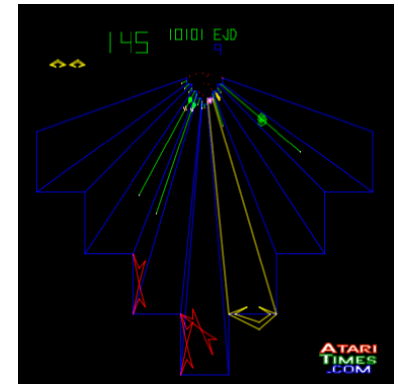
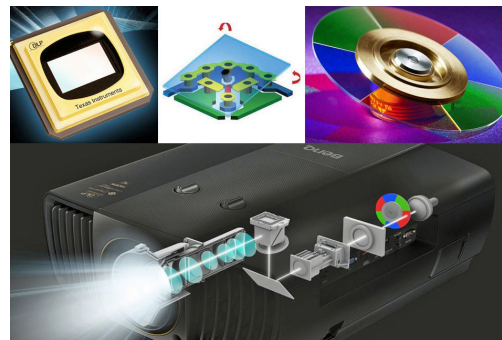
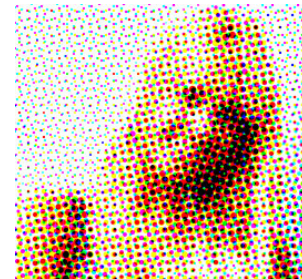
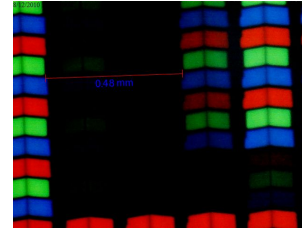


Displays - CSE160 – Nov 19

- The display matters
- CRT and Interlacing
- LCD
- DLP
- E-Ink
- Perception
- Gamma
- Dithering
- Administrative
- Q&A



The display matters

Displays



Graphics = Framebuffer

(but that's not the end of the story)

Discrete Image Representation

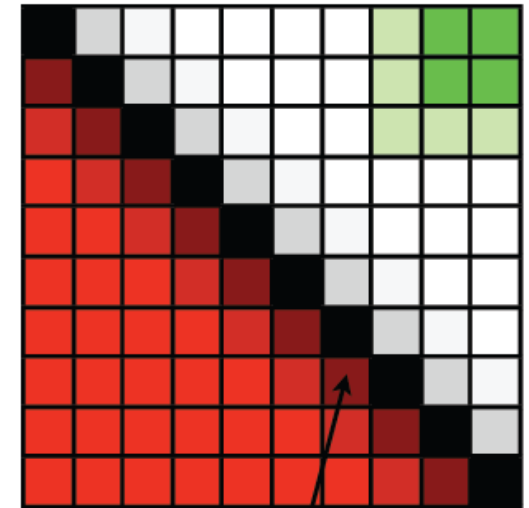
- Rectangular grid of **pixels**
- Each pixel encodes:
 - RGB triple for color images
 - Single value for grayscale images

Resolution

- Number of pixels
- 640x480, 1024x768, etc.

Color Depth

- Number of bits per pixel
- 24 bit color image uses 8 bits per channel



R: 01110100
G: 00001101
B: 00001001

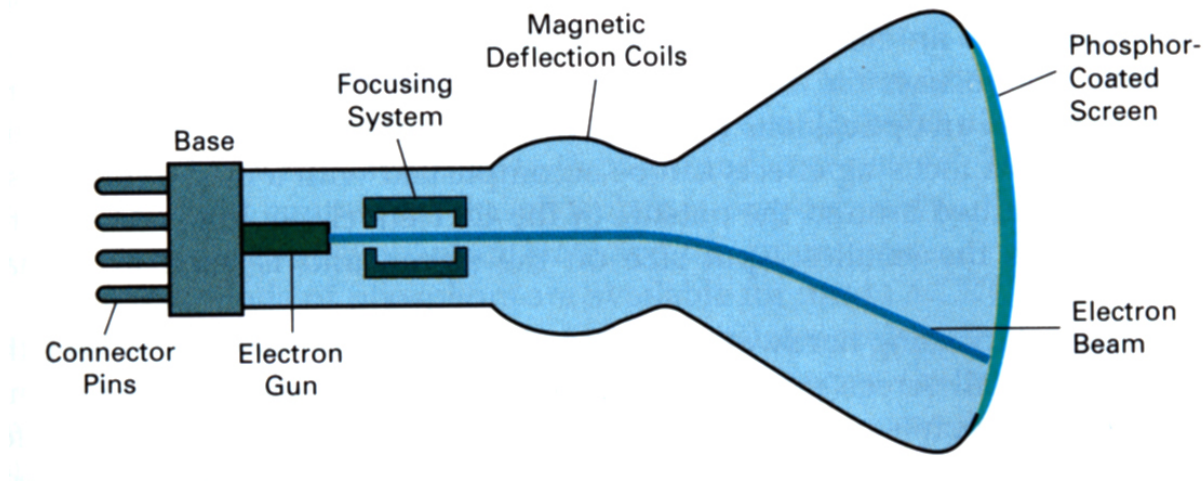
CRT and Interlacing





Cathode ray tube (CRT)

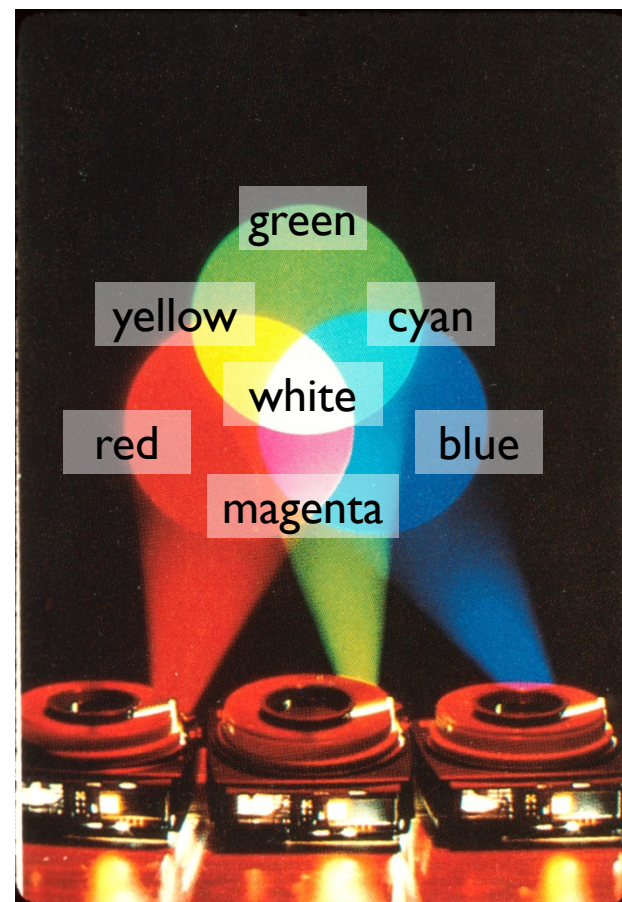
- First widely used electronic display
 - developed for TV in the 1920s–1930s



[H&B fig. 2-2]

Color displays

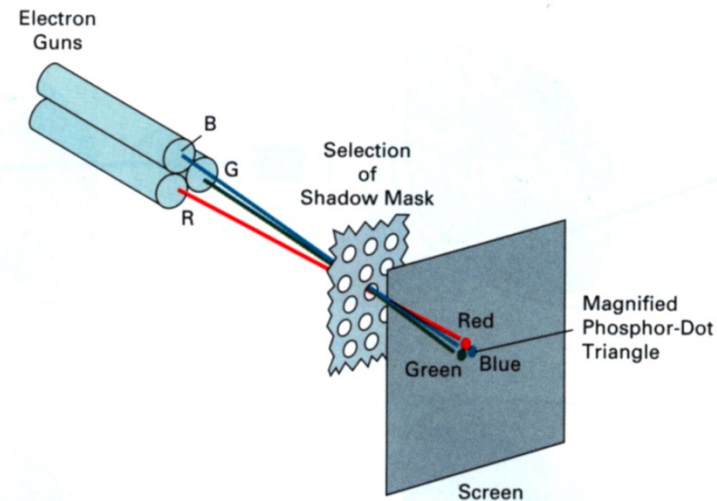
- Humans are trichromatic
 - match any color with blend of three
- Additive color
 - blend images by sum
 - R, G, B make good primaries



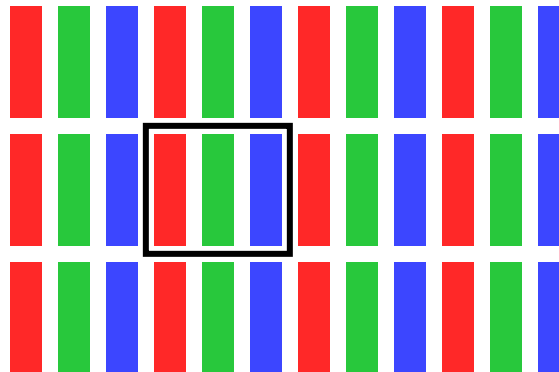
[cs417 S02 slides]

Color displays

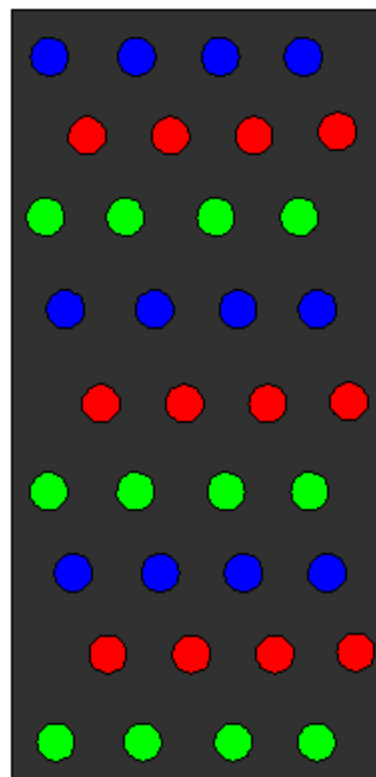
- CRT: phosphor dot pattern to produce finely interleaved color images



