AV1

An open-source video codec developed by the Alliance for Open Media

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What is AV1?

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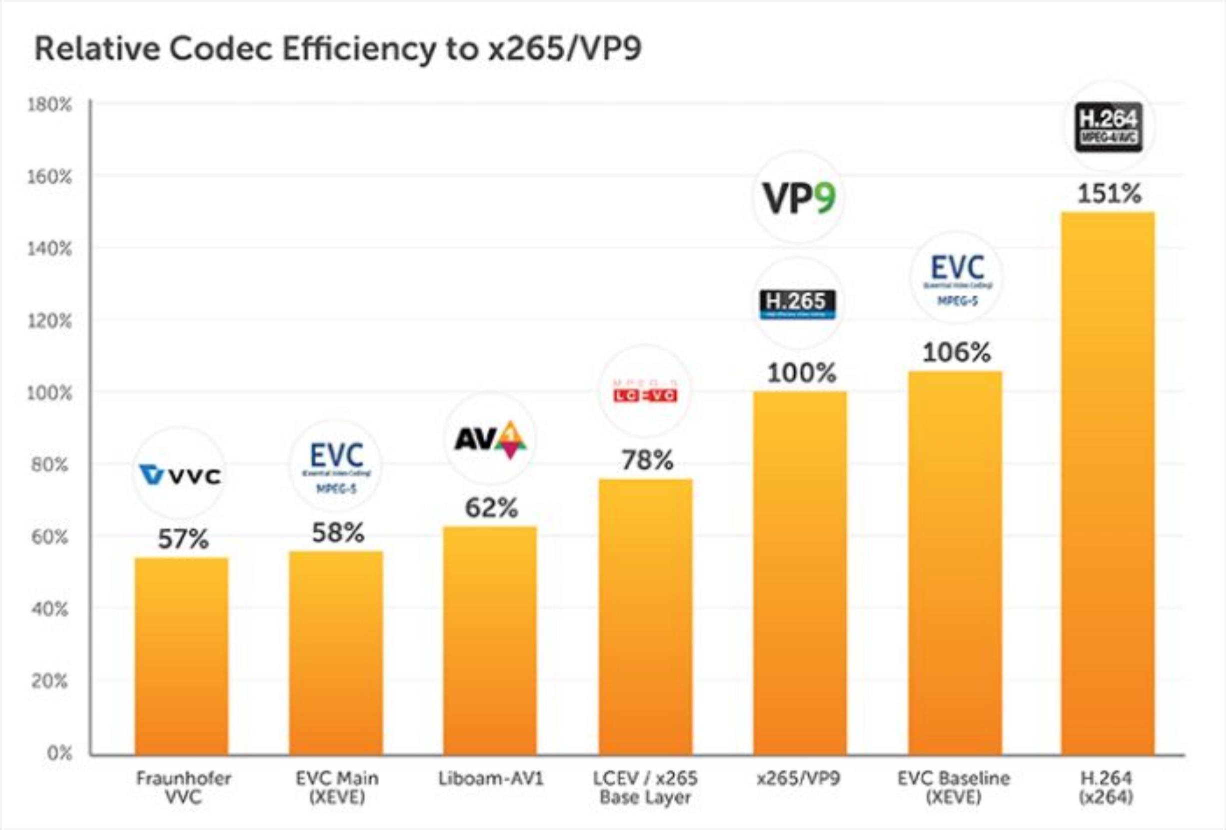
- “AOMedia Video 1 (AV1) is an open, royalty-free video coding format initially designed for video transmissions over the Internet”
- It was created in 2018 by the Alliance for Open Media, a consortium of corporations including names like Amazon, Apple, Google, Intel, Meta, Microsoft, Netflix and Nvidia
- Their goal was to create a new video codec as a successor to VP9 and an alternative to HEVC

How does it Compare to other Formats?



