Soojin Park
CINE-GT 3403: Video Preservation 1
Instructors: Kelly Haydon and Ben Turkus
Assignment 1

ITU-R Recommendation BT.601/BT.709

ITU-R Recommendation BT.601, developed by the standardization body ITU-R (International Telecommunication Union Radio Sector), is an encoding standard for encoding interlaced analog video signals in component digital video form. Formally published in 1984 as CCIR Rec. 601, as it was known then, it was the first international agreement on how to migrate from two incompatible analog television scanning formats to a common sampling concept and structure in digital form that determined their use in television studios and professional applications.[1] This paper aims to discuss the brief history and context of the video/broadcasting scene in the late 1970s to explain why a digital video standard was needed, its significance in video digitization with particular regards to the 4:2:2 color space as well as its rectangular pixels which is incompatible with today's monitors, and its relationship with BT.709 in regards to pixels.

The late 1970s was a time when digital interfaces were used increasingly in studios, while digital videotape was just starting to emerge. The need for a digital video standard that can create a smooth path between the analog and the digital was therefore becoming more apparent. Interoperability with existing equipment was also important; "if analog video signals were to be passed through digital equipment (and vice versa), the sampling rate of the video signal (among other factors) would need to be set, so that equipment could be used with predictable and repeatable results."[2] The early effort toward digitization of the video signal were divided into the Society of Motion Picture and Television Engineers (SMPTE) in the US developing a standard specific to NTSC and European Broadcasting Union (EBU) of Europe around the characteristics of the PAL signal. Because of the differences between NTSC and PAL, most notably their frame rates: 29.97fps and 25fps respectively, this would have resulted in different "standards". In the late 1970s, this approach was dropped in favor of the development of BT.601.[3]

Although color space is only one of the many specifications that BT.601 determined such as resolution and scanning standard, the 4:2:2 digital interface is often mentioned as it involved shifting the incoming video signal from the simpler but more redundant trichromatic representation of the RGB color space to the more complex but more efficient color representation of the YCbCr component video color model, developed as a part of ITU-R BT.601 for digital component video standards.[4] Here, a luminance or grey scale channel (Y) and two color-difference signals (R-Y and B-Y) are provided. The two color-difference components take advantage of the characteristics of the human visual system which is less sensitive to high-resolution information for color than for luminance.[5] As a result, it allows for the use of a lower number of samples to represent the color-difference signals without observable losses in the restored images; true color 24-bit RGB video images were compressed with minimal loss of visual information during videotape digitization.[6] However, in the 1990s, the 4:2:2 chroma subsampling format was adopted for HDTV.

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[1] Ricardo Cedeño Montaña, *Portable Moving Images* (Berlin/Boston: Walter De Gruyter, 2017), 189.; CCIR (International Radio Consultative Committee) is a forerunner of the ITU-R.
[2] Katherine Frances Nagels, "PAR, SAR, and DAR: Making Sense of Standard Definition (SD) Video Pixels," BAVC, July 15, 2016, https://bavc.org/blog/par-sar-and-dar-making-sense-standard-definition-sd-video-pixels#ref6.
[3] Khalid Sayood, *Introduction to Data Compression*, The Morgan Kaufmann Series in Multimedia Information and Systems (San Francisco: Elsevier Science & Technology, 2012), 579.
[4] Gerhard Goos, Juris Hartmanis, and Jan van Leeuwen, *Computer and Information Sciences - ISCIS 2003: 18th International Symposium, Antalya, Turkey, November 3-5, 2003. Proceedings*, vol. 2869, Lecture Notes in Computer Science 2869 (Berlin/Heidelberg: Springer Berlin Heidelberg, 2003), 693.
[5] Stanley Baron and David Wood, "Rec. 601— the Origins of the 4:2:2 DTV Standard," October 2005, 4, https://tech.ebu.ch/docs/techreview/trev_304-rec601_wood.pdf.
[6] R Gaunt, "Color Spaces in Digital Video," May 1, 1997, https://www.osti.gov/servlets/purl/358797.

