alphabets with up to $3 \times (2^n - 1)$ symbols can be encoded using n bits (m) and a trit (t) per character, and reconstructed using the equation $((t \times 2^n) + m)$.
- Alphabets with up to $5 \times (2^n - 1)$ symbols can be encoded using n bits (m) and a quint (q) per character, and reconstructed using the equation $((q \times 2^n) + m)$.

When the number of characters in a sequence is not a multiple of three or five we must avoid wasting storage at the end of the sequence, so we add another constraint on the encoding. If the last few values in the sequence to encode are zero, the last few bits in the encoded bit string must also be zero. Ideally, the number of nonzero bits is easily calculated and does not depend on the magnitudes of the previous encoded values. This is challenging to arrange during compression, but it is possible. This means that we do not need to store any padding after the end of the bit sequence, because we can safely assume that they are zero bits.

With this constraint in place, and by some smart packing of the bits, trits, and quints, BISE encodes a string of S characters in an N symbol alphabet using a fixed number of bits:

- S values up to $(2^N - 1)$ use (NxS) bits.
- S values up to $(3 * 2^N - 1)$ use $(NxS + \text{ceil}(8S / 5))$ bits.
- S values up to $(5 * 2^N - 1)$ use $(NxS + \text{ceil}(7S / 3))$ bits.

The compressor chooses the option which produces the smallest storage for the alphabet size that is being stored. Some use binary, some use bits and a trit, and some use bits and a quint. If we compare the storage efficiency of BISE against simple binary for the range of possible alphabet sizes that we might want to encode, we see that BISE is much more efficient. The following chart shows the efficiency gain of BISE storage over binary storage:



5.7 Block sizes

ASTC always compresses blocks of texels into 128-bit outputs. However, ASTC allows the developer to select from a range of block sizes to enable a fine-grained tradeoff between image quality and size. The following table shows the different block sizes result and the corresponding bits per texel:

Table 5-1 ASTC 2D block sizes

Block footprint	Bits per texel
4x4	8.00
5x4	6.40
5x5	5.12
6x5	4.27
6x6	3.56
8x5	3.20
8x6	2.67
10x5	2.56
10x6	2.13
8x8	2.00
10x8	1.60
10x10	1.28
12x10	1.07
12x12	0.89

5.8 Color endpoints

The color data for a block is encoded as a gradient between two color endpoints. Each texel selects a position along that gradient, which is then interpolated during decompression. ASTC supports 16 color endpoint encoding schemes, known as endpoint modes.

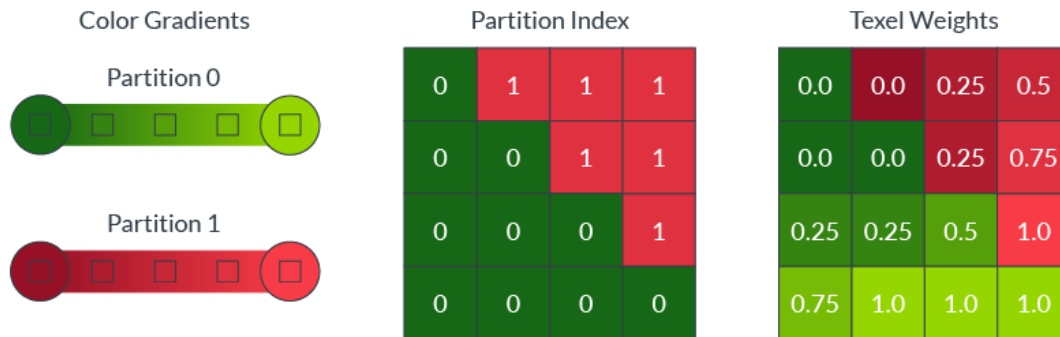
The options for endpoint modes let you vary the following:

- The number of color channels. For example, luminance, luminance+alpha, rgb, or rgba
- The encoding method. For example, direct, base+offset, base+scale, or quantization level
- The data range. For example, low dynamic range or High Dynamic Range

The endpoint modes, and the endpoint color BISE quantization level, can be chosen on a per-block basis.

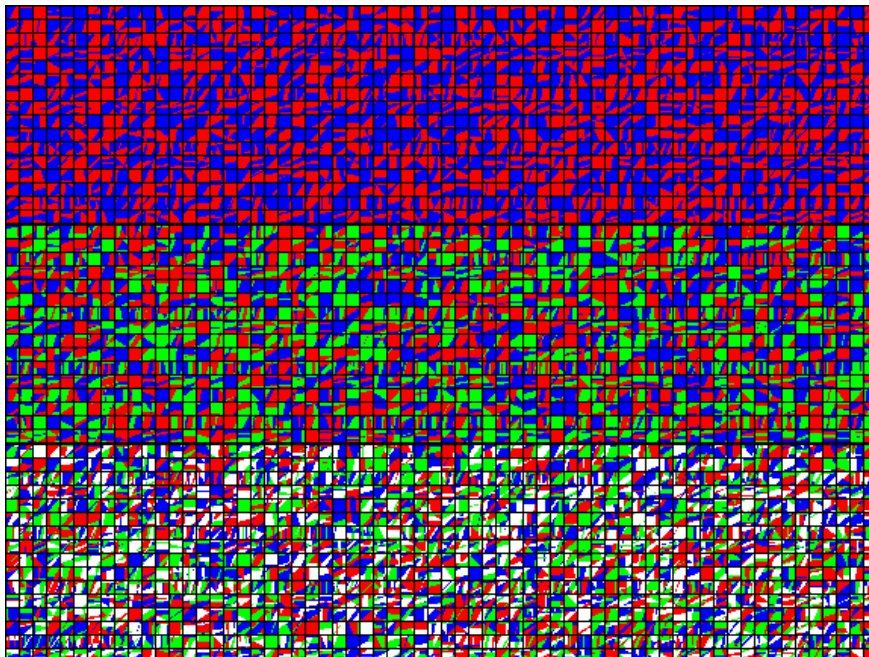
5.9 Color partitions

Colors within a block are often complex. A single-color gradient often cannot accurately capture all the colors within a block. For example, the red ball lying on green grass described earlier in this section requires two color partitions, as shown in the following diagram:



ASTC allows a single block to reference up to four color gradients, called partitions. Each texel is then assigned to a single partition for the purposes of decompression.

Directly storing the partition assignment for each texel would need a lot of decompressor hardware to store it for all block sizes. Instead, ASTC algorithmically generates a range of patterns, using the partition index as a seed value. The compression process selects the best pattern match for each block. The block then only needs to store the index of the best matching pattern. The following image shows the generated patterns for two (top section of image), three (middle section of image), and four (bottom section of image) partitions for the 8x8 block size:



The number of partitions and the partition index can be chosen on a per-block basis, and a different color endpoint mode can be chosen per partition.

ASTC uses a 10-bit seed to drive the partition assignments. The hash that is used introduces horizontal bias in a third of the partitions, vertical bias in a third, and no bias in the final third. Because they are procedurally generated, some of the partitions are not useful, especially the smaller block sizes.