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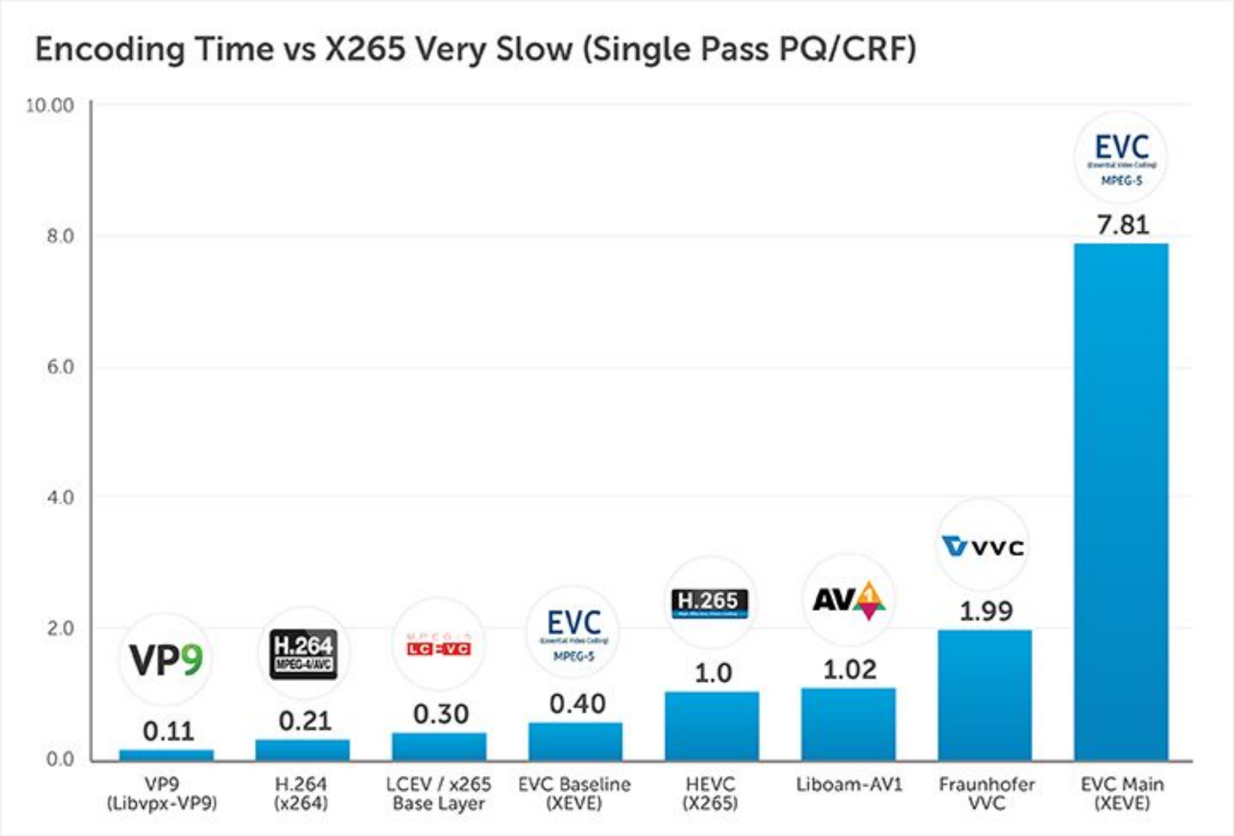
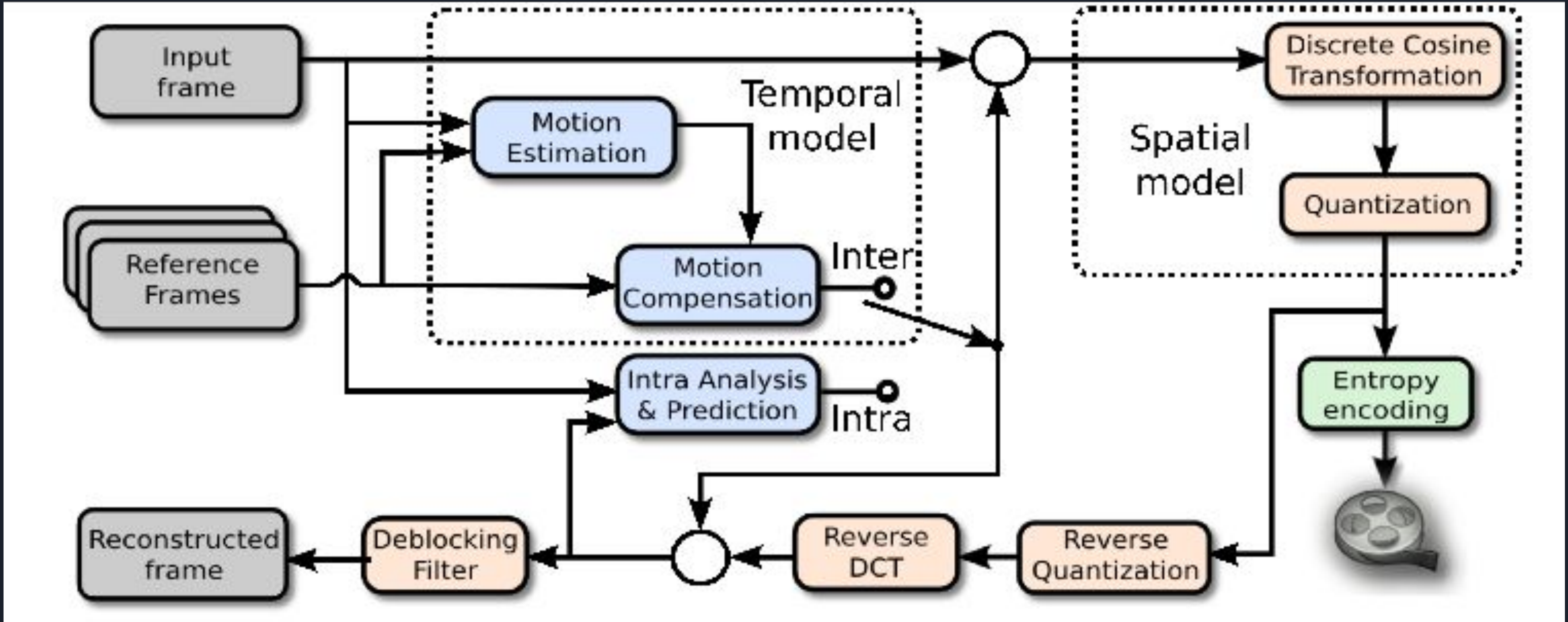