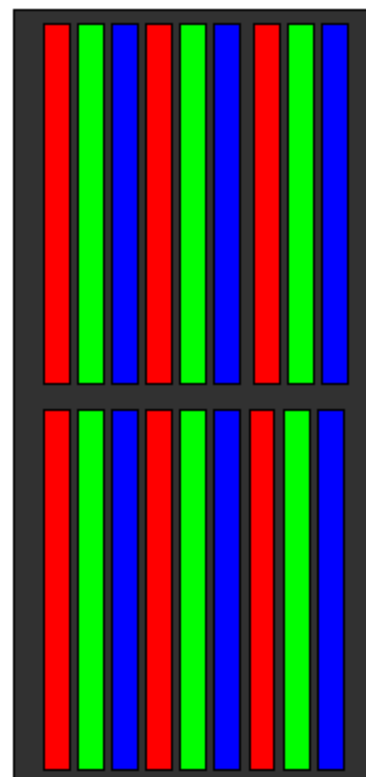
- LCD: interleaved R,G,B pixels



[H&B fig. 2-10]



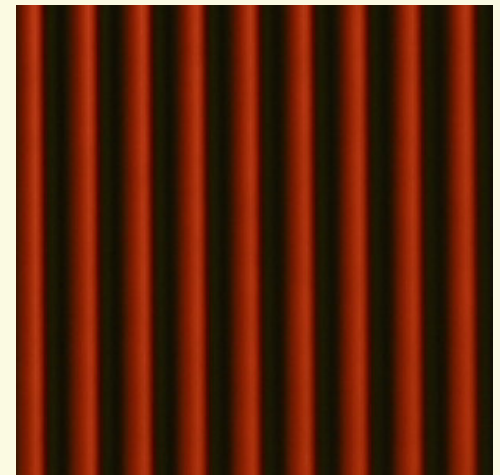
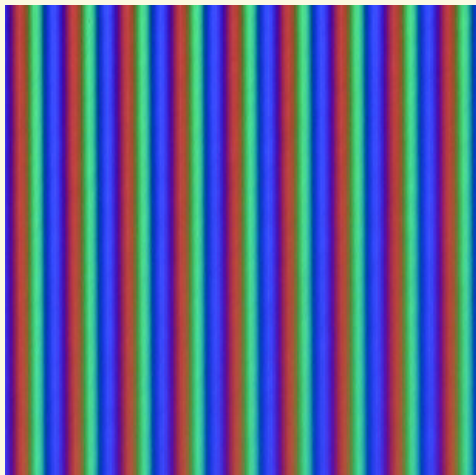
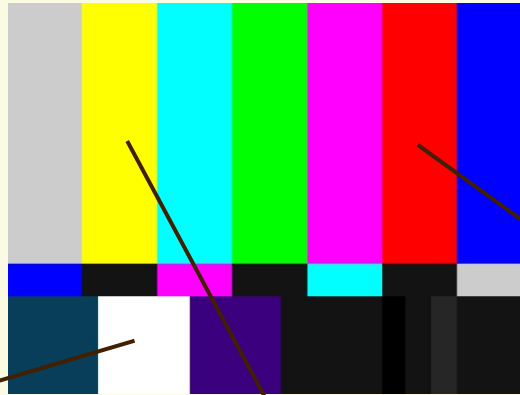
Traditional mask



Trinitron

Triads and color mixing

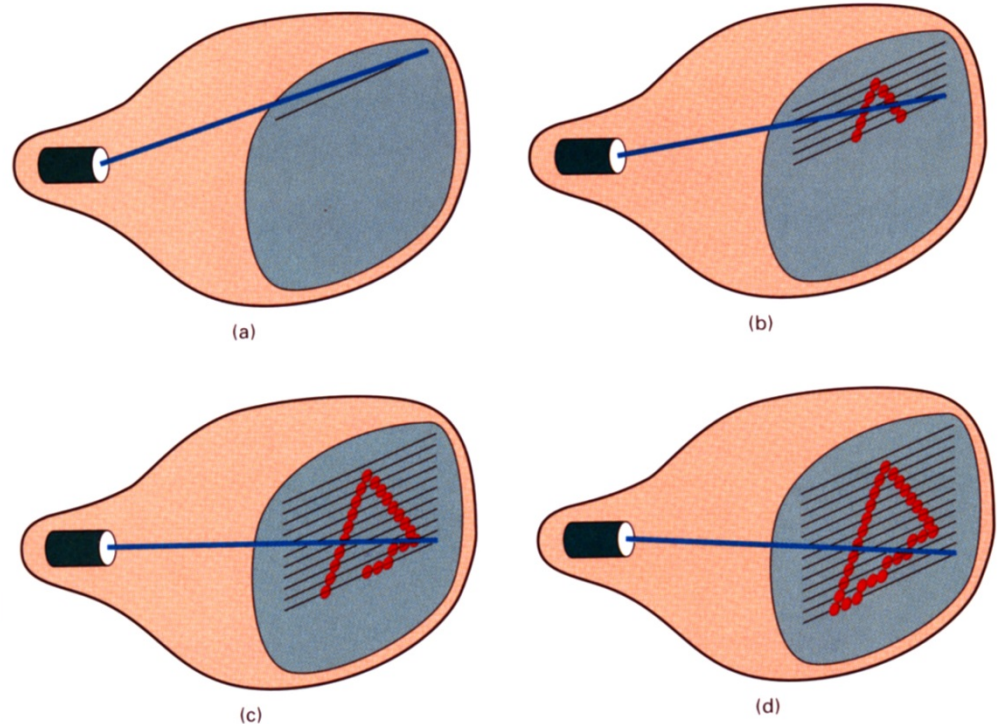
SMPTE color bars



closeup on a Sony Trinitron monitor

Raster CRT display

- Intensity modulated to produce image
- Originally for TV
 - (continuous analog signal)



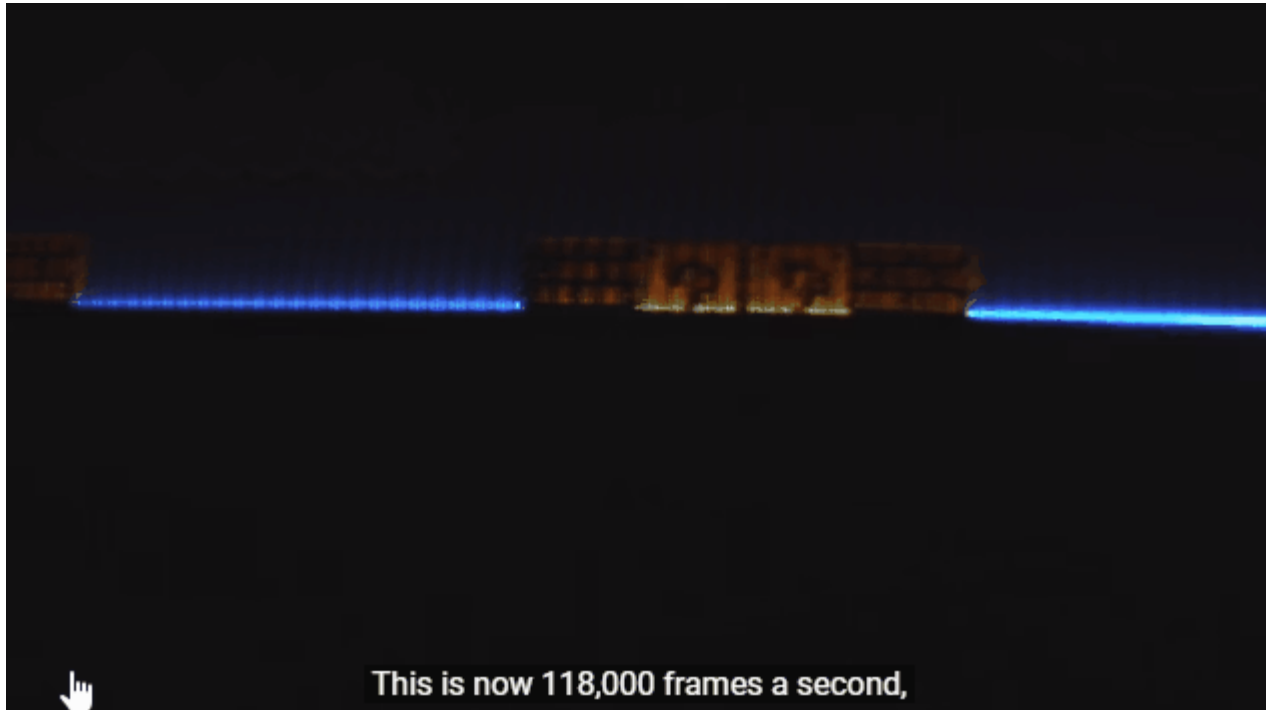
CRT refresh images





<https://www.youtube.com/watch?v=3BJU2drirtCM&feature=youtu.be>

How a TV Works in Slow Motion – The Slow Mo Guys



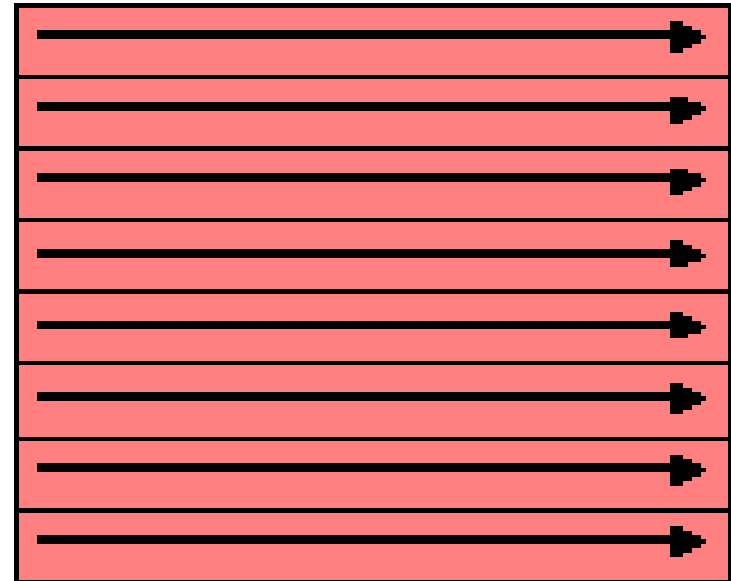
This is now 118,000 frames a second,

Interlacing vs progressive scan

From Computer Desktop Encyclopedia
© 2007 The Computer Language Co. Inc.