Many partitions are duplicates, and many are degenerate. An N partition hash results in at least one partition assignment that contains no texels.

5.10 Choosing the best pattern for each block

During compression, the algorithm must select the correct distribution pattern and boundary color pairs, then generate the quantized value for each pixel. There is a certain degree of trial and error involved in the selection of patterns and boundary colors. When compressing, there is a trade-off between compression time and final image quality. The higher the quality, the more alternatives the algorithm tries before deciding which is best. However long the compression takes, the decompression time is fixed. This is because the image data can always be re-extrapolated from the pattern and boundary colors in a single pass.

The compression algorithm can use different metrics to judge the quality of different attempts. These metrics range from pure value ratios of signal to noise, to a perceptual judgment weighted towards human visual acuity. The algorithm can also judge the channels individually rather than as a whole. Treating channels individually preserves detail for textures where the individual channels may be used as a data source for a shader program, or to reduce angular noise, which is important for tangent space normal maps.

5.11 Texel weights

Each texel requires a weight, which defines the relative contribution of each color endpoint when interpolating the color gradient.

For smaller block sizes, we can choose to store the weight directly, with one weight per texel. However, for the larger block sizes there are not enough bits of storage to do this. To work around this issue, ASTC allows the weight grid to be stored at a lower resolution than the texel grid. The per-texel weights are interpolated from the stored weight grid during decompression using a bilinear interpolation.

Both the number of texel weights, and the weight value BISE quantization level, can be chosen on a per-block basis.

5.12 Dual-plane weights

Using a single weight for all color channels works well when there is good correlation across the channels, but this is not always the case. Common examples where we might get low correlation include:

- Textures storing RGBA data. Alpha masks are not usually closely correlated with the color value.
- Textures storing normal data. The X and Y normal values often change independently.

ASTC provides a dual-plane mode, which uses two separate weight grids for each texel. A single channel can be assigned to a second plane of weights, while the other three use the first plane of weights.

The use of dual-plane mode can be chosen on a per-block basis, but its use prevents the use of four-color partitions. This is because there are not enough bits to concurrently store both an extra plane of weights and an extra set of color endpoints.

6 ASTC benefits

ASTC offers several advantages over existing texture compression schemes. We will look at these advantages in this section of the guide.

6.1 Adaptive compression

The first word in the acronym ASTC is adaptive, and after reading this guide it should be clear why. Each block always compresses into 128 bits of storage, but the developer can choose from a wide range of texel block sizes. The compressor gets a huge amount of latitude to determine how those 128 bits are used.

The compressor can trade off the number of bits assigned to colors and weights on a per-block basis to get the best image quality possible.

Factors that affect the number of bits assigned to colors include:

- the number of partitions
- the endpoint mode
- the stored quantization level

Factors that affect the number of bits assigned to weights include:

- the number of weights per block
- the use of dual-plane
- the stored quantization level

6.2 Range of supported formats

The compression scheme that ASTC uses effectively compresses arbitrary sequences of floating-point numbers, with a flexible number of channels, across any of the supported block sizes. There is no real notion of color format in the compression scheme, beyond the color endpoint mode selection. However, a sensible compressor would use some format-specific heuristics to drive an efficient state-space search.

The orthogonal encoding design allows ASTC to provide complete coverage of our desirable format matrix, across a wide range of bit rates, as shown in the [Block sizes](#) table.

This wide range of supported formats and bit rates means that ASTC can compress almost any asset to some degree. You can make appropriate bit rate choices based on quality needs rather than format constraints.

6.3 Image quality

The high level of flexibility ASTC provides does not mean that image quality is compromised. On the contrary, an ASTC compressor is not forced to spend bits on things that do not improve image quality. This is made possible by the high packing efficiency allowed by BISE encoding, and the ability to dynamically choose where to spend encoding space on a per-block basis.

This dynamic compression efficiency results in significant improvements in image quality compared to older texture formats, despite ASTC handling a much wider range of options. Comparisons with older formats give the following results:

- ASTC at 2 bpt outperforms PVRTC at 2 bpt by ~2.0dB.
- ASTC at 3.56 bpt outperforms PVRTC and BC1 at 4 bpt by ~1.5dB, and ETC2 by ~0.7dB, despite a 10% bit rate disadvantage.
- ASTC at 8 bpt for LDR formats is comparable in quality to BC7 at 8 bpt.
- ASTC at 8 bpt for HDR formats is comparable in quality to BC6H at 8 bpt.

For more information about this data, see [ASTC: The Future of Texture Compression](#).

Differences as small as 0.25dB are visible to the human eye. Remember that dB uses a logarithmic scale, so these results are significant image quality improvements.

6.4 3D compression

The techniques in ASTC which underpin the format generalize to compressing volumetric texture data without needing very much extra decompression hardware.

ASTC optionally supports compression of 3D textures, which is a unique feature not found in any earlier format, at the bit rates shown in the following table:

Table 6-1 ASTC 3D block sizes

Block footprint	Bits per texel
3x3x3	4.74
4x3x3	3.56
4x4x3	2.67
4x4x4	2.00
5x4x4	1.60
5x5x4	1.28
5x5x5	1.02
6x5x5	0.85
6x6x5	0.71
6x6x6	0.59

7 ASTC compression tools

Several different tools are available to help developers use the ASTC format to compress their texture images.

These tools include:

- [Arm ASTC Encoder](#)
- [Arm Mali Texture Compression Tool](#)
- [Intel Fast ISPC Texture Compressor](#)
- [AMD Compressorator](#)

7.1 Arm ASTC Encoder

Arm ASTC Encoder (`astcenc`) is a command-line tool for compressing and decompressing images using the ASTC format.

Arm ASTC Encoder supports compression of the following formats into ASTC format output images:

- Low Dynamic Range image formats: BMP, JPEG, PNG, and TGA
- High Dynamic Range image formats: EXR and HDR
- DDS and KTX container formats, though only a subset of format features is supported.

The `astcenc` application provides a full list of available command-line arguments. Use the `-help` option, shown in the following code, to see extensive help information, including usage instructions and details of all available command-line options:

```
astcenc -help
```

7.1.1 Basic commands

To compress an input file `<inputfile>`, and save the compressed form to a texture file `<outputfile>` run the following command:

```
astcenc -c <inputfile> <outputfile> <rate> [options]
```

To decompress a texture file run the following command:

```
astcenc -d <inputfile> <outputfile> [options]
```

To see what a texture would look like compressed with a given set of options, you can compress and then immediately decompress an input file by running the following command:

```
astcenc -t <input.file> <output.file> <rate> [options]
```

The `-t` option compresses the file with the given options, then immediately decompresses it into the output file. The interim compressed image is not saved, and the input and output files are both in a decompressed file format.

