计算机色彩理论入门不靠谱科普

2025/04/19

申奥

要讲的以及不会讲的

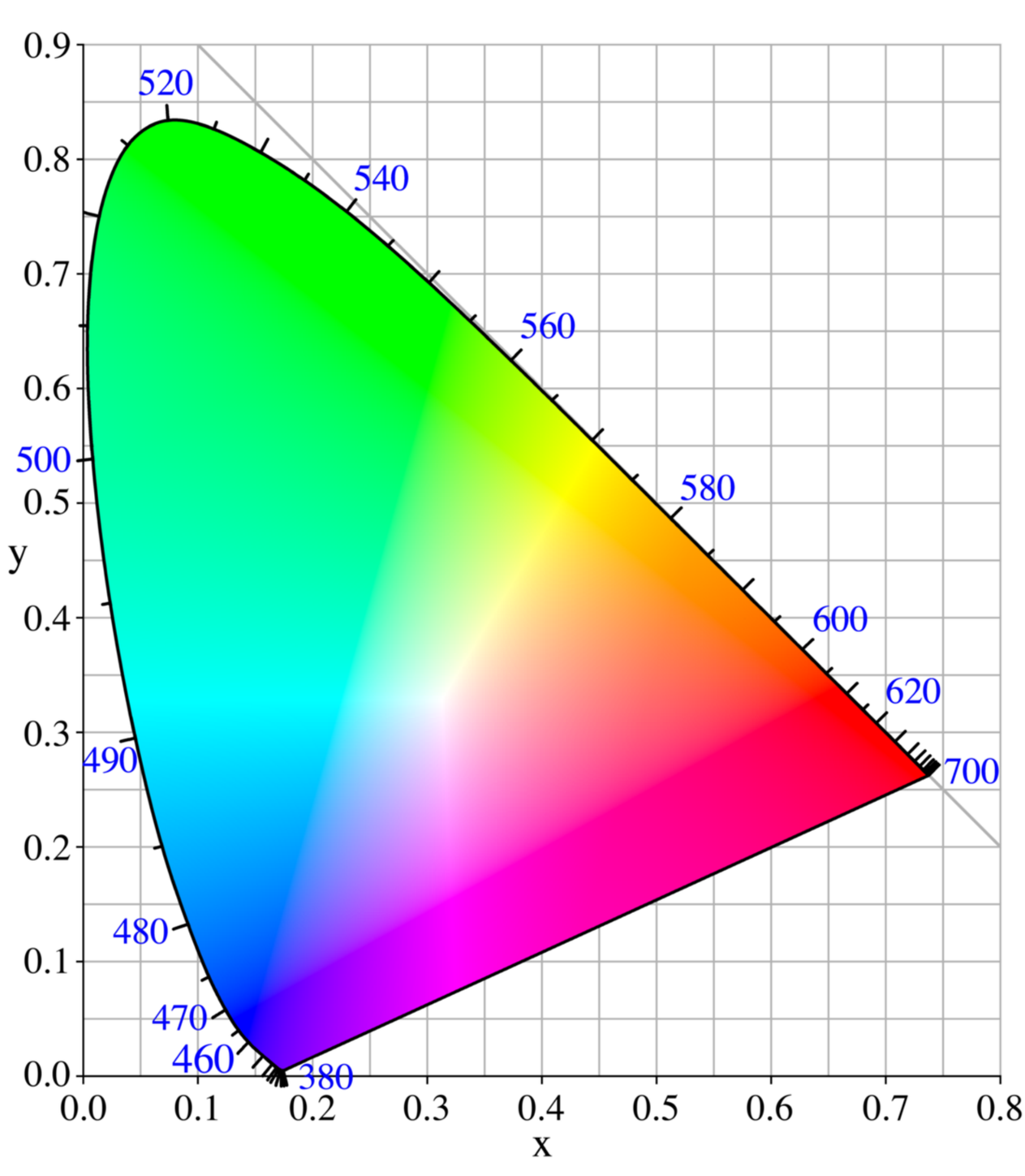
- 要讲的：
  - 什么是 Colorspace，为什么需要定义 Colorspace
  - 不懂这些知识在编写程序处理（SDR）多媒体内容时会遇到什么坑
- 不会讲的：（因为讲者自己也没搞懂）
  - HDR™
  - 打印机（Grayscale & CMYK）

色彩空间（Color space）

- 色域（Gamut）
- 白点（White point）
- 传输特性（Transfer characteristics, aka Gamma）

这是什么?