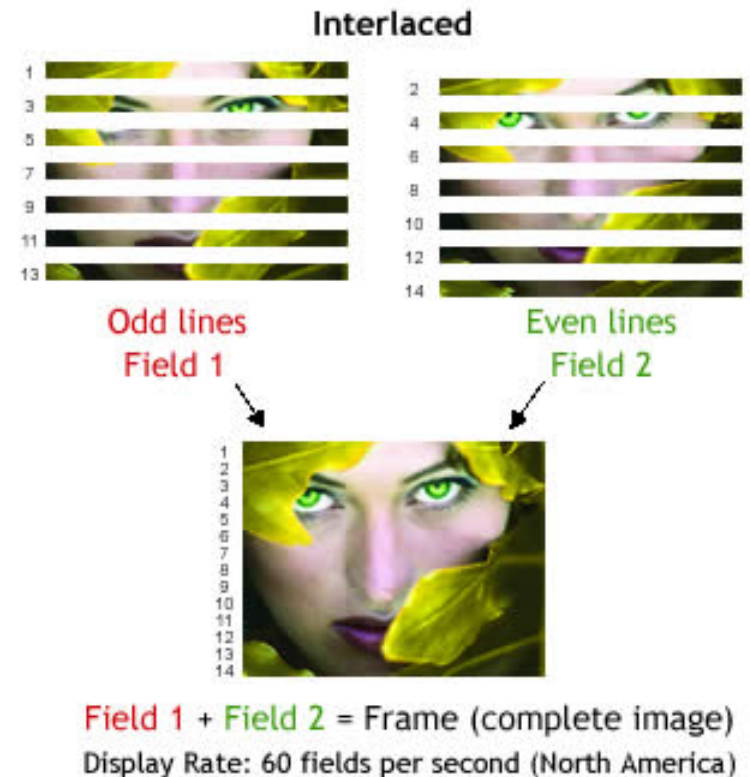
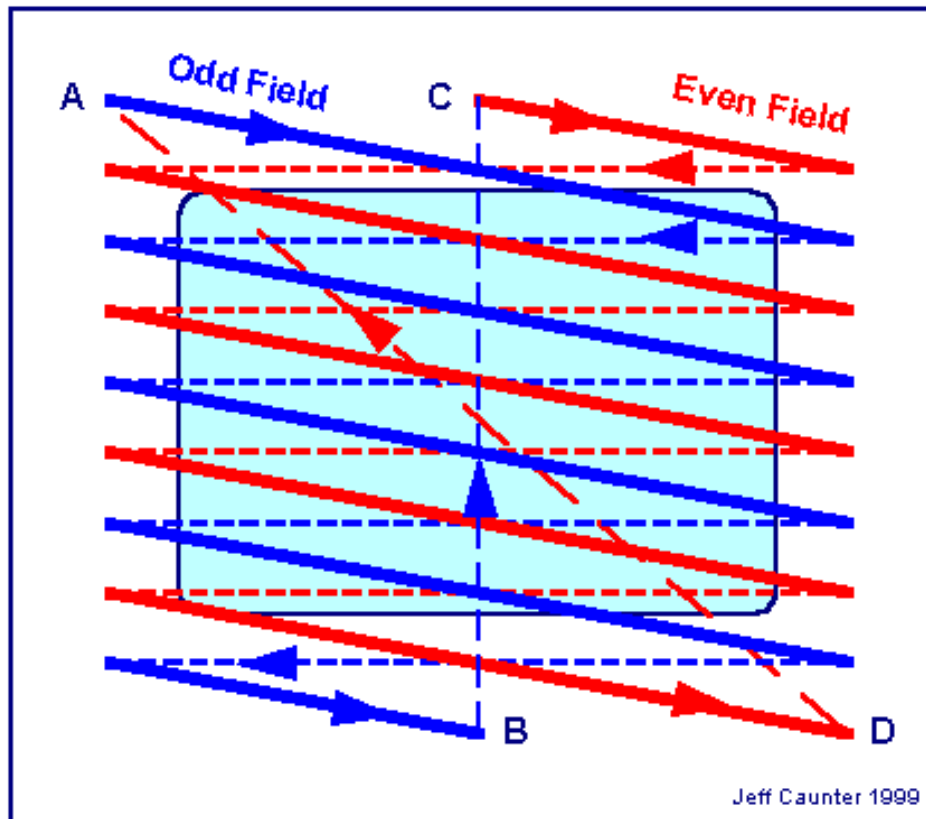


Interlaced



**Progressive Scan
(Non-interlaced)**

Interlacing vs progressive scan



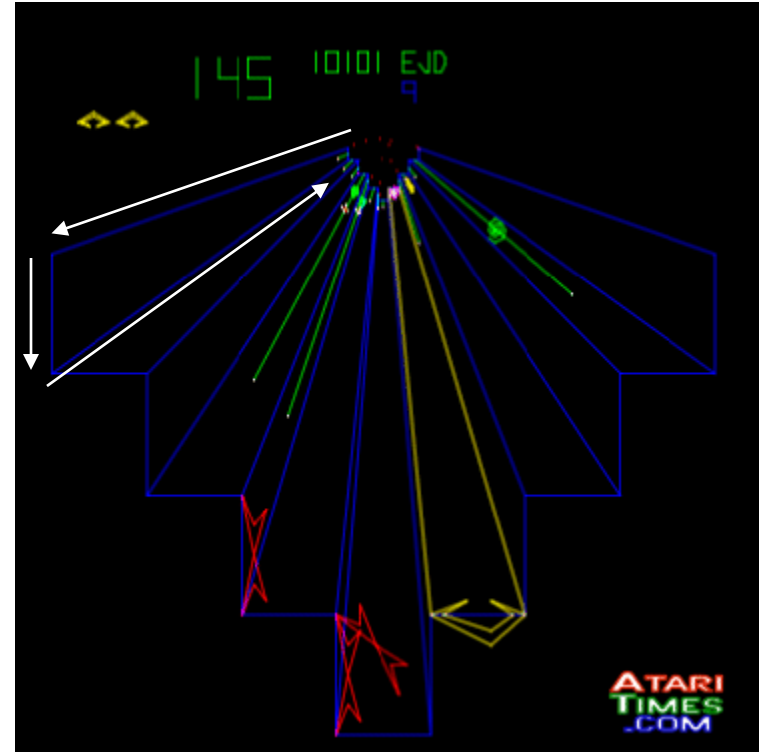
Interlacing vs progressive scan



Vector vs raster scan



Arthur Clokey, the creator of Gumby, trying out NYIT CGL's BBOP 3D keyframe animation system using an E & S vector display, 1984.



Tempest

4051 personal computing:

Ask a BASIC question, get a Graphics answer.

Compare Tektronix' 4051 to any other compact computing system. There's a Graphic contrast.

Wide-ranging performance right at your desk. BASIC power. Graphics power. Terminal capability. You've got instant access to answers, all from one neat package.

Easy-to-learn, enhanced BASIC. We took elementary, English-like BASIC, and beefed it up for more programming muscle. We've designed it with MATRIX DRAW, features like VIEWPORT,

WINDOW, and ROTATE, to help you get your teeth into Graphics almost instantly.

There's a Graphic contrast.

The 4051 will handle most application problems. But for your most complex problems, the 4051's Data Communications Interface option can put you on-line to powerful Graphic applications that no stand alone system can tackle.

Just \$6995.* Less than most comparable alphanumeric only systems. Including 8K workspace, expandable to 32K, with 300K byte cartridge tape drive, full Graphics CRT, upper/lower case, and all the BASIC firmware.

Talk to Tektronix today! Your local Sales Engineer will fill you in on our 4051 software. Our range of peripherals. Our flexible purchase and lease agreements. And he'll set up a demonstration right on your desk. Call him right now, or write:

Tektronix, Inc.
Information Display Group
P. O. Box 500
Beaverton, Oregon 97077



TEKTRONIX®

Circle 189 on reader service card

8K memory!

This is why early
graphics did not
have a frame
buffer.

$1024 \times 1024 = 1 \text{ Mega bit}$



Brain teaser

We have a CRT which can change the electron gun direction at a maximum rate of 1,000,000 pixels/second. Suppose we have a display which is nominally 1,000 x 1,000 pixel resolution.

- a. If this is a raster scan display, how many times per second can we draw a single 10x10 square on the screen?
- b. If this is a vector display, how many times per second can we draw a single 10x10 square on the screen?

Now suppose that we need to draw 1,000,000 squares.