7.1.2 Rate

The `<rate>` is used to decide a block size. This argument can be specified in one of two ways:

- Use a decimal number to specify a required bitrate. The codec picks a block size to match the specified bitrate as closely as possible. The bitrate must contain at least one decimal place. For example:

```
astcenc -c input.png output.astc 0.8 -fast
```

- Use a block size to specify the block dimensions to use along the X, Y (and for 3D textures) Z axes. The dimensions are separated with the character `x`, with no spaces, as you can see here:

```
astcenc -c input.png output.astc 8x8 -fast
```

7.1.3 Options

The `[options]` specified in the command syntax provide further control over the operation of the `astcenc` tool. Some of the most important options are:

- The most useful arguments are the quality presets: `-veryfast`, `-fast`, `-medium`, `-thorough`, and `-exhaustive`

The `-veryfast` option, while almost instantaneous, gives good results only for a small subset of input images.

Conversely, the `-exhaustive` quality level attempts every possible bounding pattern combination for every block. This option takes a much longer time, but often has very little visible difference to a file that is compressed with the `-thorough` option.

- There are many available options to set various compression quality factors including:
 - `-plimit` specifies the number of block partition patterns to attempt.
 - `-dblimit` stops compression work on a block when the signal to noise level of the block, as measured in dB, reaches the specified limit.
 - `-maxiters` specifies a maximum number of refinement iterations for colors and weights.

To see all available options, use the `-help` option, as shown here:

```
astcenc -help
```

7.1.4 HDR

ASTC supports HDR image formats. Using HDR image formats requires no additional effort in code.

To compress an HDR input image, use the standard command form, as shown here:

```
astcenc -c <inputfile> <outputfile> <rate> [options]
```

By default, the encoder does not use HDR encoding for the output when it is encoding an input image in an HDR format. To enable the use of HDR encoding, use one of the following options:

- `-forcehdr_rgb` uses an HDR or LDR encoding, as appropriate, on a per-block basis. The alpha channel, if present, is always encoded as LDR.
- `-forcehdr_rgba` uses an HDR or LDR as appropriate on a per-block basis.

7.1.5 3D textures

The `astcenc` application supports 3D textures at a block level.

Encoding a 3D texture requires the following syntax:

```
-array <size>
```

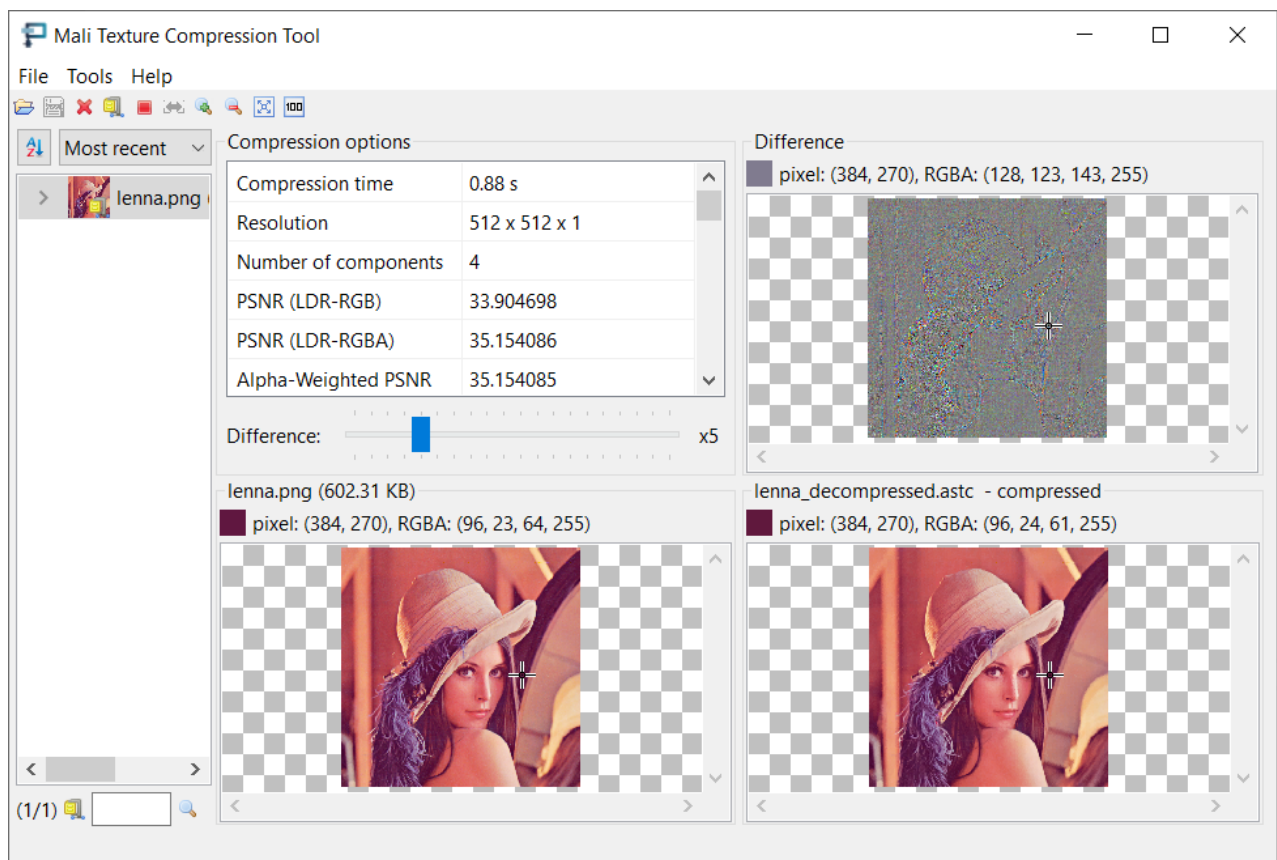
When the `-array` argument is specified, the input filename is interpreted as a prefix. The actual input files are named with the specified prefix plus `_0`, `_1`, and so on, up to `<size>-1`.

For example, the following command loads files named `slice_0.png`, `slice_1.png`, `slice_2.png`, and `slice_3.png`:

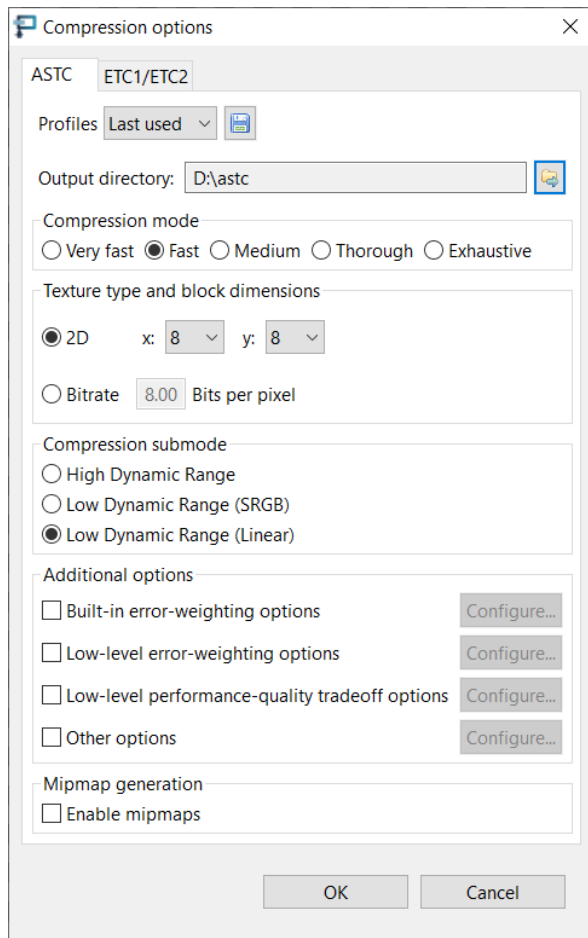
```
astcenc -c slice.png slice.astc 4x4x4 -array 4 -medium
```