How does it Compare to other Formats?

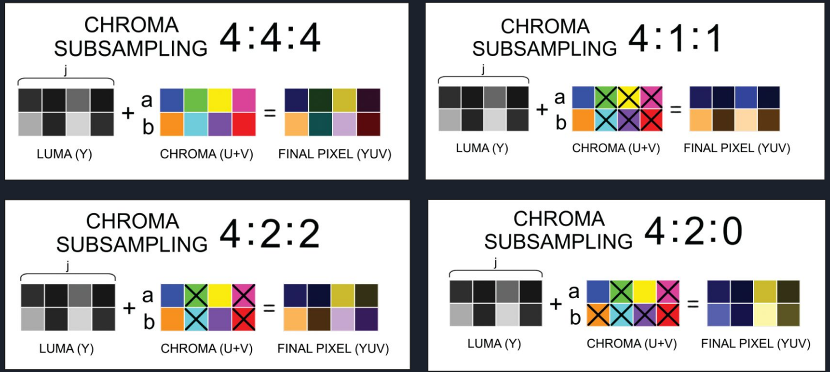
Processing stages of an AV1 encoder

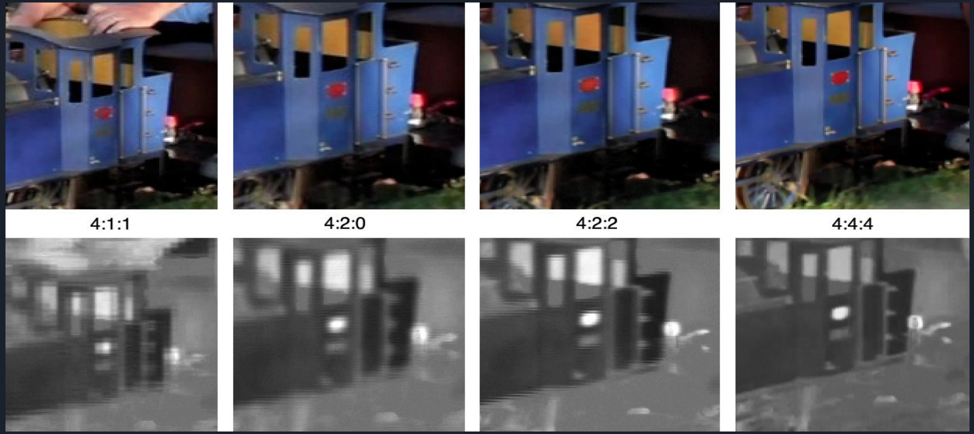


How AV1 Works:
Image Representation

Chroma and Luma vs RGB

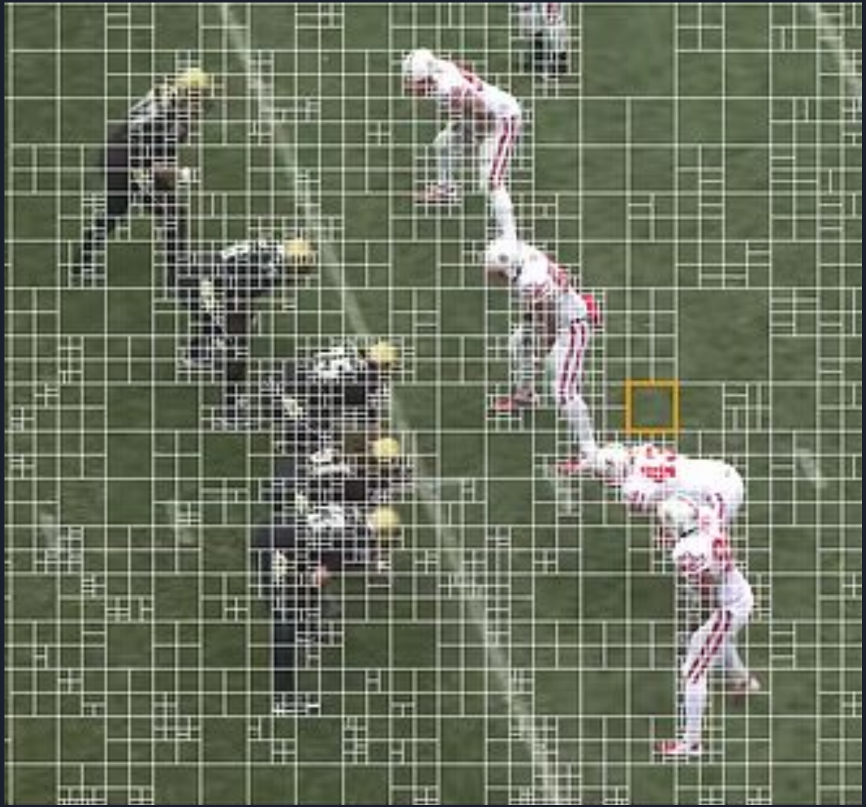
- Before getting started on AV1-specific details it's interesting to note that AV1, like some other codecs, does not use RGB to store pixel data.
- Instead it uses Luma to store the brightness of each pixel and Chroma to store its color as two values.
- This is useful because it allows for Chroma Subsampling - using less bits to store color than brightness - as our eyes are less sensitive to color changes than brightness ones.





Block Partitioning

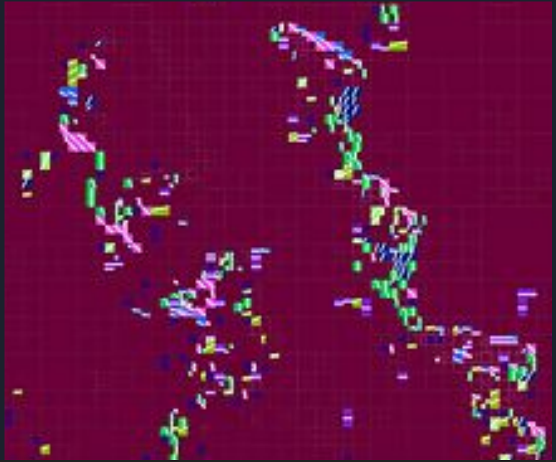
- The first step in modeling the information inside each frame is to divide it into small "**Blocks**"
- Each block's size depends on its level of detail
- Note how larger blocks are assigned to simple chunks of grass in this example, whereas smaller blocks are used for the players