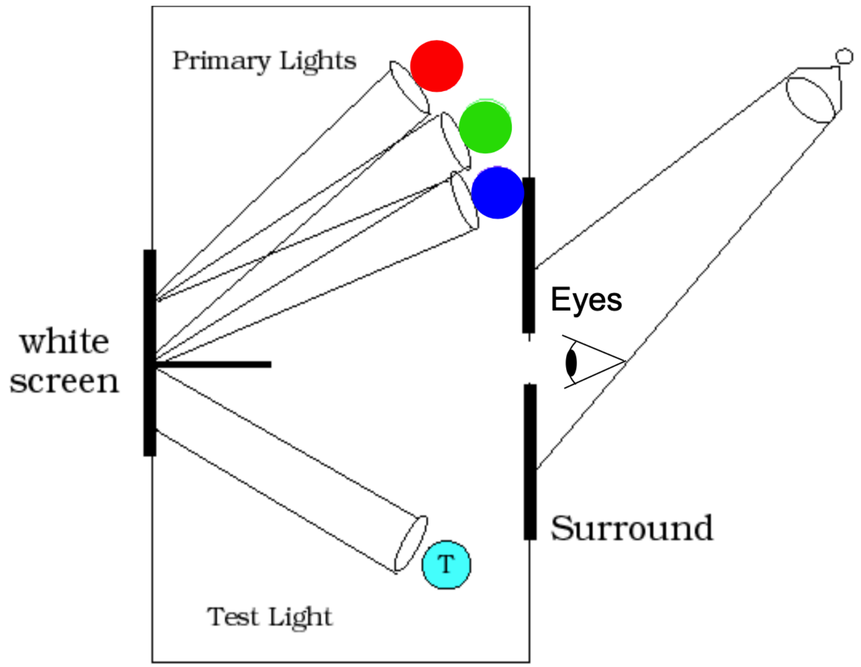
- https://commons.wikimedia.org/wiki/File:CIExy1931.png

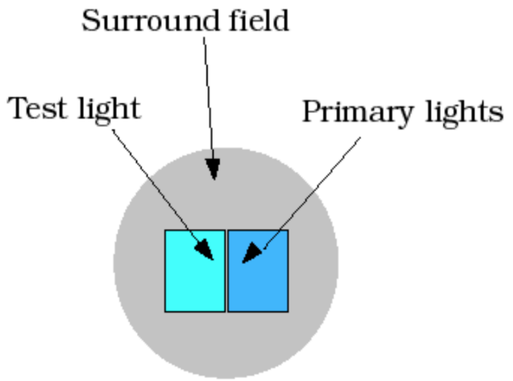


人类视力基准测试

Color-matching experiment

- Grassmann's law: color vision is (approximately) linear





TRANSACTIONS OF THE OPTICAL SOCIETY

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A RE-DETERMINATION OF THE TRICHROMATIC COEFFICIENTS OF THE SPECTRAL COLOURS

BY W. D. WRIGHT, A.R.C.S., D.I.C., B.Sc.

MS. received, 7th February, 1929. *Read and discussed, 14th March*, 1929.

ABSTRACT—Using a new trichromatic colorimeter a series of colour matches through the spectrum has been made by ten observers. The results have been averaged and a mean set of trichromatic coefficients for the spectral colours derived. These results are compared with previous determinations made by König and Abney. The variations in the coefficients that have been found amongst the ten observers must, as a consequence of a new method of basing the trichromatic units, be attributed to variations in the process of reception, but their magnitude appears to be of a small order. On the other hand, there are big differences in the amount of the macular pigment in different eyes and probably some variation in its dominant hue. These variations have been investigated by matches on a standard white, results for 36 observers being given in the paper and a mean value determined. This value, combined with the mean spectral coefficients, has been used to compute an average locus for the spectral colours in the colour triangle, with white at the centre.

Other points discussed in the paper include the technique of colour matching, the range of intensity over which matches remained valid, and variations of luminosity.