- c. If this is a raster scan display, how many times per second can we draw all the 10x10 square on the screen?
- d. If this is a vector display, how many times per second can we draw all the 10x10 square on the screen?

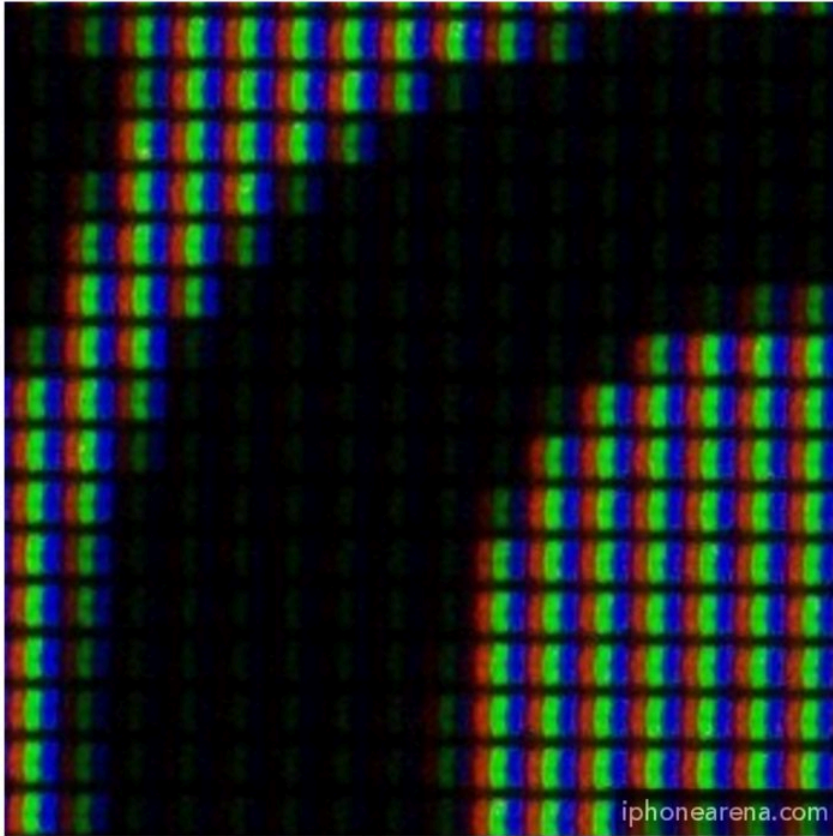
Poll answers:

- A <1 fps
- B 1 fps
- C 10 fps
- D 100 fps
- E >100 fps

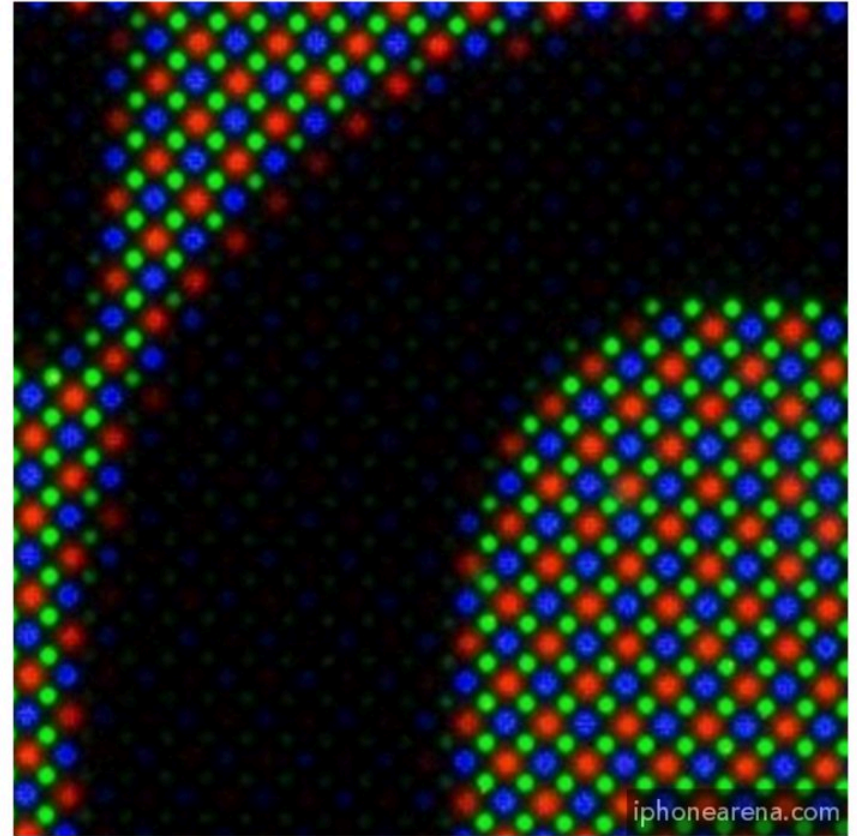
LCD



real LCD screen pixels (closeup)



iPhone 6S

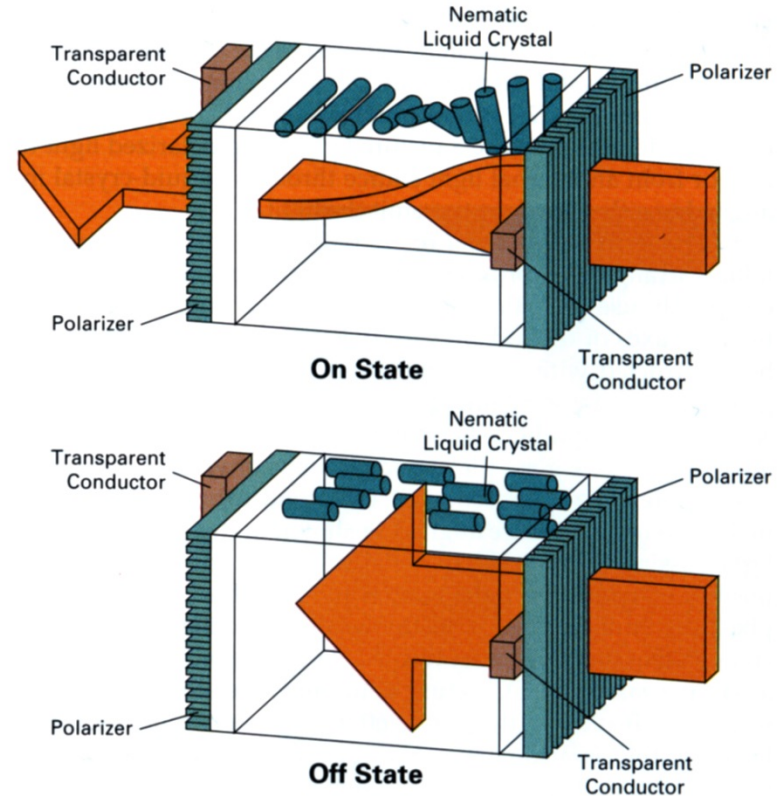


Galaxy S5

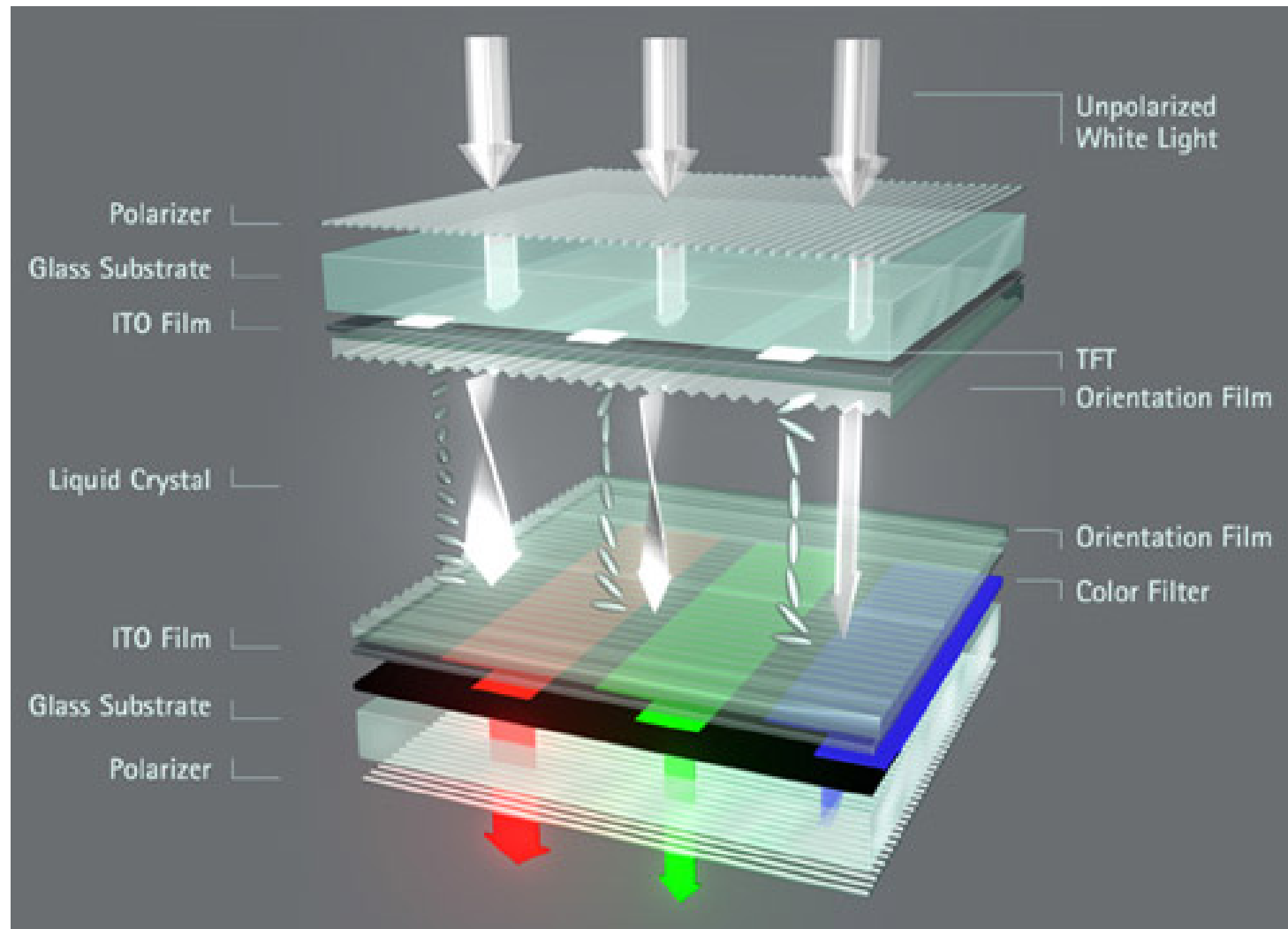
**Notice R, G, B sub-pixel geometry.
Effectively three lights at each (x,y) location.**