7.2 Arm Mali Texture Compression Tool

[Arm Mali Texture Compression Tool](#) is a GUI application which supports ASTC and ETC formats. This tool lets you preview and analyze your texture images to assess image quality after compression and decompression. The following image shows the Arm Mali Texture Compression Tool:



The following image shows the **Compression options** dialog. This dialog lets you select a quality preset (**Compression mode**) and other settings depending on texture usage:



7.3 Intel Fast ISPC Texture Compressor

Intel produces [Fast ISPC Texture Compressor](#), a tool which uses the ISPC compiler to provide a significant performance boost. Fast ISPC Texture Compressor is an open-source library. You must download ISPC compiler to build this tool.

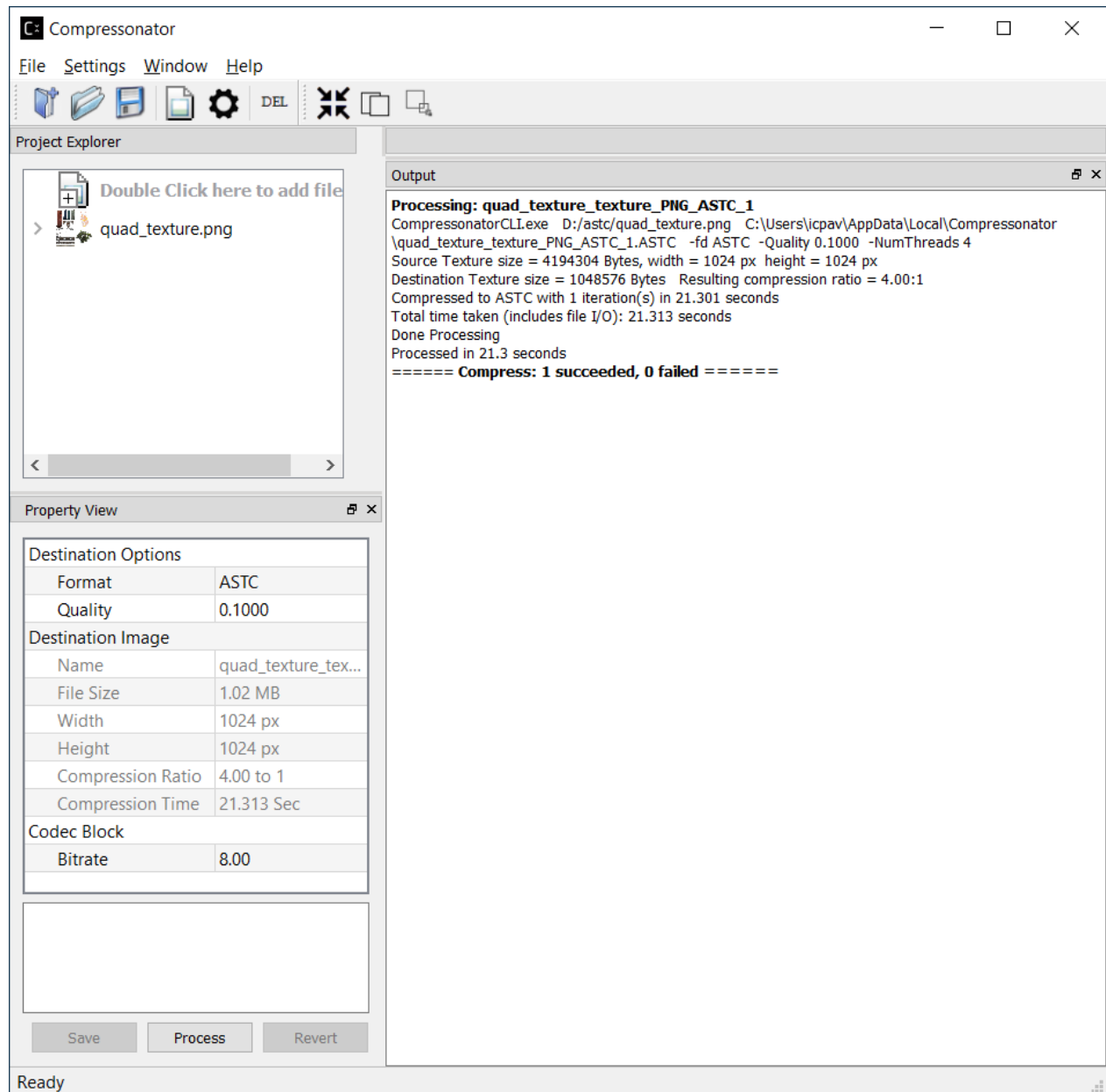
Fast ISPC Texture Compressor supports several texture compression formats and has a fast compression time. However, ASTC support is very basic, limited to 2D LDR profiles with block sizes up to 8x8, and with no fine-grained control over quality.

7.4 AMD Compressorator

AMD Compressorator is a set of SDK, command-line, and GUI tools. Compressorator supports many texture compression formats and provides useful features like batch processing and texture preview.

ASTC support is limited, with little control over quality. Compression is not as fast as other tools.

The following image shows AMD Compressorator:



8 Using ASTC for game assets

As a developer, you must consider several things when compressing game assets. These considerations depend on how the texture is used, and the required image quality.

8.1 Choosing a suitable bitrate

Choosing a higher or a lower bitrate lets you trade image quality against data size to obtain the optimum balance. Both `astcenc` and Mali Texture Compression Tool, and other tools and game engines, allow you to specify either bitrate or block size in the entire range that is supported by ASTC.

The following image shows how different bit rates affect image quality:



A good practice is to split all your texture assets into quality categories based on their distance to the viewer or general visibility and importance. For example, you can split your assets into three categories: high, medium, and low. Instead of adjusting the bitrate for each individual texture, experiment with a few textures from each category and determine the best bitrate for each category. You can then use these bitrates to batch-compress the rest of the textures in each category.

You must differentiate between textures that are used in 3D content from textures that are used in GUI elements. Sometimes it might be best to leave the GUI textures uncompressed to avoid unwanted artifacts.

If your device supports ASTC, use it to compress the textures in your 3D content. If your device does not support ASTC, try using ETC2.

8.2 Normal maps

Normal maps must be treated in a specific way to avoid undesired artifacts.

The `astcenc` tool provides two options for encoding normal maps: `-normal_psnr` and `-normal_percep`.

