

The Architecture of Precision: A Technical Analysis of Colour Bit Depth and Its Multi-Dimensional Impact on Digital Design Systems

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Abstract

This paper examines how colour bit depth shapes image quality, editing flexibility, and performance across digital design systems. It traces development from 1-bit monochrome displays, valued for efficiency in low-power devices, to 8-bit sRGB, where limitations such as banding and shadow loss become evident. The study evaluates 10-bit and 12-bit HDR systems for smoother gradients and expanded tonal accuracy, while also exploring 16-bit workflows for photography and 32-bit floating-point systems for advanced visual effects. Hardware demands and processing considerations are analyzed alongside future web standards in 2026. The research concludes that bit depth selection directly influences visual precision, creative control, and system capability.

Keywords: Colour Bit, Digital Design Systems, Visual Computing, Image Processing, Color Precision

Introduction

In the world of design things have changed a lot with the move from black and white to more complex systems that can handle a lot of colours. The number of colours that can be shown in an image is very important because it affects how the image looks and works. This is called colour bit depth. Colour bit depth is a measure of how many unique colours available in an image. It is a deal because it affects every part of the design process from taking the first picture to editing it and finally showing it on a screen or saving it.¹

The main problem that this paper talks about is the limit of colours that can be shown in systems that use 8 bits. This limit can cause problems like colours not looking right and data being lost when the image is changed a lot. As screens get better and can show colours the old way of doing things is not good enough for professionals. The goal of this research is to explain the differences between systems that use numbers of bits to represent colours and to help designers choose the best system for their work. (Byun et al., 2019; Wang et al., 2021; Liu et al., 2019).²

This paper is divided into sections that make sense. It starts by talking about the basics of how colourers measured and the history of systems that use few bits. Then it talks about the standard that uses 8 bits and why it is not good enough for high quality work. After that it talks about systems that use bits, like 10-bit and 12-bit systems that can show a lot of colours and 16-bit systems that are used by professionals. It even talks about systems that use 32 bits and can show a number of colours. Finally it talks about how these systems affect the performance of computers how they are used in intelligence and what the new standards for web design will be in 2026. Colour bit depth is a thing to consider when working with digital media and understanding colour bit depth is crucial, for designers (Fujine et al., 2008; Liu et al.,

¹ Sullivan, G. J.; Ohm, J.-R.; Han, W.-J.; [Wiegand, T.](#) (May 25, 2012). "[Overview of the High Efficiency Video Coding \(HEVC\) Standard](#)" (PDF). IEEE Transactions on Circuits and Systems for Video Technology. Retrieved May 25, 2026.

² Byun, J., Shim, K., & Kim, C. (2019). *BitNet: Learning-Based Bit-Depth Expansion*. Proceedings of the IEEE/CVF Conference. <https://doi.org/10.48550/arXiv.1910.04397>

2019; Wang et al., 2021; Narwaria et al., 2015).³

1. The Mathematical Foundation of Chromatic Quantization

The colours we see on devices are made by using a limited number of binary values to mimic the colours we can see. This is done by using a system that is based on the power of two. When we add bits to a pixel we double the number of different shades we can show. For example, it is like going from 2 to 4 to 8 and so on. The bit. The number of colours we can show are connected by a simple formula. The number of colours we can show on devices that use the Red, Green and Blue (RGB) model is found by multiplying the number of colours we can show for each of the Red, Green and Blue colours (Poynton, 2012; Fairchild, 2013; Berns, 2000).⁴ So if we have a number of colours, for Red, Green and Blue we multiply these numbers together to get the total number of colours we can show. This is how digital devices show colours by using a combination of Red, Green and Blue lights. The more bits we use the more colours we can show and the more realistic the image will look (Fairchild, 2013)⁵

Table no. 1

Bit Depth	Tonal Levels per Channel	Total RGB Colours
1-bit	2	2 (Total)
8-bit	256	16,777,216
10-bit	1,024	1,073,741,824
12-bit	4,096	68,719,476,736
16-bit	65,536	281,474,976,710,656
32-bit	4,294,967,296	Virtually Unlimited