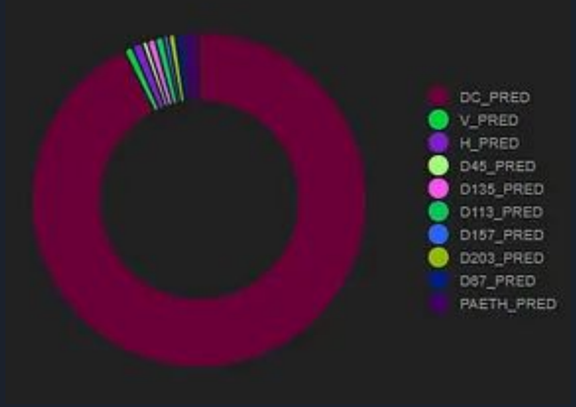


How AV1 Works:
Intra Frame Coding

Intra Prediction: Spatial Redundancy

- When coding Intra Frames, the created blocks are coded based on their relations to their neighbours
- In the example, the contents of the green grass blocks are predicted based on the boundary pixels of the adjacent ones
- The supported modes of Intra Prediction are:
  - Directional Intra Prediction
  - Non-directional Smooth Intra Prediction
  - Recursive Intra Prediction
  - Intra Block Copy
  - Chroma from Luma
  - Color Palette





How AV1 Works:
Inter Frame Coding

Inter Prediction: Motion Compensation

- Inter prediction tries to predict the motion of moving object by tracking it across frames
- Motion vectors are used to determine the new position of the block from a reference frame
- The encoder can choose a reference frame for the computation of the motion vector, from a buffer of 8 possible reference frames
- The encoder can also compensate rotation and scaling by using a matrix transformation instead of a vector