人类视力基准测试

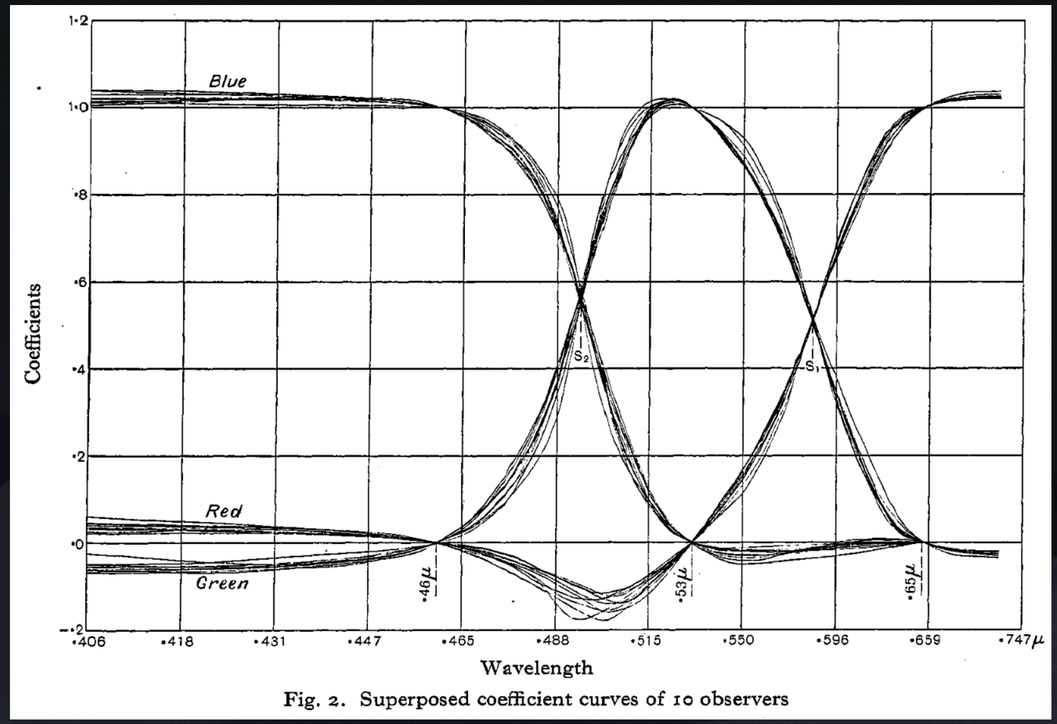
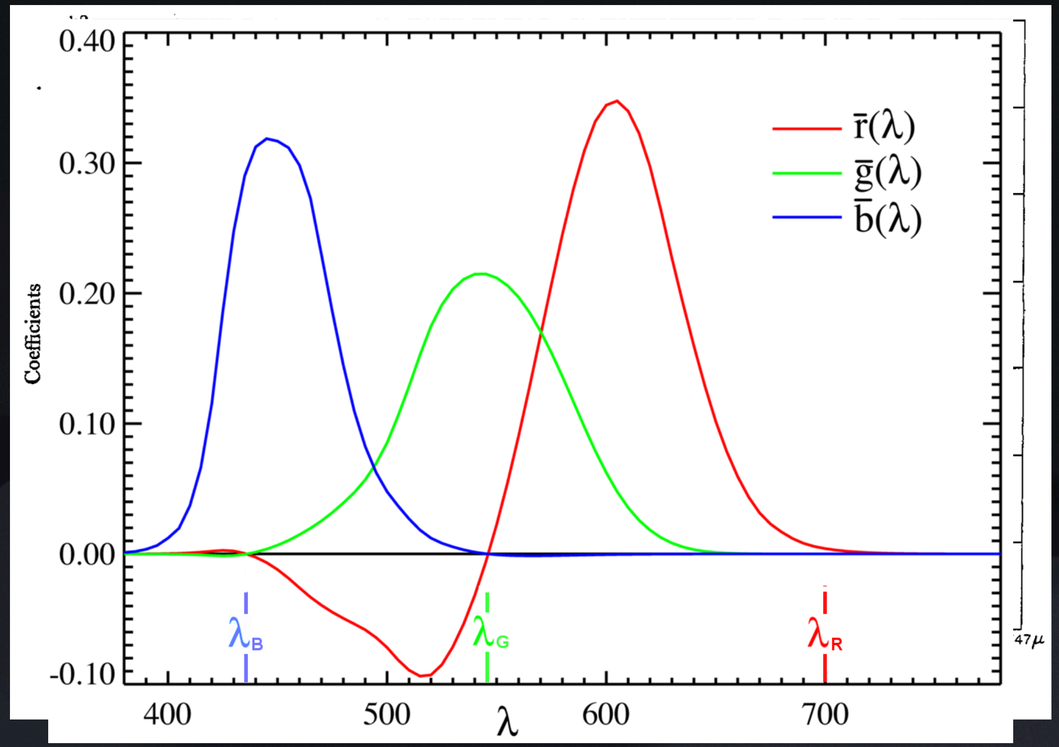