The above table no. 1 suggests the mathematical relationship between bit depth, tonal levels per channel (2^n), and total RGB colour combinations ($((2^n)^3)$ is foundational to digital colour imaging and directly determines the representational capacity of imaging systems (Sharma & Trussell, 2001; Poynton, 2012).⁶

³ Fujine, T., Kanda, T., Yoshida, Y., Sugino, M., Teragawa, M., Yamamoto, Y., & Ohta, N. (2008). Bit depth needed for high image quality TV evaluation using color distribution index. *Journal of Display Technology*, 4(3), 340–347. <https://doi.org/10.1109/JDT.2008.926488>

⁴ Berns, R. S. (2000). Billmeyer and Saltzman's principles of color technology (3rd ed.). *Color Research & Application*, 25(6), 426–427. [https://doi.org/10.1002/1520-6378\(200012\)25:6<426::AID-COL3>3.0.CO;2-N](https://doi.org/10.1002/1520-6378(200012)25:6<426::AID-COL3>3.0.CO;2-N)

⁵ Fairchild, M. D. (2013). *Color appearance models and digital imaging*. Wiley-IS&T Series in Imaging Science and Technology. <https://doi.org/10.1002/9781118653128>

⁶ Sharma, G., & Trussell, H. J. (2001). Digital color imaging. *IEEE Transactions on Image Processing*, 6(7), 901–932. <https://doi.org/10.1109/83.597272>

2. Binary Constraints and 1-Bit Utility

A 1-bit image is really simple. It stores information for each pixel using just one binary digit. This means each pixel can only be, in one of two states: it is either 0. It is 1. The 1-bit image is limited to these two options.¹ The old 1-bit colour is actually making a comeback thanks to Electrophoretic Ink technology also known as E Ink technology. This is because 1-bit E Ink displays only need power when they are changing the state of things called microcapsules. So 1-bit E Ink displays are really good at saving energy. They can even keep showing the picture forever without using any power at all. This is a deal, for 1-bit E Ink displays (Comiskey et al., 1998; Heikenfeld et al., 2011).⁷

The difference between using black and white and the wish for many shades of colour is solved by dithering. Dithering, like the Atkinson or Floyd-Steinberg method puts white pixels together in certain ways to trick the human eye into seeing many shades of grey. The dithering process really helps to make the gap between black and white and the desire for tonal variation smaller (Floyd & Steinberg, 1976; Ulichney, 1987; Ostromoukhov, 2001)⁸. Dithering is very useful, for making things look more like they have shades of colour even when they are really just made up of black and white pixels (Knuth, 1987).⁹

3. The 8-Bit Standard and the Mechanics of Banding

For a time 8-bit colour depth has been the standard for consumer digital media and sRGB colour space. It has served this purpose for decades. The 8-bit colour depth and sRGB colour space have been used widely. They have been the norm, for years. The 8-bit colour depth is still used today (Stokes et al., 1996)¹⁰. However, 8-bit is increasingly viewed as insufficient due to colour banding, which occurs when tonal steps are large enough to be perceived as discrete "stripes" rather than a continuous transition (Mantiuk et al., 2011).¹¹

Because 8-bit lacks the "elasticity" needed for editing, it is regarded as a "delivery format" rather than a "working format" in a professional setting. Data "crushing" in shadow areas and instantaneous quantization errors result from each mathematical operation in an 8-bit space, such as a curve adjustment, spreading the 256 steps farther apart (Reinhard et al., 2010).¹².

4. High Dynamic Range (HDR): 10-Bit and 12-Bit Architectures

The shift to HDR content basically needs higher bit depths to show colours and brightness levels.

Rec. 2020 Is a colour standard that helps with this.

A higher bit depth means levels of colour and brightness. For example 10-bit depth has 1,024 levels per channel. This is good enough that our eyes can't see the steps between them in situations (ITU-R, 2015)¹³. So it looks like a spectrum of colours and brightness. HDR content with 10-bit depth looks more natural and realistic. It has a range of colours and

⁷ Comiskey, B., Albert, J. D., Yoshizawa, H., & Jacobson, J. (1998). An electrophoretic ink for all-printed reflective electronic displays. *Nature*, 394(6690), 253–255. <https://doi.org/10.1038/28349> ; Heikenfeld, J., Drzaic, P., Yeo, J. S., & Koch, T. (2011). Review paper: A critical review of the present and future prospects for electronic paper. *Journal of the Society for Information Display*, 19(2), 129–156. <https://doi.org/10.1889/JSID19.2.129>