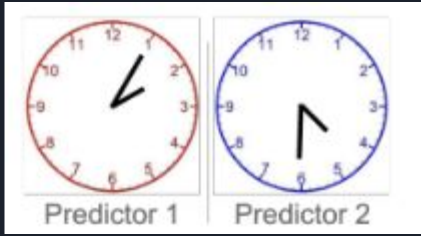
Inter Prediction: Compound Prediction

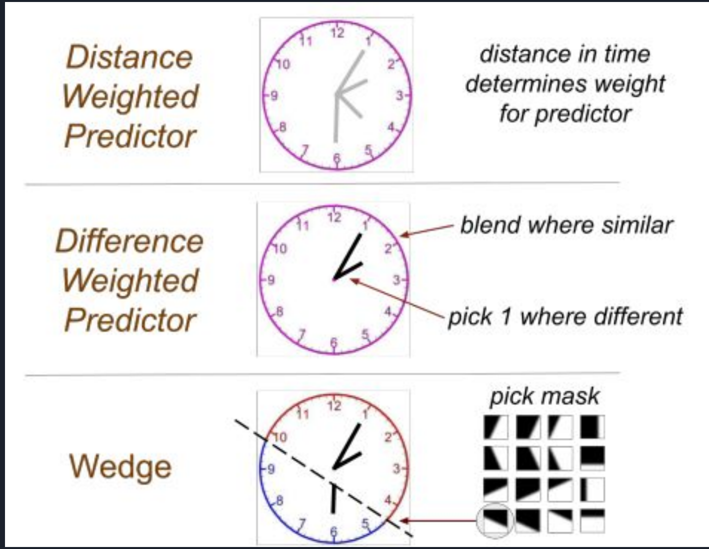
- The motion compensated predictions from two reference frames can be combined to better predict the current frame. These references can be past frames, future frames or both.
- It is most common for one reference frame to be in the past and another in the future, so that the decoder can perform interpolation (bi-directional compound). In contrast, if both are past or future frames, the decoder must perform extrapolation (unidirectional compound), which is less accurate.
- The contributions of each reference are then combined by assigning different weights to each one of them:

$$P(x, y) = w(x, y) * R_1(x, y) + (1 - w(x, y)) * R_2(x, y)$$

Inter Prediction: Compound Prediction

- The weight assigned to the prediction from each one of the two reference frames can be determined in one of 4 ways, which the encoder must specify.
- They are:
  - COMPOUND_AVERAGE
  - COMPOUND_DIST
  - COMPOUND_DIFF
  - COMPOUND_WEDGE

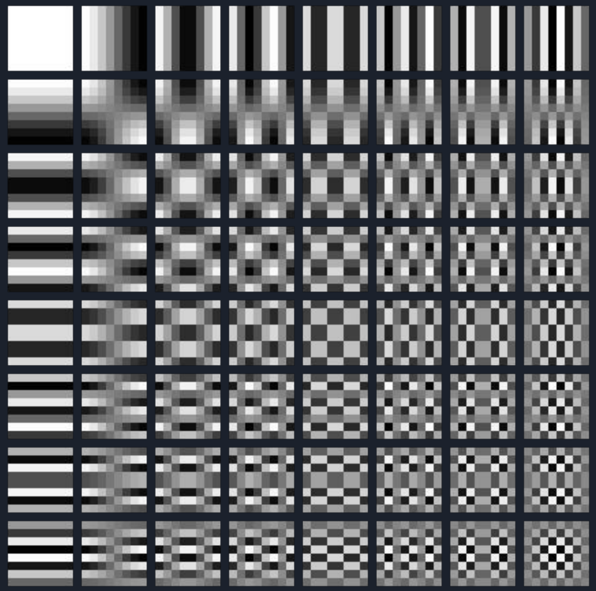




How AV1 Works: Residuals

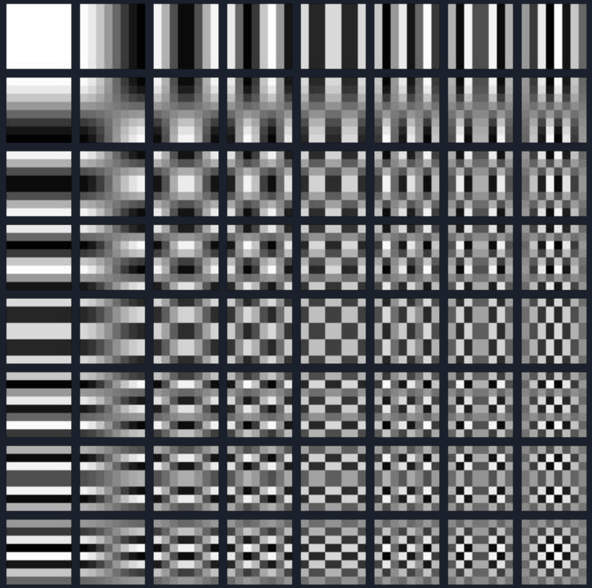
Residual Calculation and Transform Coding