Fig. 2. Superposed coefficient curves of 10 observers

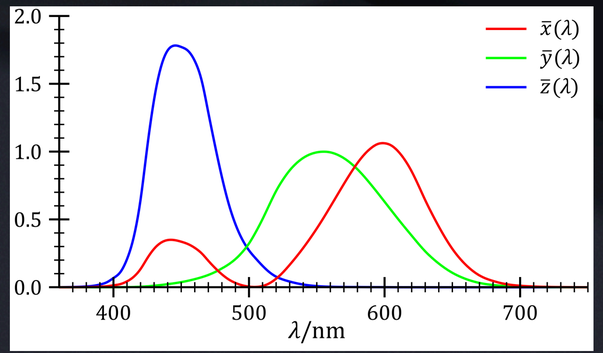
人类视力基准测试

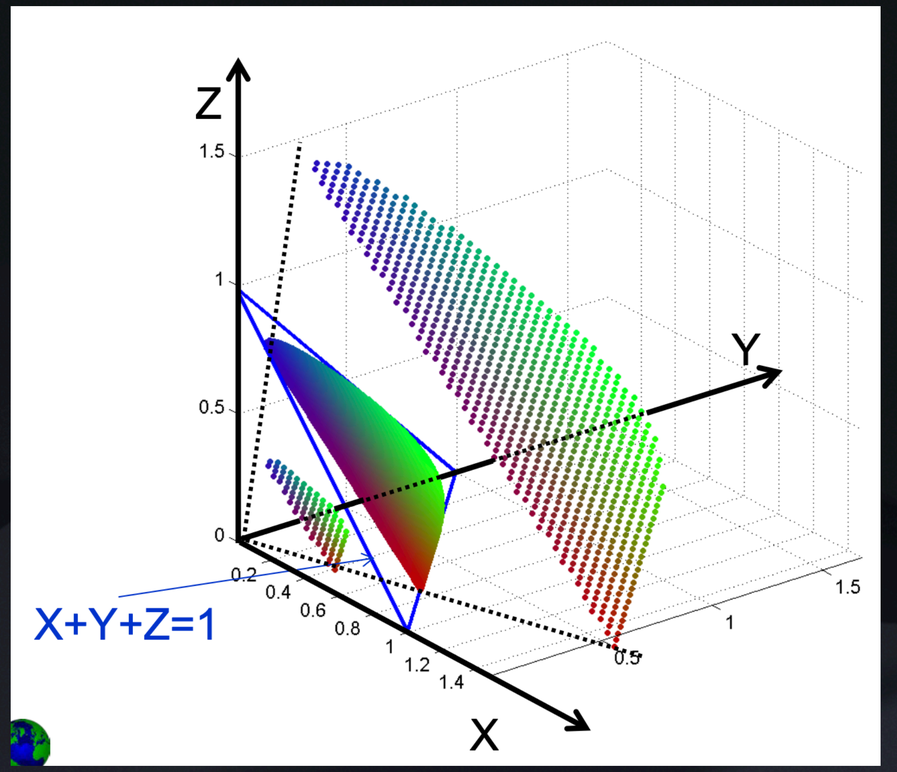
- 国际照明委员会（Commission internationale de l’éclairage, CIE）
- “CIE 1931 standard 2° observer”
- 基于三原色设定的坐标有些问题：
  - 有负数
  - 人类对三原色的亮度响应并不一致
  - “白色”没有良好的定义