LCD flat panel or projection display

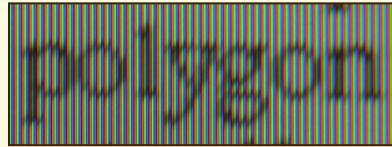
- Principle: block or transmit light by twisting its polarization
- Intermediate intensity levels possible by partial twist
- Fundamentally raster technology



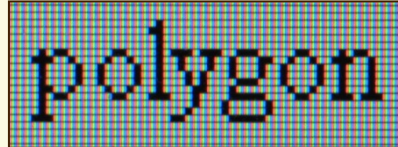
LCD



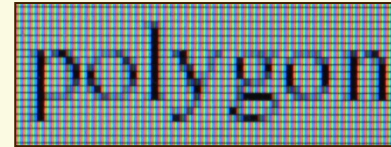
Triads versus pixels



integral pixel font
(Sony Trinitron)



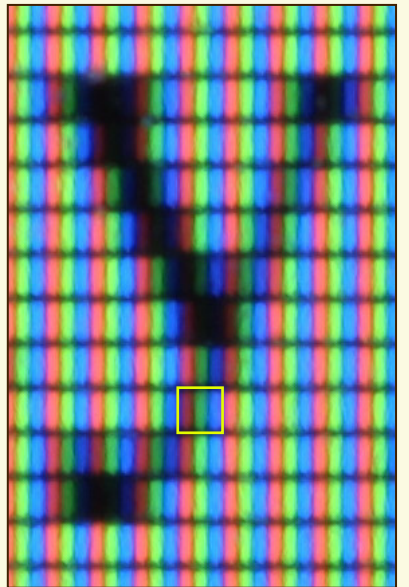
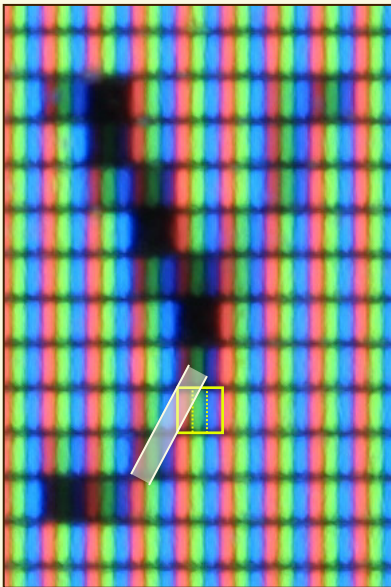
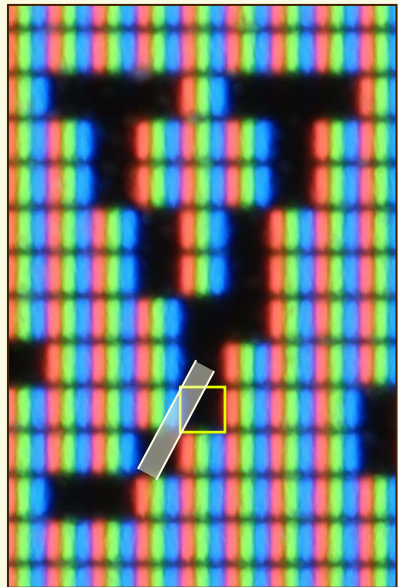
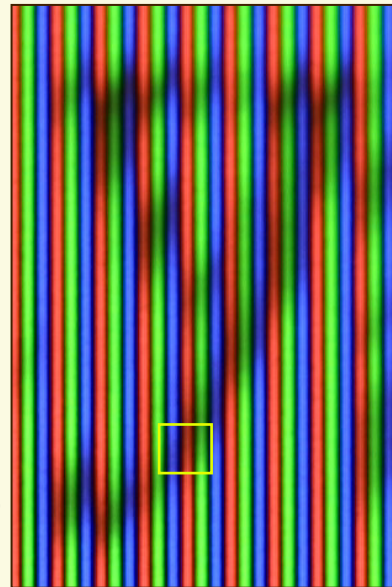
integral pixel font
(IBM LCD)



antialiased font
(Adobe Acrobat)



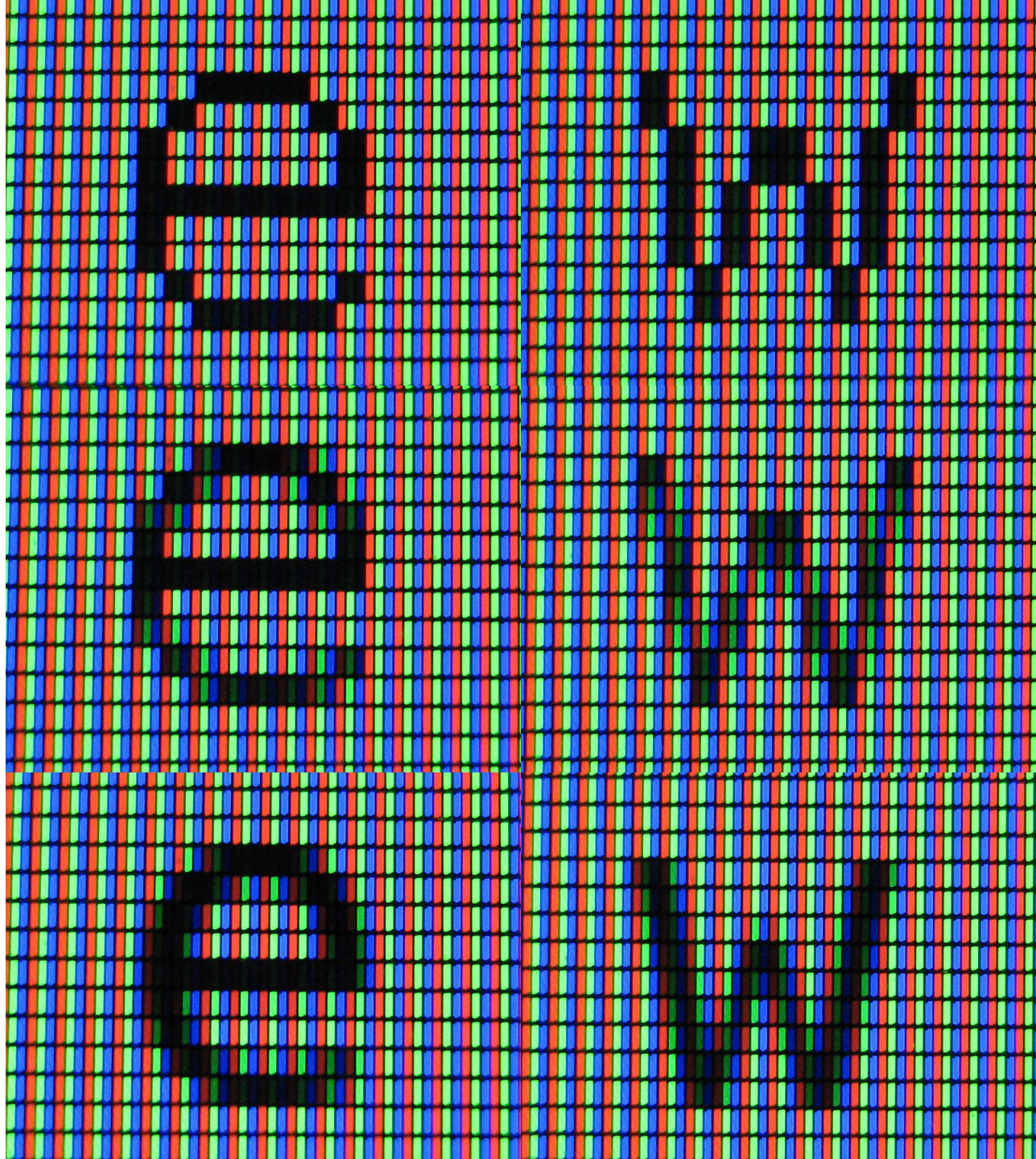
subpixel font
(Adobe Cooltype)