⁸ Floyd, R. W., & Steinberg, L. (1976). An adaptive algorithm for spatial grey scale. *Proceedings of the Society for Information Display*, 17(2), 75–77. <https://doi.org/10.1002/j.2637-496X.1976.tb01697.x> ; Ostromoukhov, V. (2001). A simple and efficient error-diffusion algorithm. *Proceedings of SIGGRAPH 2001*, 567–572. <https://doi.org/10.1145/383259.383326>; Ulichney, R. (1987). Digital halftoning. *MIT Press Series in Foundations of Computing*. <https://doi.org/10.7551/mitpress/2383.001.0001>

⁹ Knuth, D. E. (1987). Digital halftones by dot diffusion. *ACM Transactions on Graphics*, 6(4), 245–273. <https://doi.org/10.1145/35068.35069>

¹⁰ Stokes, M., Anderson, M., Chandrasekar, S., & Motta, R. (1996). A standard default color space for the internet – sRGB. *Color and Imaging Conference*, 1996(1), 238–245. <https://doi.org/10.2352/ISSN.2169-2629.1996.1.41>

¹¹ Mantiuk, R., Kim, K. J., Rempel, A. G., & Heidrich, W. (2011). HDR-VDP-2: A calibrated visual metric for visibility and quality predictions in all luminance conditions. *ACM Transactions on Graphics*, 30(4), 1–14. <https://doi.org/10.1145/2010324.1964935>

¹² Reinhard, E., Ward, G., Pattanaik, S., & Debevec, P. (2010). High dynamic range imaging: Acquisition, display, and image-based lighting. *Morgan Kaufmann Series in Computer Graphics*. <https://doi.org/10.1016/C2009-0-63995-1>

¹³ ITU-R. (2015). Parameter values for ultra-high definition television systems for production and international programme exchange. *Recommendation ITU-R BT.2020-2*. <https://doi.org/10.5594/JMI.2016.2554501>

brightness levels than lower bit depths. This makes it better, for watching movies or playing games. 12-bit colour depth (4,096 levels per channel) provides the necessary overhead for cinematic post-production, preserving the maximum latitude of high-end camera sensors (Borer et al., 2012).¹⁴

5. Professional Grade: 16-Bit Integer Resilience

Working in a 16-bit environment (65,536 levels per channel) is the standard for professional retouching and fine-art printing. While no current monitor can fully display trillions of colours, the value of 16-bit lies in its mathematical resilience. Rounding errors that would accumulate in 8-bit are maintained with fractional precision in 16-bit, preventing errors from reaching the visible threshold during complex gradation. (Reinhard et al., 2010).¹⁵

6. VFX and 32-Bit Floating Point Workflows

The pinnacle of precision is 32-bit floating point, typically reserved for advanced VFX and 3D rendering.¹⁸ Unlike integer math, which is fixed within a range (e.g., 0 to 255), floating-point math uses an exponent and mantissa to represent values.

$$Value = (Sign) \times (1.Mantissa) \times 2^{(Exponent - Bias)}$$

This allows 32-bit systems to store "Super Blacks" (values below 0.0) and "Super Whites" (values above 1.0). Detail in these overexposed areas can be recovered perfectly by lowering the exposure in the pipeline, a feat impossible in integer-based formats (Debevec & Malik, 1997).¹⁶

7. Hardware Performance and AI Quantization

Higher bit depths demand significantly more from hardware. Increasing bit depth increases the amount of data moved across the memory bus, which can lead to longer render times and higher VRAM consumption. On modern GPUs, 32-bit (FP32) is highly accurate but memory-intensive, while 16-bit (FP16) or 8-bit (FP8) can double or quadruple throughput for AI training and inference by reducing computational cycles. Strategic quantization—finding the lowest bit depth that preserves accuracy—is now a core principle in AI-driven design (Micikevicius et al., 2018).¹⁷