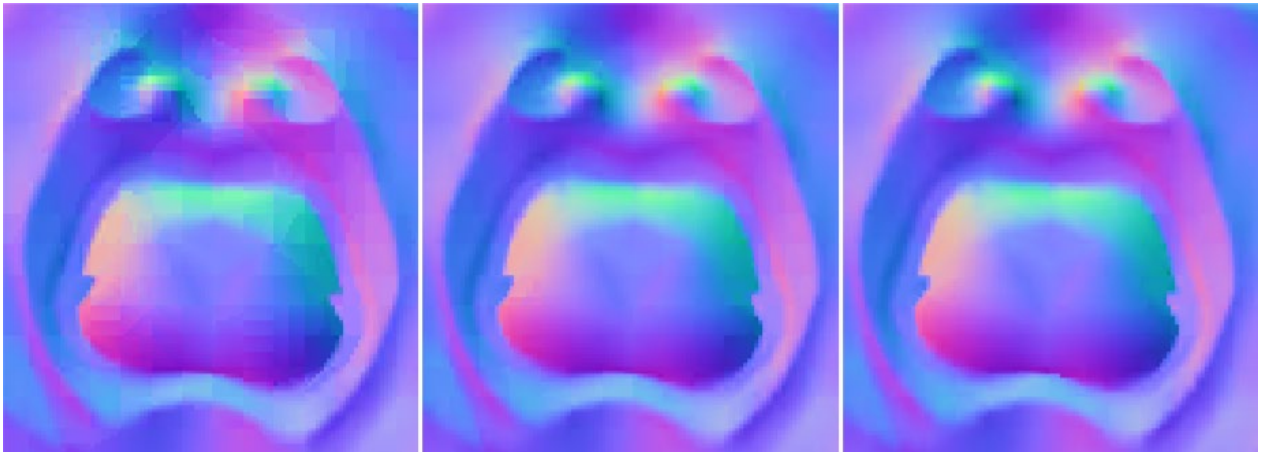
Both options specify that `astcenc` should deal with normal maps by storing the X and Y components of a unit-length tangent space normal as luminance and alpha. The Z component of the normal can be reconstructed in shader code based on the knowledge that the vector is unit length.

The GLSL code for reconstruction of the Z value is as follows:

```
vec3 normal;  
normal.xy = texture(...).ga;  
normal.z = sqrt(1 - dot(normal.xy, normal.xy));
```

The `-normal_psnr` and `-normal_percep` options also switch the compressor to optimize for angular error in the resulting vector rather than for absolute color error in the data. Angular error is more important than absolute color error for normal maps.

The following image shows the result of using the `-normal_psnr` and `-normal_percep` options:



The normal map on the left is compressed with default settings. The middle normal map uses `-normal_psnr`. The normal map on the right uses `-normal_percep`.

8.3 Masks

The `-mask` option specifies that the input texture has entirely unrelated content in each channel. This option tells `astcenc` that it is undesirable for errors in one channel to affect other channels.

The following image shows an example of a bitmap font:



The red channel represents the characters, the blue channel is a rear glow, and the green channel is a drop shadow.

The left image is the uncompressed data. The middle image is compressed with default settings, and the right image uses the `-mask` argument.

8.4 sRGB

ASTC supports non-linear sRGB color space conversion at both compression and decompression time.

To keep images in sRGB color space until the point that they are used:

1. Compress images in the usual way.
2. When loading images, use the sRGB texture formats instead of the regular texture formats.

The sRGB texture formats contain `SRGB8_ALPHA8` in the name, for example, `COMPRESSED_SRGB8_ALPHA8_ASTC_4x4_KHR`. There is an sRGB equivalent for every RGBA format.

As an alternative to using sRGB texture types at run time, there is also a command-line argument for the compressor to transform them to linear RGBA before compression. The `-srgb` argument converts the color space and compresses the texture in linear space, ready to be loaded with the usual RGBA texture formats.

9 Using ASTC with graphics APIs

OpenGL, using an extension, and Vulkan both support ASTC. This support allows easy integration and hardware utilization.

The ASTC functionality is specified as a set of three feature profiles:

- 2D LDR profile
- 2D LDR + HDR profile
- 2D LDR + HDR and 3D LDR + HDR profile

The 2D LDR profile is mandatory in OpenGL ES 3.2, and a standardized optional feature for Vulkan. This means that the 2D LDR profile is widely supported on contemporary mobile devices. The 2D HDR profile is not mandatory, but is widely supported.

9.1 Khronos OpenGL ES extensions

Official Khronos extensions exist for the feature profiles of ASTC:

- [KHR_texture_compression_astc_ldr](#): 2D LDR support
- [KHR_texture_compression_astc_sliced_3d](#): 2D + sliced 3D LDR support
- [KHR_texture_compression_astc_hdr](#): 2D + sliced 3D HDR support and 2D LDR support

There is also a convenience extension, which provides the full feature set implied by supporting all three Khronos extensions:

- [OES_texture_compression_astc](#): 2D + 3D, LDR + HDR support



There is a distinction between sliced 3D, where each slice can be compressed independently, and 3D formats like 4x4x4. [OES_texture_compression_astc](#) is the only extension that brings in the 3D formats, and is a superset of the KHR extensions.

ASTC decompresses texels into fp16 intermediate values, except for sRGB which always decompresses into 8-bit UNORM intermediates. For many use cases, this gives more dynamic range and precision than required, and can cause a reduction in texturing efficiency due to the larger data size.

The following extensions, supported on recent mobile GPUs, allow applications to reduce the intermediate precision to either UNORM8 or RGB9e5:

- [OES_texture_compression_astc_decode_mode](#): Allow UNORM8 intermediates.
- [OES_texture_compression_astc_decode_mode_rgb9e5](#): Allow RGB9e5 intermediates.

UNORM8 is recommended for LDR textures, and RGB9e5 is recommended for HDR textures.

For more information about using the ASTC decode mode extension to select decoding precision when decoding ASTC image blocks, see [OpenGL ES SDK for Android: ASTC low precision tutorial](#).

9.2 ASTC header

With both OpenGL and Vulkan, you must know certain texture image properties before you can process ASTC data. For example, you must know the ASTC block dimensions and sizes to calculate texture dimensions and compressed data size. You can find this information in the ASTC header at the beginning of compressed data.

The ASTC header has the following format:

```
/* ASTC header declaration. */  
typedef struct  
{  
    unsigned char magic[4];  
    unsigned char blockdim_x;  
    unsigned char blockdim_y;  
    unsigned char blockdim_z;  
    unsigned char xsize[3];  
    unsigned char ysize[3];  
    unsigned char zsize[3];  
} astc_header;
```

9.3 OpenGL ES

To use ASTC formats, you must run your application on hardware which supports the corresponding OpenGL ES extensions:

- GL_KHR_texture_compression_astc_ldr
- GL_KHR_texture_compression_astc_hdr

If the hardware does not support these extensions, you see messages about invalid format or internal format passing through `glCompressedTex*` functions to the underlying graphics driver.