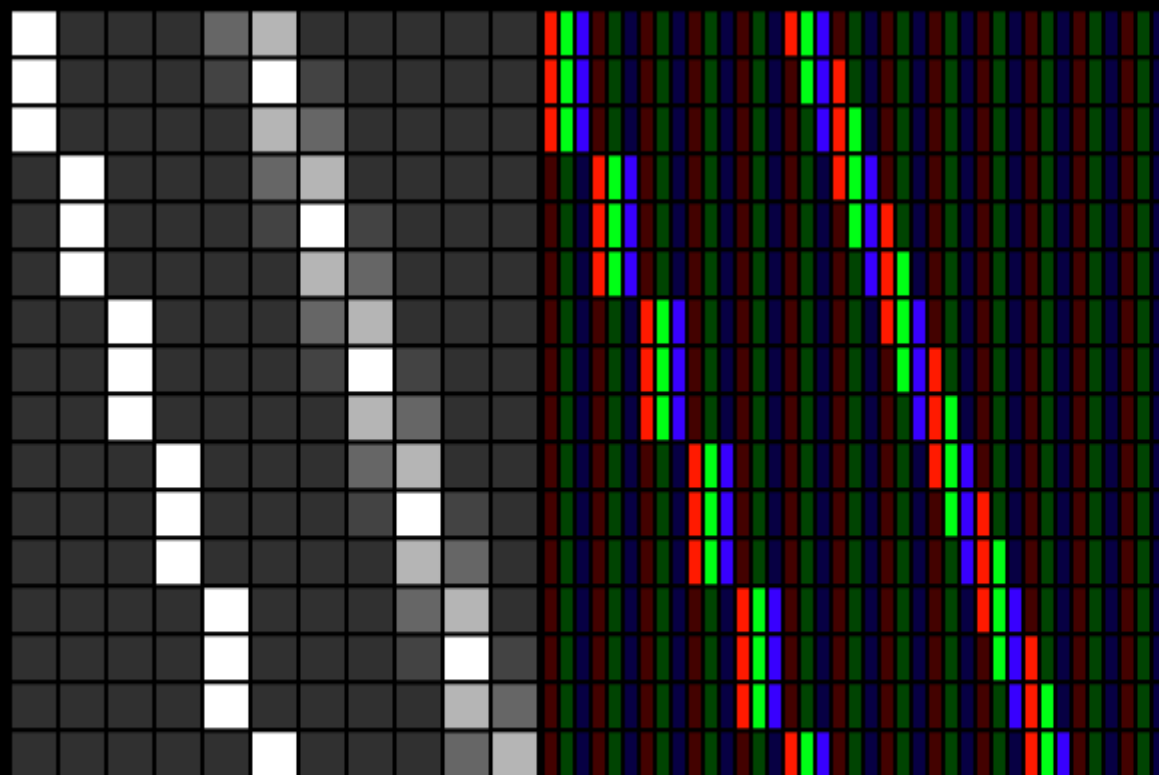


Monochrome

Antialiasing

Subpixel rendering



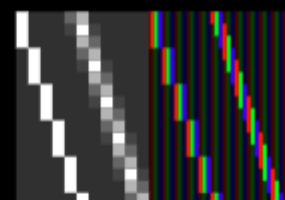


1

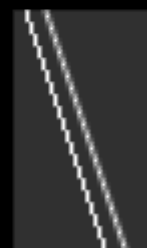
2

3

4



5

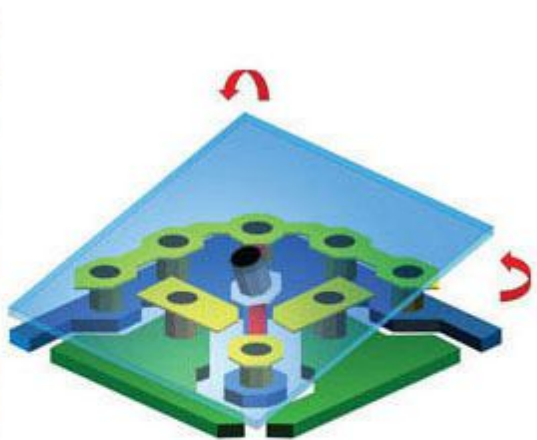


6

We stack two LCD on top of each other and place a backlight behind the whole assembly. We show yellow on the back LCD, and cyan on the front LCD. What color do we see in the front?

- a) Red
- b) Green
- c) Blue
- d) White
- e) Black

DLP



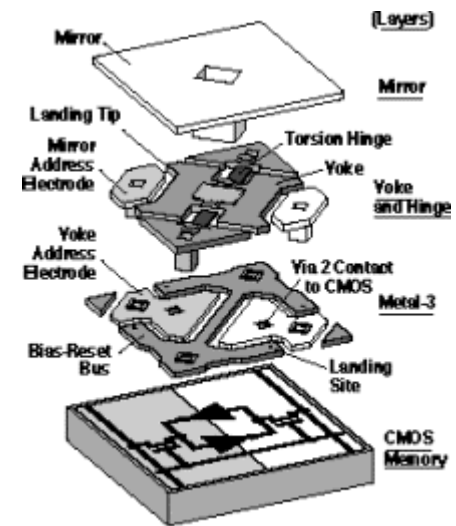
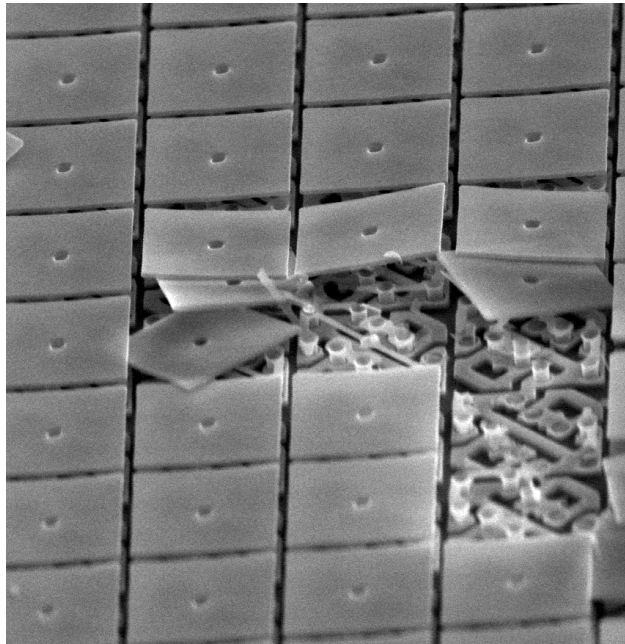
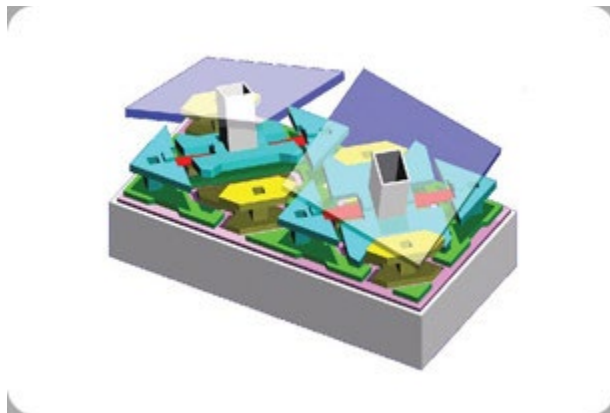
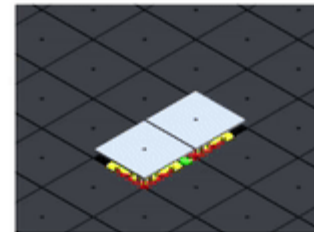