CIE XYZ 色彩空间

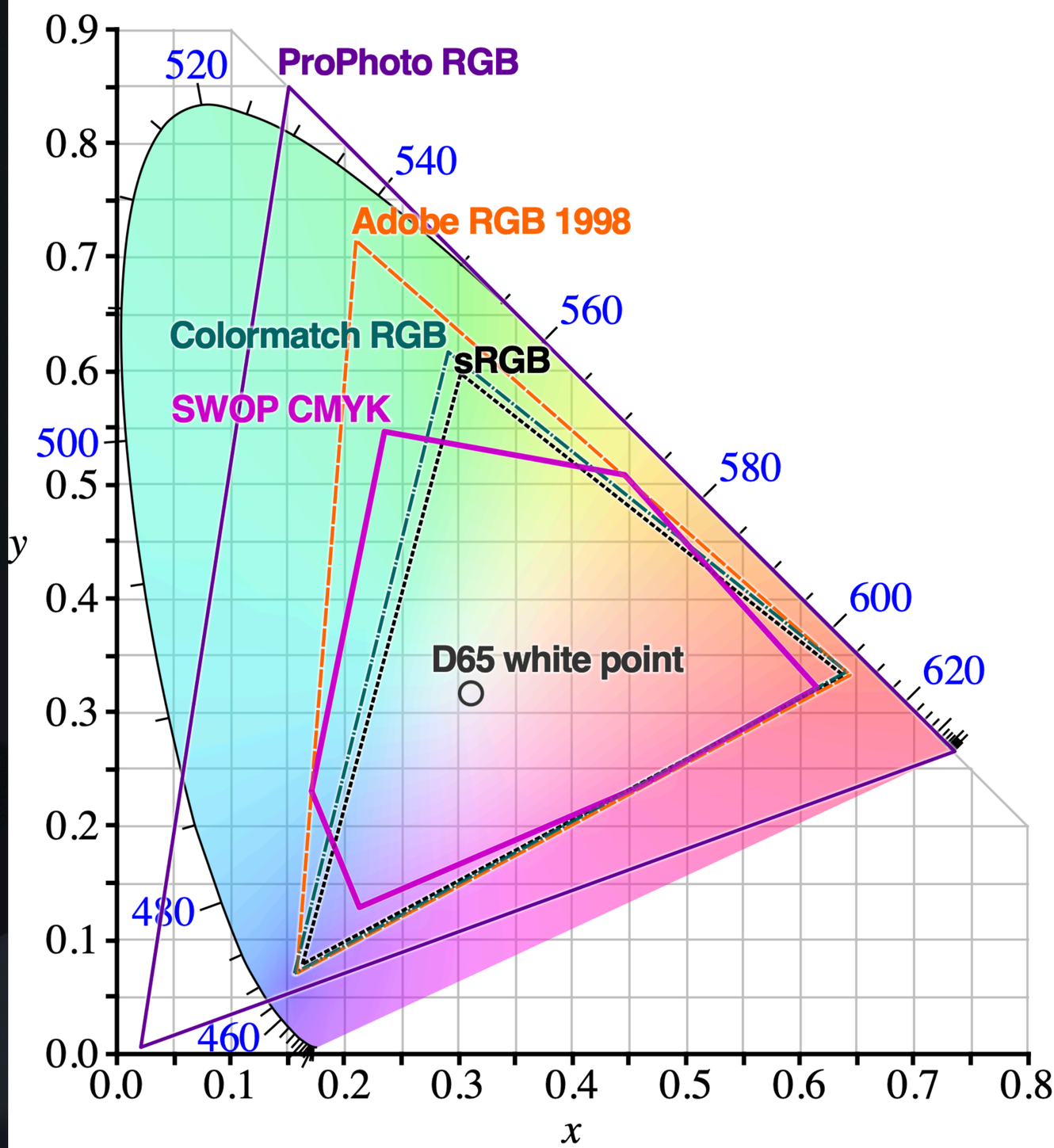
- 基于波长定义的 RGB 颜色值进行线性变换
- 变换的目标要求近似满足以下特征：
  - 对于可见光都在 [0, 1] 之间
  - Y 值对波长的曲线近似符合亮度曲线
  - X=Y=Z 对应的颜色 = 所有波长均匀混合的颜色