- The Residual is calculated by subtracting the predicted frame data from the original frame, creating a difference signal that represents the error between prediction and actual values.
- The Residual pixel values are then transformed to the frequency domain using either one or a combination of the DCT, ADST, flipped ADST (FLIPADST), and identity transform (IDTX), resulting in a total of 16 2-D transform options.



Residual Calculation and Transform Coding

- These 4 transformation options are similar and differ only in the assumed boundary conditions. The Encoder chooses the one that will blend better with the surrounding blocks.
- This frequency transformation is done because our eyes are much less sensitive to higher frequency pattern than to lower frequency ones.
- The example image shows all DCT frequencies on an 8x8 pixel block. The DCT represents the pixel data as a combination of these. Note how the difference between the patterns on the lower right is negligible.



Quantization

- The Transform Coefficients are quantized to achieve the target bitrate.
- The encoder can remove more bits from the higher frequency components than from the lower ones, according to one of 15 predefined matrices.
- The encoder can also use more bits for the luma residuals than for the chroma.

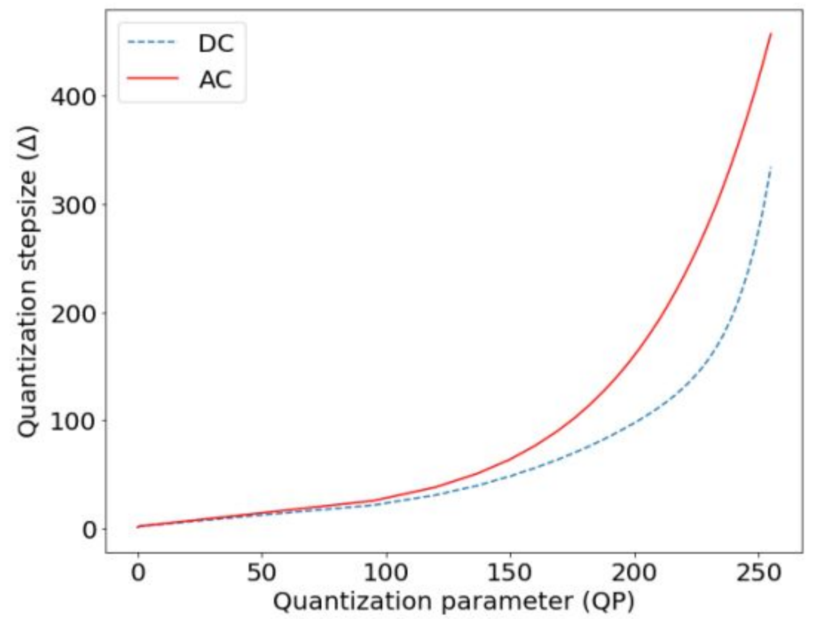


Fig. 25: The quantization parameter and quantization step size maps for DC and AC coefficients.

Entropy coding

- AV1 uses a non-binary arithmetic encoder which dynamically updates its probability model based on previously encoded symbols.
- To encode a given coefficient, one bit is reserved for its signal an then its magnitude is translated to symbols of types BR, LR or HR.
  - Base range (BR): The symbol contains 4 possible outcomes {0, 1, 2, > 2}, which are the absolute values of the quantized transform coefficient.
  - Low range (LR): It contains 4 possible outcomes {0, 1, 2, > 2} that correspond to the residual value over the previous symbols' upper limit.
  - High range (HR): The symbol has a range of [0, 2^15) and corresponds to the residual value over the previous symbols' upper limit.

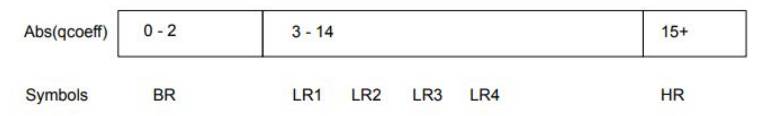


Fig. 28: The absolute value of a quantized transform coefficient V is decomposed into BR, LR, and HR symbols.