To prepare the texture, perform the following steps:

1. Open the texture image file and load it into a local memory buffer.
2. Map the local buffer onto the ASTC header.
3. Read the texture properties from the ASTC header and compute the required values of arguments to pass to the `glCompressedTexImage2D` function.

The total number of bytes to be used by this call is computed by multiplying number of bytes per block and the number of blocks, as shown in the following code:

```
/* Merge x,y,z-sizes from 3 chars into one integer value. */  
xsize = astc_data_ptr->xsize[0] + (astc_data_ptr->xsize[1] << 8) + (astc_data_ptr->xsize[2] << 16);  
ysize = astc_data_ptr->ysize[0] + (astc_data_ptr->ysize[1] << 8) + (astc_data_ptr->ysize[2] << 16);
```

```

zsize = astc_data_ptr->zsize[0] + (astc_data_ptr->zsize[1] << 8) + (astc_data_ptr->zsize[2] << 16);

/* Compute number of blocks in each direction. */
xblocks = (xsize + astc_data_ptr->blockdim_x - 1) / astc_data_ptr->blockdim_x;
yblocks = (ysize + astc_data_ptr->blockdim_y - 1) / astc_data_ptr->blockdim_y;
zblocks = (zsize + astc_data_ptr->blockdim_z - 1) / astc_data_ptr->blockdim_z;
/* Each block is encoded on 16 bytes, so calculate total compressed image data size. */
n_bytes_to_read = xblocks * yblocks * zblocks << 4;

```

4. Invoke `glCompressedTexImage2D`, as shown in the following code:

```

glGenTextures(1, &to_id);
glBindTexture(GL_TEXTURE_2D, to_id);
/* Upload texture data to ES. */
glCompressedTexImage2D(GL_TEXTURE_2D,
                      0,
                      compressed_data_internal_format,
                      xsize,
                      ysize,
                      0,
                      n_bytes_to_read,
                      (const GLvoid*) astc_data_ptr));

```

5. Configure texture parameters for the `GL_TEXTURE_2D` target:

```

glTexParameteri(GL_TEXTURE_2D, GL_TEXTURE_MAG_FILTER, GL_LINEAR);
glTexParameteri(GL_TEXTURE_2D, GL_TEXTURE_MIN_FILTER, GL_LINEAR);
glTexParameteri(GL_TEXTURE_2D, GL_TEXTURE_WRAP_S,      GL_REPEAT);
glTexParameteri(GL_TEXTURE_2D, GL_TEXTURE_WRAP_T,      GL_REPEAT);

```

For more information, see the full example at the [Arm OpenGL ES SDK website](#).

9.4 Vulkan

ASTC is a core feature in Vulkan, but supporting the format is optional. Check that the `textureCompressionASTC_LDR` physical device feature is enabled.

To detect if ASTC is supported on your GPU, use the following code:

```

VkFormatProperties properties;

vkGetPhysicalDeviceFormatProperties(pContext->getPhysicalDevice(),
VK_FORMAT_ASTC_4x4_UNORM_BLOCK, &properties);

bool supports_astc = (properties.optimalTilingFeatures &
VK_FORMAT_FEATURE_SAMPLED_IMAGE_BIT) != 0;

```

Uploading ASTC textures uses the same mechanism as uploading other images. The only real difference between uploading compressed textures and uncompressed textures is that ASTC textures use a different format: `VK_FORMAT_ASTC_*`.

Use `vkCmdCopyBufferToImage` to copy ASTC data into the texture, as shown in the following code:

```
VkBufferImageCopy region = {};  
region.bufferOffset = 0;  
region.bufferRowLength = 0; // Tightly packed.  
region.imageSubresource.aspectMask = VK_IMAGE_ASPECT_COLOR_BIT;  
region.imageSubresource.layerCount = 1;  
region.imageExtent.width = width;  
region.imageExtent.height = height;  
region.imageExtent.depth = 1;  
// Copy the buffer to our optimally tiled image.  
// No difference between ASTC and uncompressed textures.  
vkCmdCopyBufferToImage(cmd, stagingBuffer.buffer, image,  
    VK_IMAGE_LAYOUT_TRANSFER_DST_OPTIMAL, 1, &region);
```

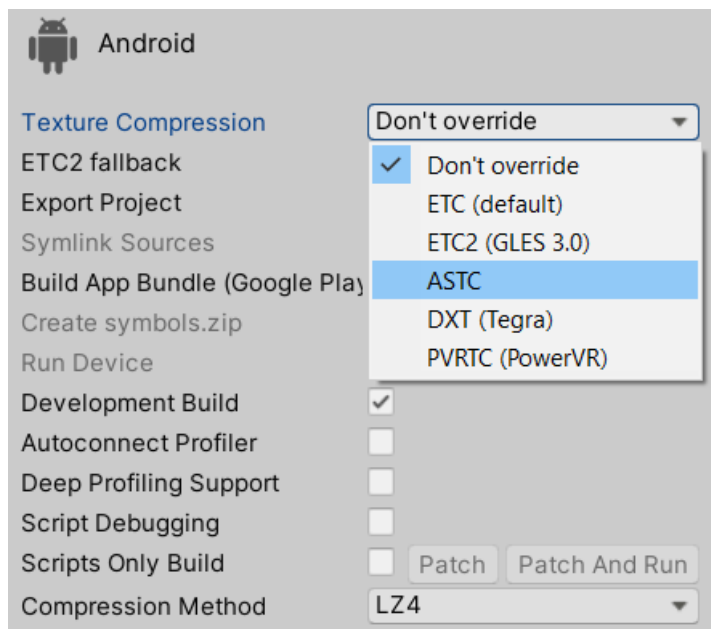
For more information, see the full example at the [Arm Vulkan SDK website](#).

10 Unity and ASTC

Unity lets you enable ASTC on Android, iOS, tvOS, and WebGL if the hardware supports it. On Android, both HDR and LDR profiles are available.

10.1 Build settings

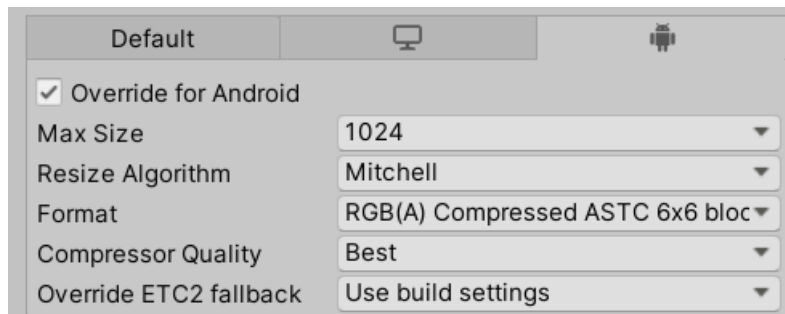
Each platform has default texture compression formats. For example, on Android the defaults are ETC2 for RGBA textures and ETC for RGB textures. You can change the compression setting in **File > Build Settings**, as you can see here:



The **Texture Compression** setting is global for all textures. The **Don't override** option means the default texture compression format is used.