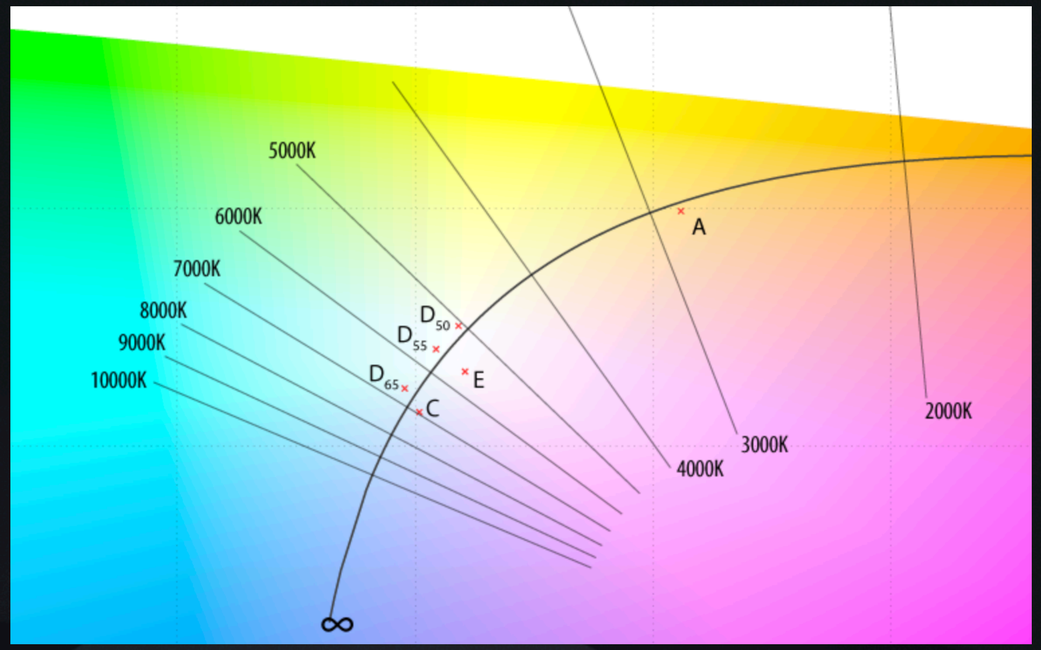
CIE XYZ 色域图

- 两种颜色的混合色一定在它们的连线上
- 不同色域之间的（绝对）大小关系



白点与色温

- 标准光源 “CIE standard Illuminants”
  - A 白炽灯
  - D XX 各种色温的太阳漫射光照近似
  - E 理论上的等波长混合光
- 和三原色的 xy 坐标加在一起，三种颜色的相对强度就清楚了



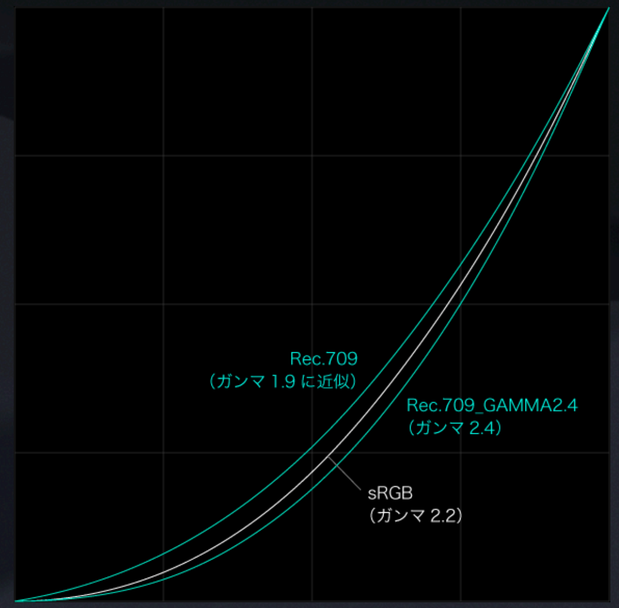
传输特性, or Gamma

- 人眼对光强度的感知相对于“真正的”光强（功率）不是线性的
- 在模拟时代这件事情不是很本质
- 进入数字时代之后，需要正确地量化颜色信号：
- 

- Gamma, aka $I \propto V_S^{\gamma}$

传输特性, or Gamma

- 颜色空间中的传输特性根据有没有做过 Gamma 变换分为两种：
  - 线性（Linear）编码值就是光照强度 I，可加但直接扔进 framebuffer 会变奇怪
  - 非线性（Non-linear）可以直接扔进 framebuffer，但是不同标准应用的值有一些区别
    - Rec. 709
    - sRGB
    - ~~人眼的 Gamma 会随着环境亮度而变化~~



如何描述颜色空间

- ICC 描述文件
  - 把这些奇奇怪怪的特性相对标准化地描述出来
  - PNG JPG JPG2000 PDF 等文件均可嵌入
- sRGB by default
  - 现代 CSS 支持标注颜色空间且默认颜色空间为 sRGB