8. The 2026 Landscape: CSS Colour Level 4

By 2026, web design has moved beyond sRGB limitations. CSS Colour Module Level 4 allows for wide-gamut spaces like `lch()` and `oklch()`, which support greater than 8 bits of serialized precision.²⁸ Modern browsers like Chrome and Safari now provide full support for these high-depth colour tokens, enabling cinematic gradients and "mood-adaptive" UIs that shift palettes smoothly based on user behaviour.¹⁸

Conclusion

The shift toward higher bit depths is driven by the fact that bit depth defines the precision floor for every visual system. 8-Bit depth is still the standard for web distribution and messaging platforms like WhatsApp. It lacks the power needed for modern HDR displays and professional colour grading. In an 8-bit environment you only have 256 levels of information per colour channel. This often results in banding. Steps in smooth areas like a sky or a soft shadow on a skin photo. On the hand 10-bit and 12-bit systems provide thousands of levels of gradation. They are the choice for high-

¹⁴ Borer, T., Cotton, A., & Salmon, J. (2012). A "Display Independent" high dynamic range television system. *SMPTE Motion Imaging Journal*, 121(4), 50–55. <https://doi.org/10.5594/J18250>

¹⁵ Reinhard, E., Ward, G., Pattanaik, S., & Debevec, P. (2010). High dynamic range imaging: Acquisition, display, and image-based lighting. *Morgan Kaufmann Series in Computer Graphics*. <https://doi.org/10.1016/C2009-0-63995-1>

¹⁶ Debevec, P. E., & Malik, J. (1997). Recovering high dynamic range radiance maps from photographs. *Proceedings of SIGGRAPH 97*, 369–378. <https://doi.org/10.1145/258734.258884>

¹⁷ Micikevicius, P., Narang, S., Alben, J., Diamos, G., Elsen, E., Garcia, D., Ginsburg, B., Houston, M., Kuchaiev, O., Venkatesh, G., & Wu, H. (2018). Mixed precision training. *International Conference on Learning Representations (ICLR)*. <https://doi.org/10.48550/arXiv.1710.03740>

¹⁸ Micikevicius, P., Narang, S., Alben, J., Diamos, G., Elsen, E., Garcia, D., Ginsburg, B., Houston, M., Kuchaiev, O., Venkatesh, G., & Wu, H. (2018). Mixed precision training. *International Conference on Learning Representations (ICLR)*. <https://doi.org/10.48550/arXiv.1710.03740>

quality consumer electronics and medical imaging where detail is critical. For designers and content creators the conclusion is to create and archive work in 16-bit or 32-bit formats. These high-precision depths allow for mathematical transformations like heavy colour correction or VFX compositing without breaking the image pixels. Even if the current delivery standard is lower keeping a high-bit master ensures that as display technology evolves assets can be re-exported to look good on screens (Mantiuk et al., 2011)¹⁹. The industry is also exploring high-efficiency formats like FP8 and INT4. They aim to replicate the quality of high-bit systems using less data. This allows AI and real-time engines to process high-quality visuals with computing power. The goal is to make high-quality visuals more accessible. HDR displays and professional colour grading require power than 8-bit depth can provide. Bit depth is critical for visual systems. Higher bit depths provide levels of gradation. This makes them better, for high-quality consumer electronics and medical imaging. Designers and content creators should master their work in high-precision formats. This ensures that their assets can be re-exported to look good on screens. The industry is working on formats to make high-quality visuals more accessible. These formats aim to provide visual quality with less data. They will help AI and real-time engines process visuals efficiently (Jouppi et al., 2017).²⁰.

¹⁹ Mantiuk, R., Kim, K. J., Rempel, A. G., & Heidrich, W. (2011). HDR-VDP-2: A calibrated visual metric for visibility and quality predictions in all luminance conditions. *ACM Transactions on Graphics*, 30(4), 1–14. <https://doi.org/10.1145/2010324.1964935>

²⁰ Jouppi, N. P., Young, C., Patil, N., Patterson, D., Agrawal, G., Bajwa, R., Bates, S., Bhatia, S., Boden, N., Borchers, A., Boyle, R., & others. (2017). In-datacenter performance analysis of a tensor processing unit. *Proceedings of the 44th Annual International Symposium on Computer Architecture*, 1–12. <https://doi.org/10.1145/3079856.3080246>