Figure 8. DMD pixel exploded view



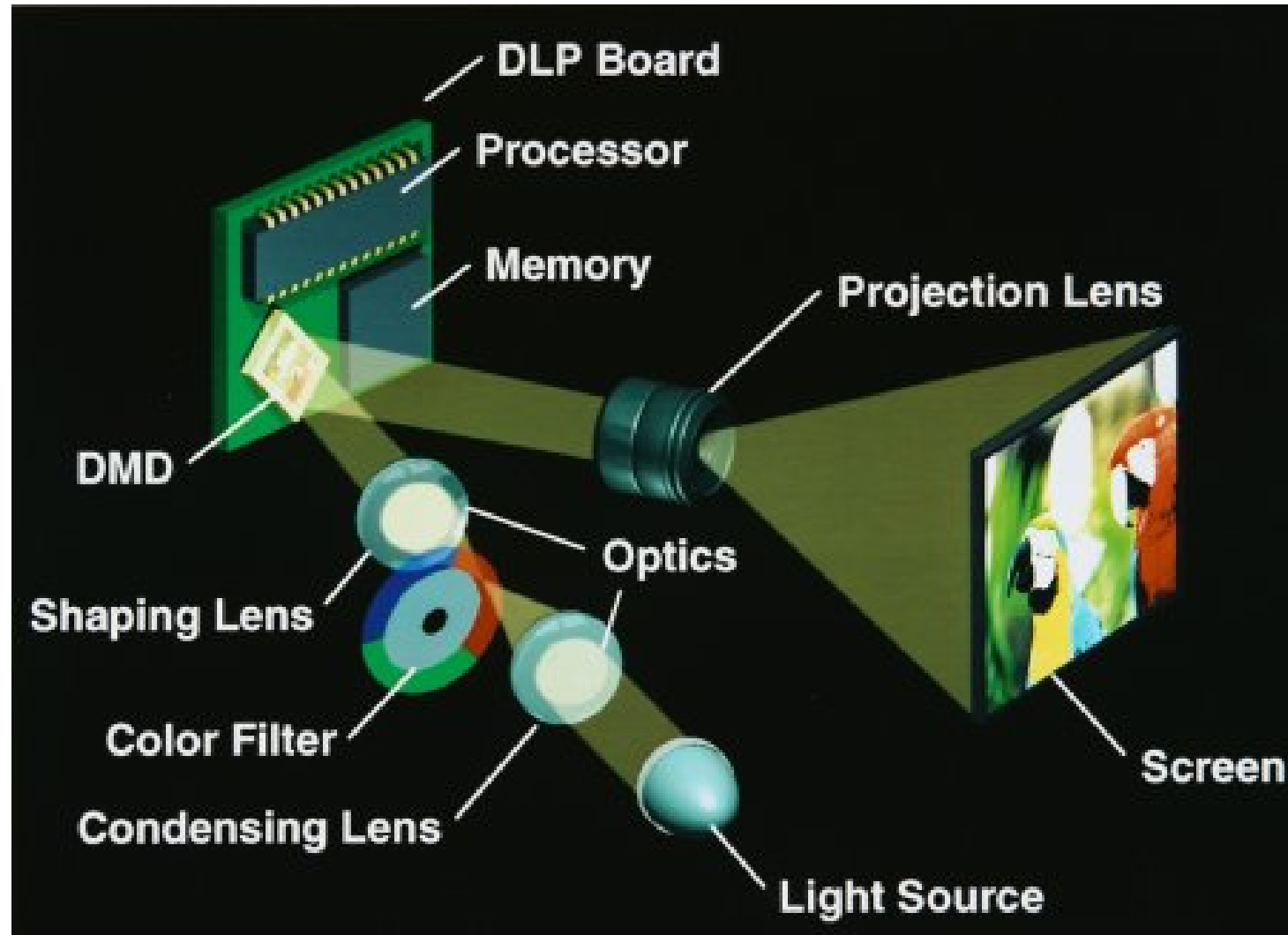
DLP High-speed Spatial Light Modulation

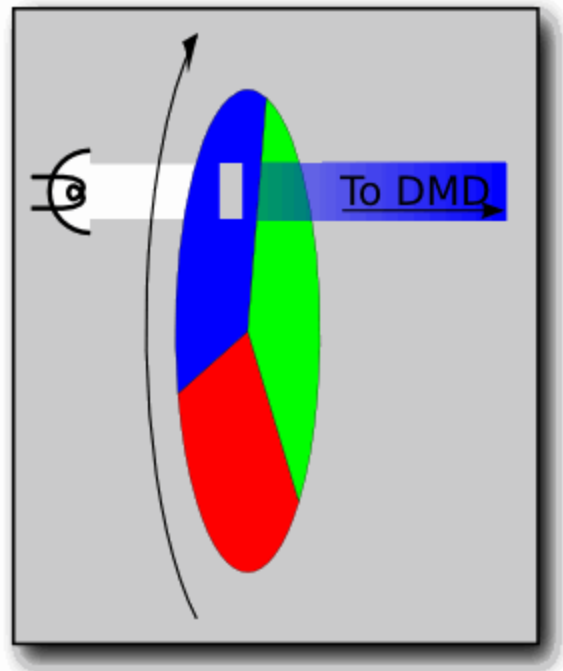


ti.com/DLPspeed

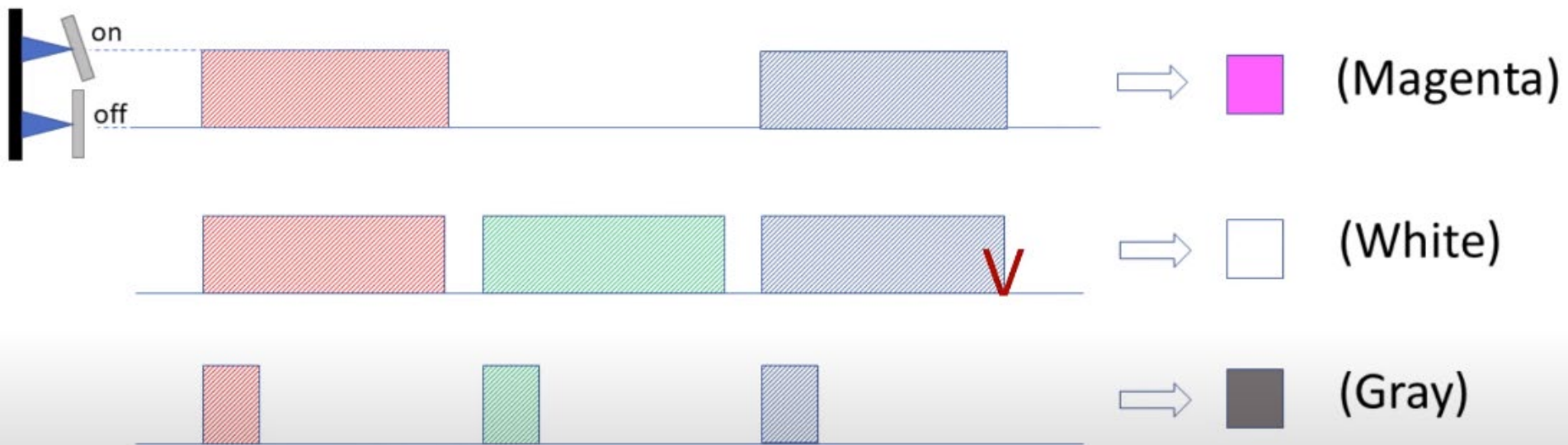
MakeAGIF.com

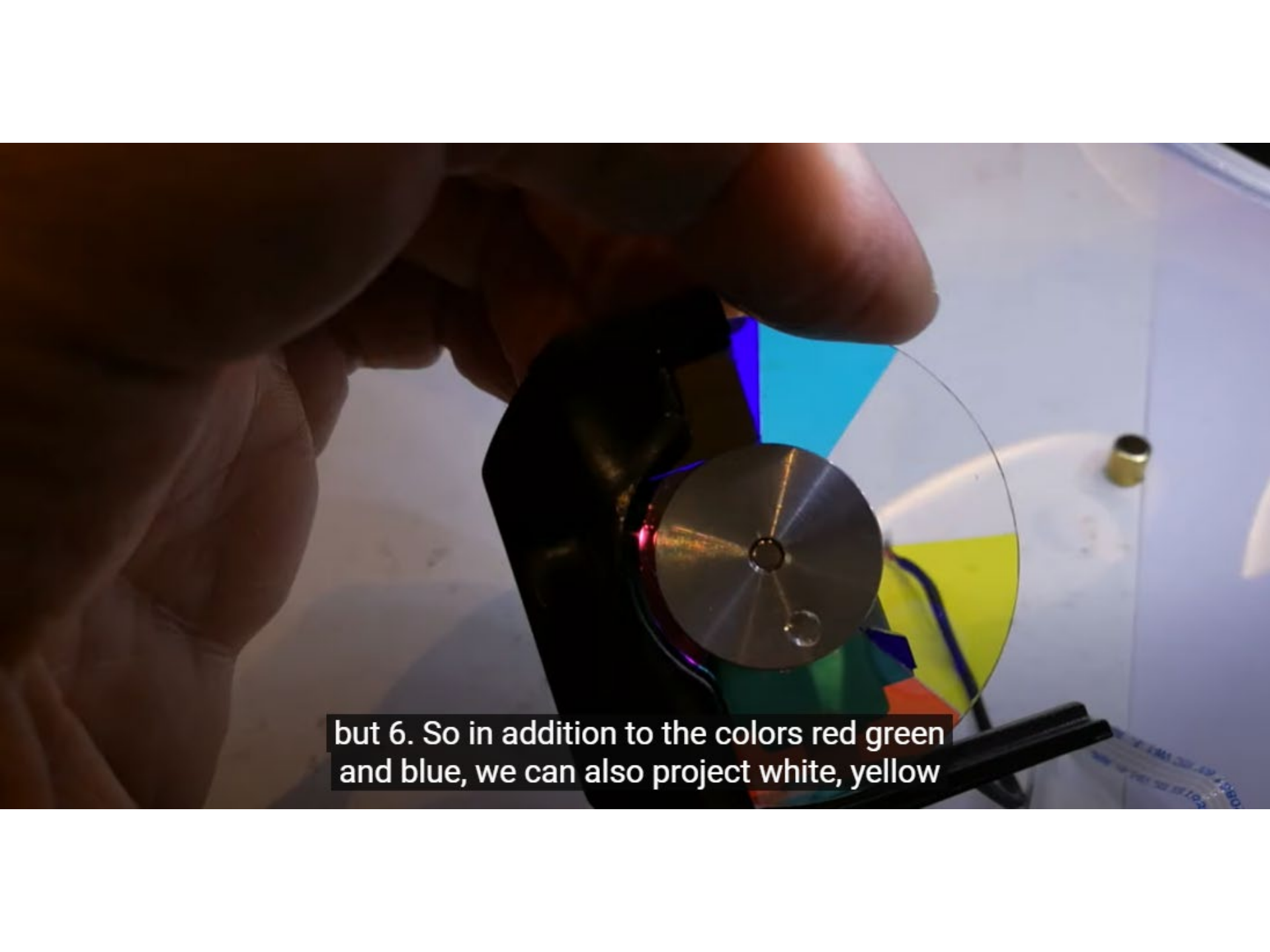
DLP





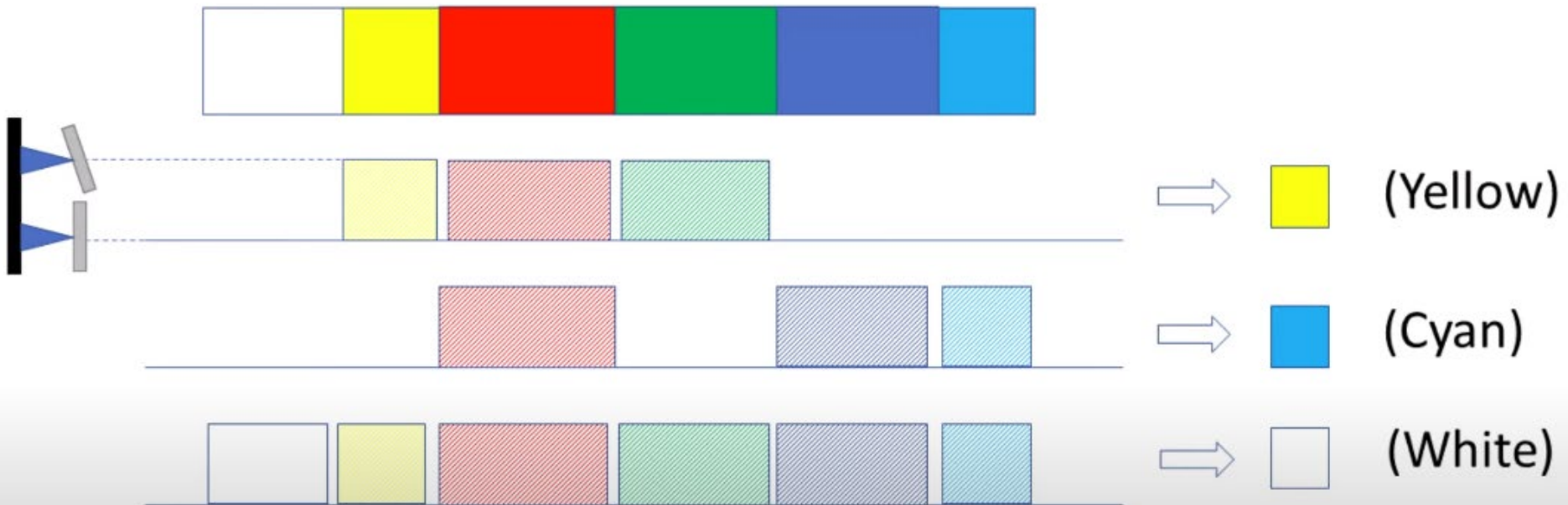
3-segment color wheel (primary colors only)



A close-up photograph showing a person's hand holding a compact disc (CD) in front of a color wheel. The color wheel is a circular disk with several colored segments: red, green, blue, yellow, and cyan. The CD is positioned such that its reflective surface is catching light and projecting the colors of the wheel. The background is a plain, light-colored surface.

but 6. So in addition to the colors red green and blue, we can also project white, yellow

6-segment color wheel



The only difference here is that for some colors, extra yellow cyan or white light are

E-ink

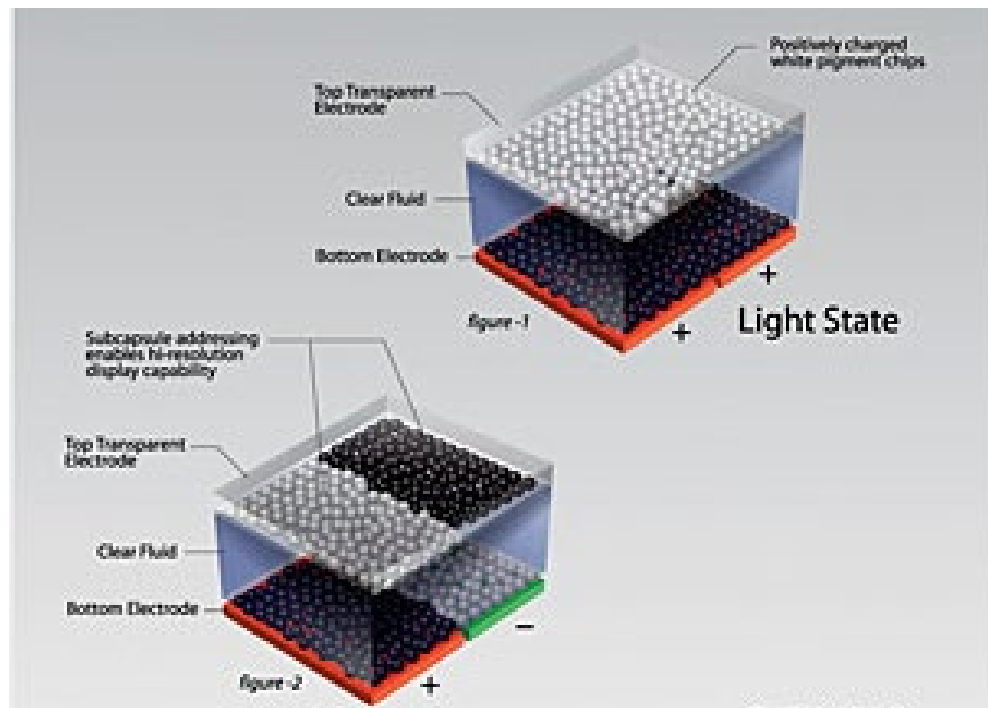