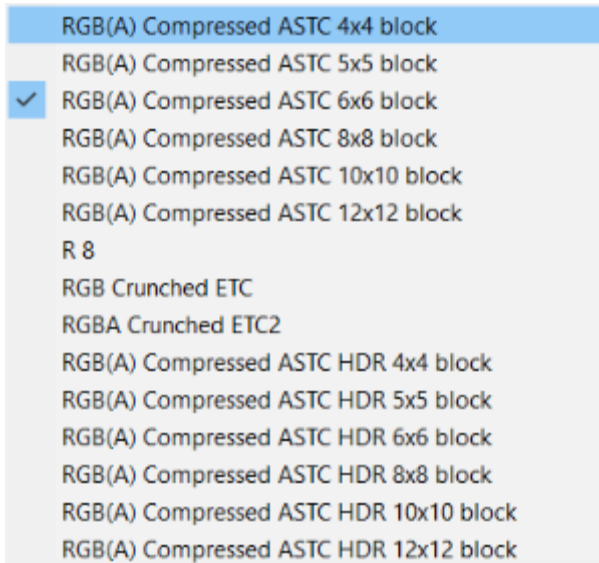
10.2 Texture-specific settings

Use the **Override for platform** section in **Texture settings** to override the global compression format for each texture, as you can see in this screenshot:



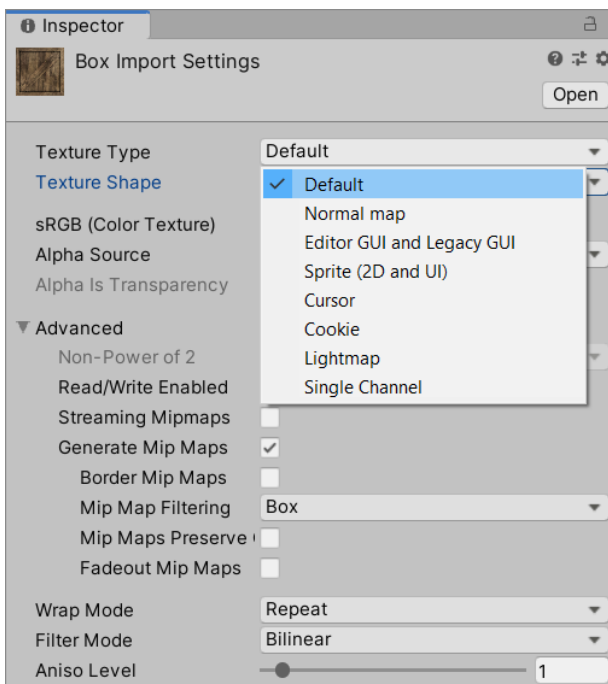
If you select **Best** for **Compression Quality**, the compressor thoroughly chooses the optimum ASTC blocks, but at the cost of increased compression time.

You can specify the size of ASTC blocks by choosing the corresponding **Format**, as shown in the following screenshot:



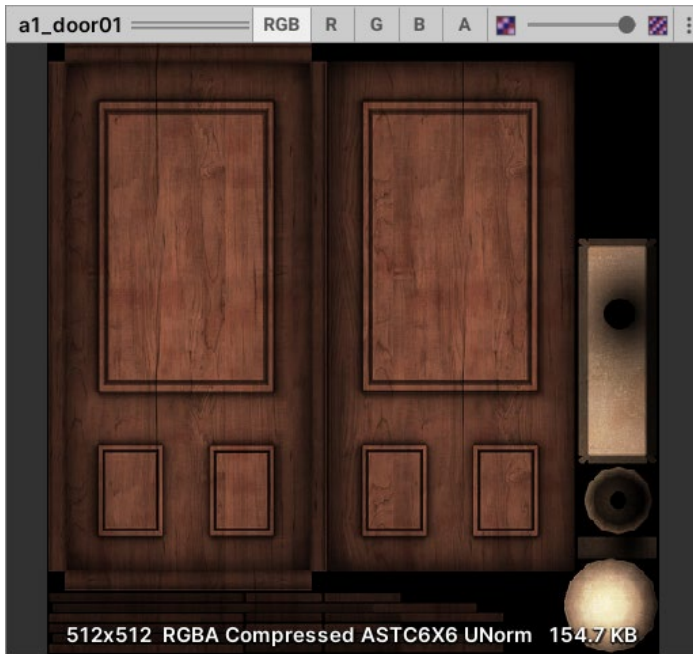
If **Override for platform** is disabled, the settings in this section are still useful. You can consult these settings to see which format and settings are in use for this specific texture, based on the global setting and texture type.

Import Settings let you specify texture type and alpha channel information. These settings let Unity choose appropriate compression settings for the texture, as you can see in the following screenshot:



Make sure you select **Normal map** if needed.

After you apply the texture settings, **Texture Preview** lets you see the result and the selected compression format and memory usage:



10.3 Building for different hardware

Not every device supports ASTC. If you have chosen a texture format your platform does not support, texture data is decompressed at runtime. This does not have a huge impact on loading time because Unity uses robust decoders. However, you lose all the other benefits of texture compression like lower memory footprint and cache efficiency.

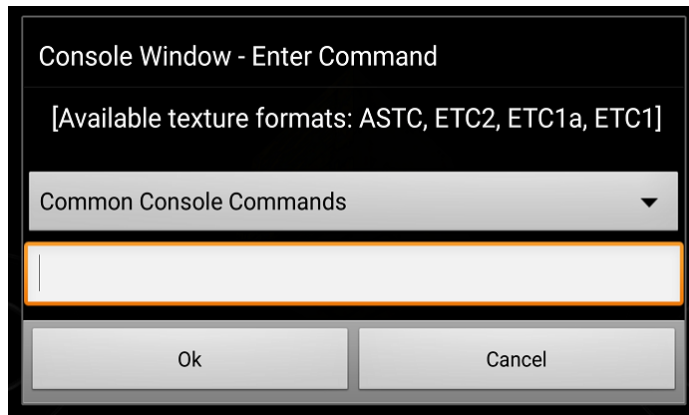
To avoid this situation, you can build separate APKs for different hardware. For example, ASTC is available on devices with OpenGL ES 3. For OpenGL ES 2, you can use ETC.

For example, the following steps show one of the possible workflows that you can follow to build different APKs for different platforms:

1. Build for OpenGL ES 3 and Vulkan:
 - a. Select **ASTC** in **File > Build Settings for Android**.
 - b. Go to **Edit > Project Settings > Player Settings** and disable **OpenGL ES 2**.
 - c. Build the APK.
2. Build for OpenGL ES 2:
 - a. Select **Don't override** in **File > Build Settings for Android**.
 - b. Ensure that all the texture-specific overrides for the platform are either disabled or use ETC format.
 - c. Go to **Edit > Project Settings > Player Settings** and leave only **OpenGL ES 2** enabled.
 - d. Build the APK.