如何在各种颜色空间中转换

- 不同的颜色空间标准表示颜色的能力有区别
- 直接 clip 会导致图片的观感发生巨大的变化
- ICC rendering intent (Perceptual, Saturation, Relative Colorimetric, Absolute Colorimetric)
- 调色（从某种角度上来说，RAW 图片调色也是一种手动操作的色域缩限）

不懂色彩理论入门导致的后果

- 如何编写图形学大作业
  - GPU Gems: The importance of being linear
  - 读材质文件之后不能把 RGB 值直接加和

(a) (b)

Figure 24-4 Rendering with Proper Gamma Correction () and Rendering Ignoring Gamma ()

不懂色彩理论入门导致的后果

- 如何正确使用 ffmpeg
- 希望现在大家能看懂 ffmpeg 里面 AVFrame 一万个参数有什么作用了（并没有）
- 视频的颜色表示有它独特的坑

AVCOL_RANGE_MPEG	Narrow or limited range content.
	• For luma planes:
	`(219 * E + 16) * 2^(n-8)`
	F.ex. the range of 16-235 for 8 bits
	• For chroma planes:
	`(224 * E + 128) * 2^(n-8)`
	F.ex. the range of 16-240 for 8 bits

AVCOL_RANGE_JPEG	Full range content.
	• For **RGB** and luma planes:
	`(2^n - 1) * E`
	F.ex. the range of 0-255 for 8 bits
	• For chroma planes:
	`(2^n - 1) * E + 2^(n - 1)`
	F.ex. the range of 1-255 for 8 bits

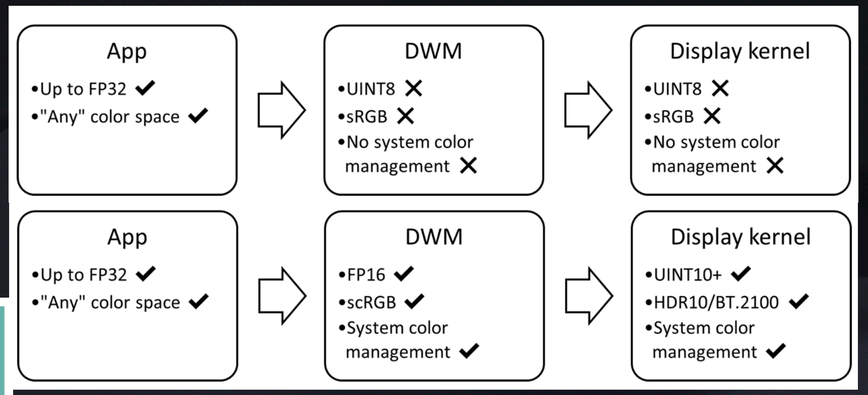
```
            1st 2nd        1st 2nd horizontal luma sample positions
             v   v          v   v
            ____           ____
```

1st luma line > lX X ... l3 4 X ... X are luma samples, l l1 2 1-6 are possible chroma positions 2nd luma line > lX X ... l5 6 X ... 0 is undefined/unknown position

Enumerator	
AVCHROMA_LOC_UNSPECIFIED	
AVCHROMA_LOC_LEFT	MPEG-2/4 4:2:0, H.264 default for 4:2:0.
AVCHROMA_LOC_CENTER	MPEG-1 4:2:0, JPEG 4:2:0, H.263 4:2:0.
AVCHROMA_LOC_TOPLEFT	ITU-R 601, SMPTE 274M 296M S314M(DV 4:1:1), mpeg2 4:2:2.
AVCHROMA_LOC_TOP	
AVCHROMA_LOC_BOTTOMLEFT	
AVCHROMA_LOC_BOTTOM	
AVCHROMA_LOC_NB	Not part of ABI.

不懂色彩理论入门导致的后果（我也不懂）

- HDR™
  - 随着显示技术的进步，我们希望显示器显示更多的亮度和颜色
  - 渲染 API 可以支持 >1.0 的浮点值塞进 framebuffer（D3D 和 Metal 似乎都能这么干）
  - 但是操作系统 - HDMI - 显示器的流程还有很多不一致
  - 程序员不懂事发动亮度战争



While double the size of `.bgra10a2Unorm`, working in linear space is very easy. For example, to map SDR content in `[0, 1]` to HDR, you can simply multiply the content by the `currentEDRHeadroom` value. Just remember to linearize the input first if necessary.