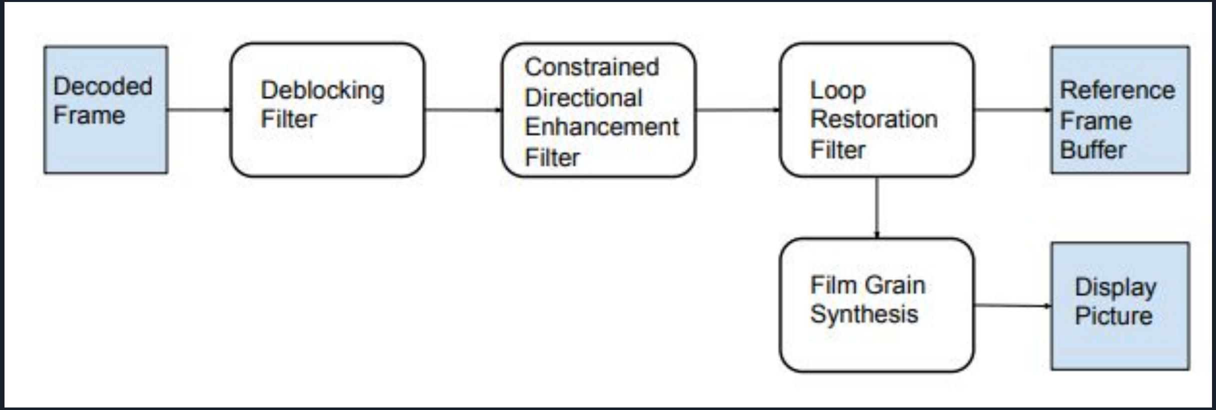
Entropy coding - Example

- If the magnitude of the coefficient we want to code, $|V| \in [0, 2]$, the BR symbol is sufficient to signal it and the coding of $|V|$ is terminated.
- Otherwise the outcome of the BR symbol will be "> 2", in which case an LR symbol is used to signal $|V|$.
- If $V \in [3, 5]$, this LR symbol will be able to cover its value and complete the coding. If not, a second LR is used to further code $|V|$. This is repeated up to 4 times, which effectively covers the range [3, 14].
- If $|V| > 14$, an additional HR symbol is coded with the remainder, $(|V| - 15)$.
- So, for example, the value $|V| = 3$ would be coded as: "BR>2", "LR=0"
- And the value $|V| = 18$ would be coded as: "BR>2", "LR>2", "LR>2", "LR>2", "LR>2", "HR=3"
- These symbols will then be passed on to the arithmetic encoder.

How AV1 Works:
Filters and Grain Synthesis

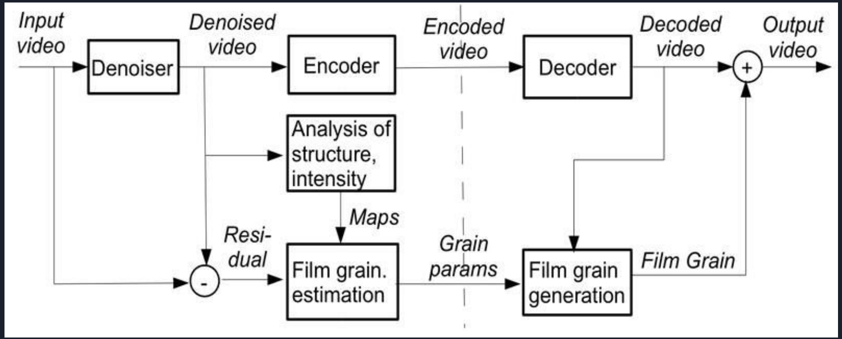
Decoding Filters

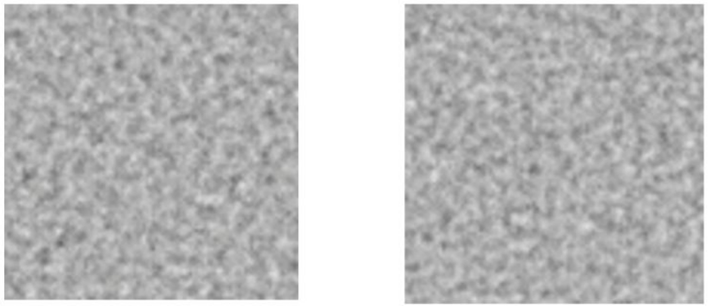
- The way AV1 models and encodes video may lead to some artifacts, namely around the block edges and around straight lines.
- In the decoder, there are 3 optional filters in place to rebuild the image as best as possible without any additional information.