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As a result, 4:2:2 is no longer clearly limited to SDTV, and no longer clearly denoted a scanning or interface standard.[7]

BT.601 standard proposed a family of sampling rates based on the sampling frequency of 3.75MHz (3.75 million samples per second). Each component can be sampled at an integer multiple of 3.75MHz, up to a maximum of four times this frequency. Thus, with 4:2:2, it would mean that the luminance signal is sampled at 13.5MHz, while the lower-bandwidth chrominance signals are sampled at 6.75MHz.[8] This sampling rate applied to both 625-line and 525-line video, and yielded 720 samples (pixels) across the width of the image. Because of the set number of scan lines, the vertical resolution of the video frame was already fixed: 576 (for the 625-line system) or 486 (for the 525-line system), although for mathematical reasons, this was reduced down to 480.[9] In both NTSC and PAL video, the frame displayed has an aspect ratio of 4:3, yet neither 720 x 480 nor 720 x 576 constitutes a 4:3 ratio. The solution to this problem was to display the pixels taller-than-wide, or wider-than-tall, so that they fit into a 4:3 frame. This is how the "rectangular pixels" came about —pixels that must be stretched or squeezed to fit in the 4:3 frame.[10]

Most current high-definition studio standards call for square sampling and it is difficult to imagine any future studio standard being established with non-square sampling.[11] The reason BT.601 did not pursue square pixels in the first place is because it all took place before the era of digital monitors and computing, when cathode-ray monitors were in dominance. It was not a necessity, then, that pixels were square.[12] When BT.709: high-definition television format for 1080i and 1080p standards, for 16:9 (widescreen) aspect ratio – was approved in 1990, square pixel common image format came along and it was firmly established as the broadcast standard.[13] Directly mapping an image with a certain pixel aspect ratio on a device whose pixel aspect ratio is different makes the image look stretched or squashed in either the horizontal or vertical direction; it is the technical metadata embedded within the video file that take into consideration the parameters such as Storage Aspect Ratio (SAR), Display Aspect Ratio (DAR), and Pixel Aspect Ratio (PAR) that allow video playback software to play the video file so it looks "right".[14] However, according to the IASA-TC 06 guideline, there are still problems when an archive makes materials available to users on the web, for example, via streaming services like Netflix or DVD disk players, or via other computer-based systems, which often use monitors that present color and tonal range as if the signal conformed to BT.709, and as if the scan were progressive with square pixels.[15]

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[7] Charles Poynton, *Digital Video and HD*, Morgan Kaufmann Series in Computer Graphics and Geometric Modeling (US: Morgan Kaufmann Publishers Inc, 2003), 127.
[8] (Sayood, 2012)
[9] 480 is divisible by 16; "Modern digital video applications such as DV, DVD and digital television (DVB, ATSC) often use MPEG-1 or MPEG-2 formats (or their derivatives) which are all based on 16×16-pixel macroblocks. Having the height and width of the image readily divisible by 16 makes it easier and more efficient for an MPEG encoder to compress video" – read Section 4.5 from "A Quick Guide to Digital Video Resolution and Aspect Ratio Conversions," Wayback Machine, January 2008, https://web.archive.org/web/20140816103129/http://lipas.uwasa.fi/~f76998/video/conversion/.
[10] "Final Cut Pro Help," Apple, accessed September 25, 2019, https://www.andrew.cmu.edu/user/lshea/2.Tech_PDFs/Pixel_Fun_Aspect-NonSquare.pdf.
[11] Charles A Poynton, *Digital Video and HD* (Amsterdam: Elsevier, Morgan Kaufmann, 2012), 134.; Chris Meyer and Trish Meyer, *Creating Motion Graphics with After Effects* (Taylor and Francis, 2013), 679.; Please note a few high-definition standards like HDCAM and HDV use non-square pixels.
[12] (Frances Nagels, 2016)
[13] "Parameter Values for the HDTV Standards for Production and International Programme Exchange," ITU, June 2015, https://www.itu.int/dms_pubrec/itu-r/rec/bt/R-REC-BT.709-6-201506-I!!PDF-E.pdf.; BT.709 was first published ("part 1") for two video formats that were never fully implemented (1035i30 and 1152i25 HDTV) and then ("part 2") for the widely implemented 1080i and 1080p standards (1080 horizontal lines, interlaced scan or progressive scan).
[14] (Frances Nagels, 2016) – refer to explanation on each parameter in the post.
[15] "Guidelines for the Preservation of Video Recordings: Part B. Video Signal, Preservation Concepts, and Target Formats; IASA-TC 06," 2018, https://www.iasa-web.org/sites/default/files/publications/IASA-TC_06-B_20180518.pdf.

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