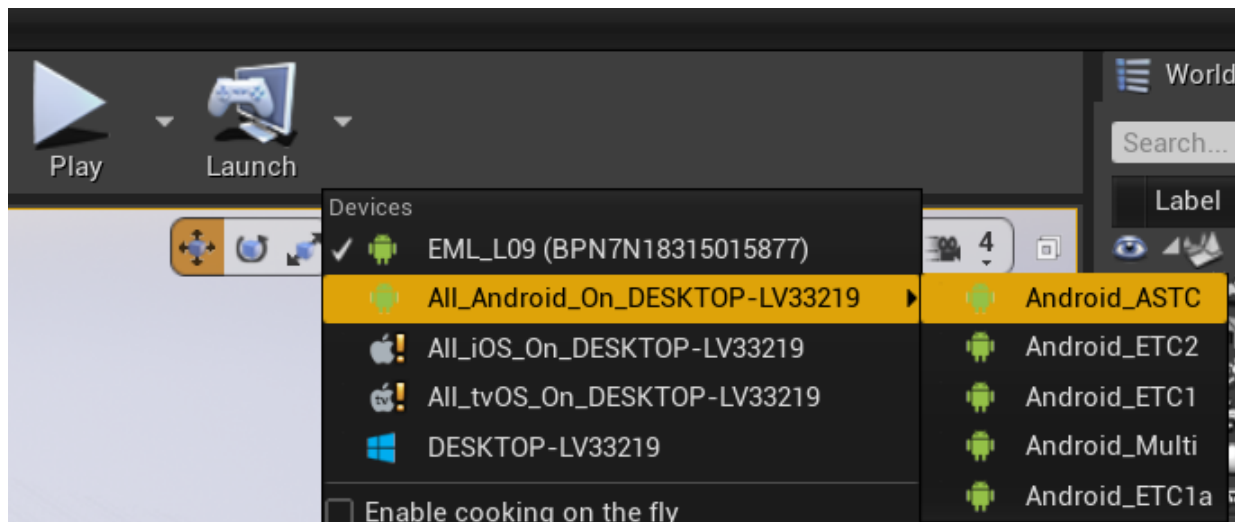
11 Unreal Engine and ASTC

Unreal Engine supports ASTC for mobile devices and other formats. To see which formats your device supports, tap with four fingers when running the game. The **Console Window** appears, showing the available texture formats as shown in the following image:



The **bShowConsoleOnFourFingerTap** variable controls this behavior. The **bShowConsoleOnFourFingerTap** variable is disabled by default with the **Shipping** build configuration.

Open the **Launch** context menu to see the available options for texture compression:



The **Multi** option compresses textures with all available formats. This option increases package size and build time but guarantees that the best available format is chosen at runtime. ASTC can be unsupported on some devices, but ETC1 support is guaranteed.

In **Project Settings**, you can choose which formats are included in the **Multi** build variant and set their relative priorities, as shown in the following image:

Multi Texture Formats	
Include ETC1 textures	<input checked="" type="checkbox"/>
Include ETC1 - alpha textures	<input checked="" type="checkbox"/>
Include ETC2 textures	<input checked="" type="checkbox"/>
Include DXT textures	<input checked="" type="checkbox"/>
Include PVRTC textures	<input checked="" type="checkbox"/>
Include ATC textures	<input checked="" type="checkbox"/>
Include ASTC textures	<input checked="" type="checkbox"/>

Texture Format Priorities	
ETC1 texture format priority	0.1
ETC1 - alpha texture format priority	0.15
ETC2 texture format priority	0.2
DXT texture format priority	0.6
PVRTC texture format priority	0.8
ATC texture format priority	0.5
ASTC texture format priority	0.9

For normal maps, masks, and GUI elements, ensure that you specify the appropriate compression settings in the **Texture Editor**, as you can see here:

Compression	
Compress Without Alpha	<input type="checkbox"/>
Defer Compression	<input type="checkbox"/>
Compression Settings	Default (DXT1/5, BC1/3 on DX11) ▼
	Default (DXT1/5, BC1/3 on DX11)
	Normalmap (DXT5, BC5 on DX11)
	Masks (no sRGB)
	Grayscale (R8, RGB8 sRGB)
	Displacementmap (8/16bit)
	VectorDisplacementmap (RGBA8)
	HDR (RGB, no sRGB)
	UserInterface2D (RGBA)
	Alpha (no sRGB, BC4 on DX11)
	DistanceFieldFont (R8)
	HDRCompressed (RGB, BC6H, DX11)
	BC7 (DX11, optional A)

Texture	
Power Of Two Mode	
Padding Color	
sRGB	

File Path	
-----------	--

12 Check your knowledge

Q: What is the main difference between real-time compression schemes like ASTC and traditional compression schemes like JPG and PNG?

A: Real-time compression schemes like ASTC allow efficient random sampling of elements within a larger image. JPG and PNG are only designed to decompress the entire image.

Q: ASTC provides a wide choice of bit rates when compressing images. What are the upper and lower bounds of this range?

A: ASTC provides bit rates between 0.89 bits and 8 bits per texel (bpt), corresponding to block sizes of 4x4 texels to 12x12 texels.

Q: ASTC uses color gradients, or partitions, to assign the color values of each texel. What is the maximum number of partitions that a block can define?

A: ASTC allows a block to define up to four distinct partitions.

Q: Which `astcenc` command-line option would you use to compress an input texture where each channel contains entirely unrelated content?

A: The `-mask` option.

13 Related information

Here are some resources related to material in this guide:

- Blog posts:
 - [Arm Unveils Details of ASTC Texture Compression at HPG Conference:](#)
 - [Part 1](#)
 - [Part 2](#)
 - [ASTC does it:](#)
 - [Part 1: Overview](#)
 - [Part 2: How to use it](#)
 - [ASTC Texture Compression: Arm Pushes the Envelope in Graphics Technology](#)
 - [How low can you go? Building low-power, low-bandwidth Arm Mali GPUs](#)
- Graphics API ASTC examples
 - [ASTC and OpenGL ES SDK example](#)
 - [ASTC and Vulkan SDK example](#)
 - [OpenGL ES SDK for Android: ASTC low precision tutorial](#)
- Presentations:
 - [ASTC: The Future of Texture Compression](#)
- Technical documentation:
 - [Arm ASTC Encoder](#)
 - [Arm Mali Texture Compression Tool](#)
 - [Intel Fast ISPC Texture Compressor](#)
 - [Khronos OpenGL extensions](#)
- Video:
 - [Get the Most out of Adaptive Scalable Texture Compression](#)

14 Next steps

This guide introduced the fundamental principles of what ASTC is, how it evolved, and how to use ASTC in your applications.

The next steps are to start using the ASTC format to compress the texture assets in your own projects.

If you are using a gaming engine to develop your project, you can learn more about using ASTC with these resources:

- Unreal Engine users: [Arm Guide for Unreal Engine 4: Optimizing Mobile Gaming Graphics](#)
- Unity users: [Arm Guide for Unity Developers: Optimizing Mobile Gaming Graphics](#)

Finally, to see a demonstration of the results you can achieve with ASTC, watch [the Arm Mali ASTC Texture Compression Demo from CES 2014](#).