Film Grain Synthesis

- AV1 has support for Film Grain Synthesis, a technique that is able to replicate video grain or "noise" by estimating its nature and intensity at the encoder and then regenerating it through a pseudorandom process at the decoder.
- This does not conserve the original information, but generates an image that looks identical





(a) Original grain (b) Synthesized grain

The End

Sources

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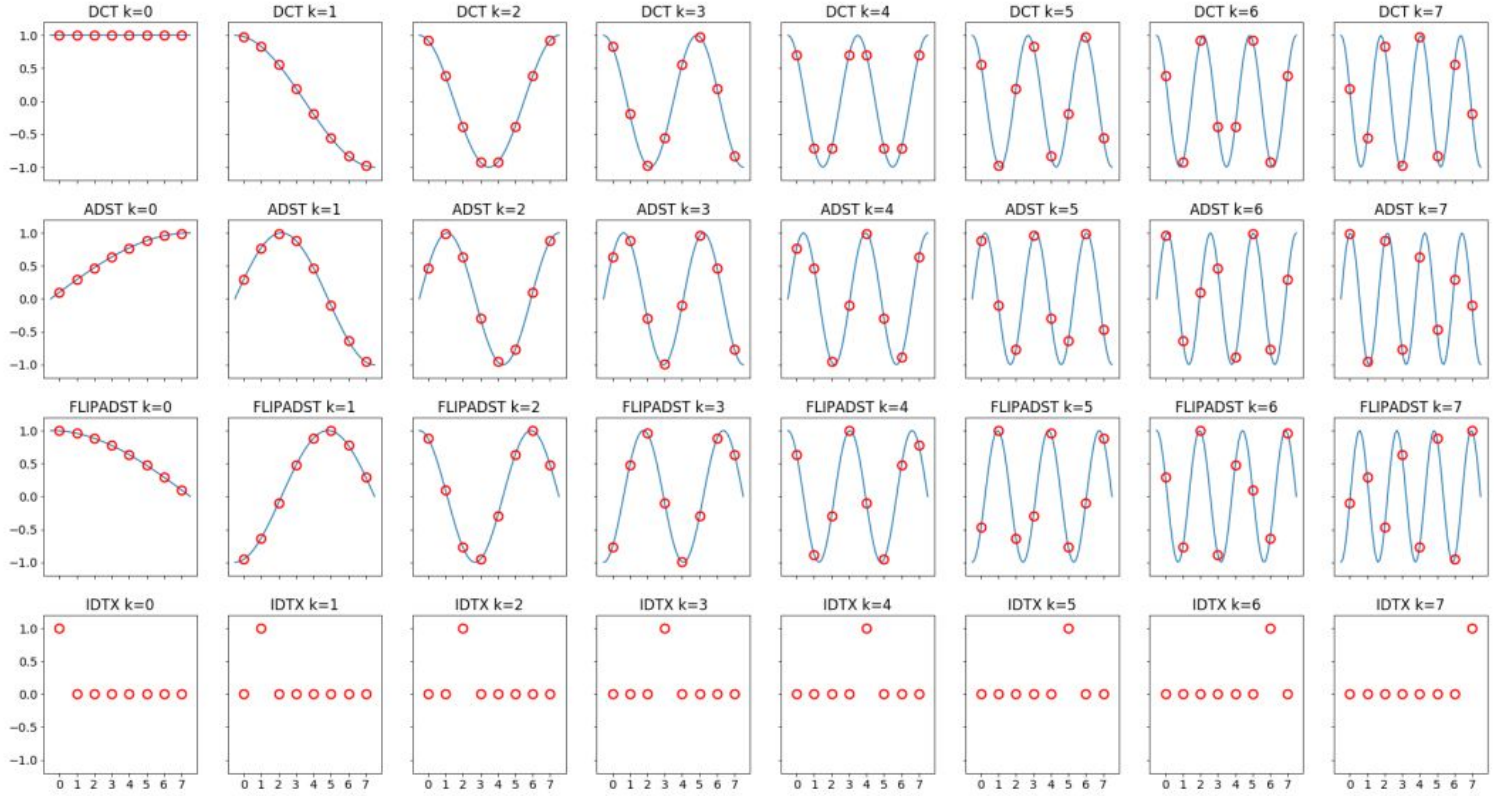

Fig. 24: Transform kernels of DCT, ADST, FLIPADST and IDTX for dimension $N = 8$. The discrete basis values are displayed as red circles, with blue lines indicating the associated sinusoidal function. The bases of DCT and ADST (a variant with a fast butterfly structured implementation) take the form of $cos(\frac{(2n+1)k\pi}{2N})$ and $sin(\frac{(2n+1)(2k+1)\pi}{4n})$ respectively, where n and k denote time index and the frequency index, taking values from $\{0, 1, ..., N-1\}$. FLIPADST utilizes the reversed ADST bases, and IDTX denotes the identity transformation.