CHAPTER I

THERE WAS NO POSSIBILITY of taking a walk that day. We had been wandering, indeed, in the leafless shrubbery an hour in the morning; but since dinner (Mrs. Reed, when there was no company, dined early) the cold winter wind had brought with it clouds so sombre, and a rain so penetrating, that further outdoor exercise was now out of the question.

I was glad of it: I never liked long walks, especially on chilly afternoons: dreadful to me was the coming home in the raw twilight, with nipped fingers and toes, the nurse, and a heart saddened by the chidings of Bessie, the nurse, and humbled by the consciousness of my physical inferiority to Eliza, John, and Georgiana Reed.

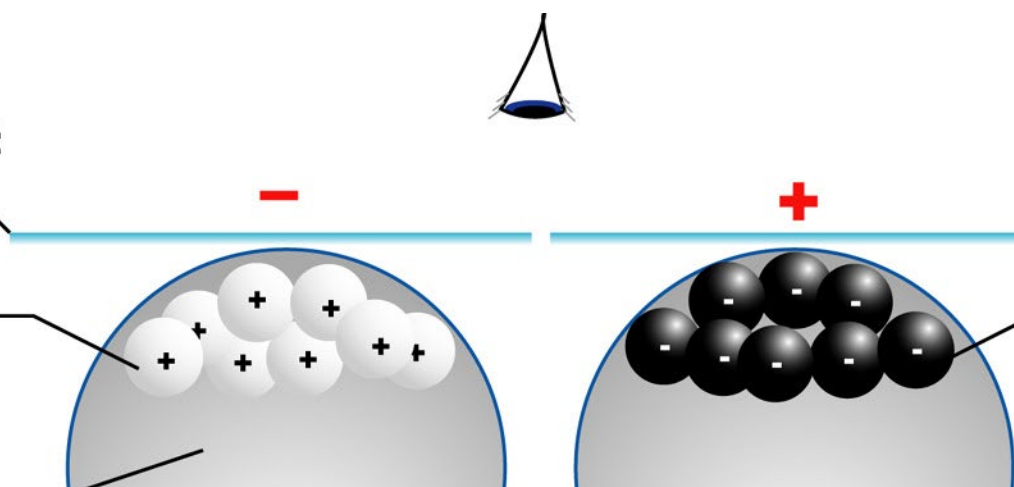
The said Eliza, John, and Georgiana were now clustered round their mama in the drawing-room: she lay reclined on a sofa by the fireside, and with her darlings about her (for the time

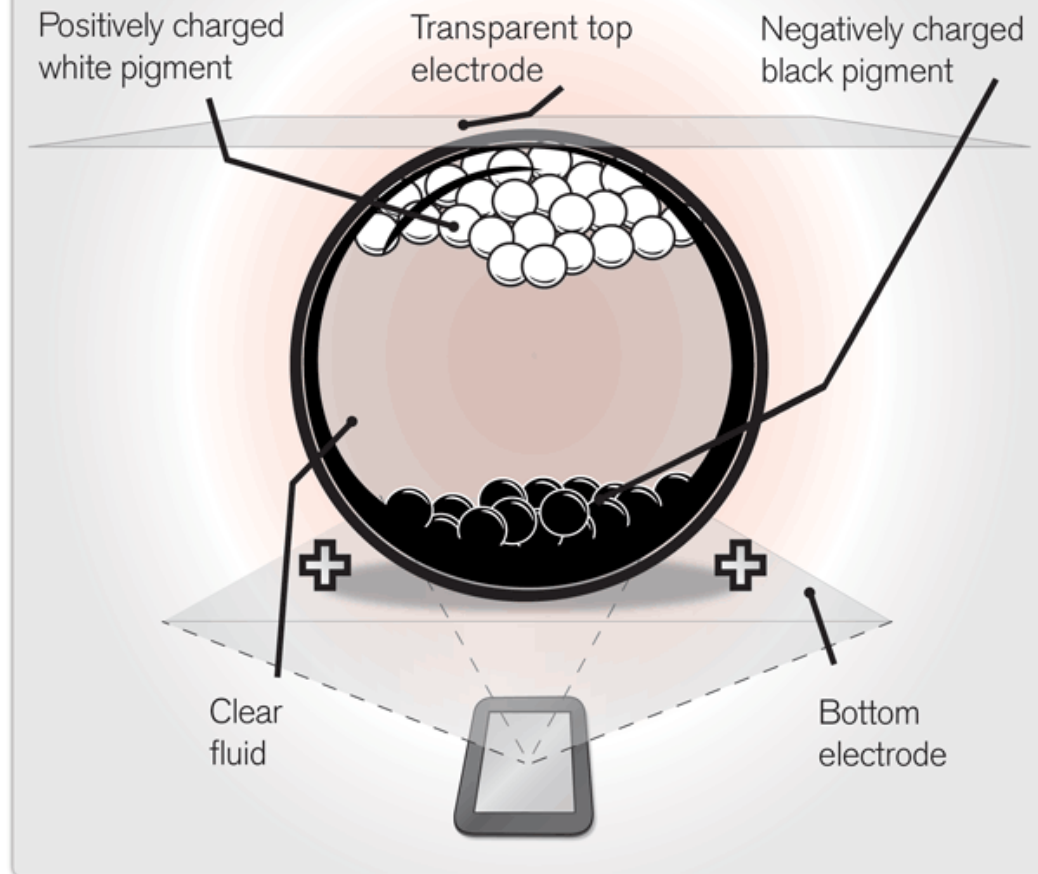
kindle



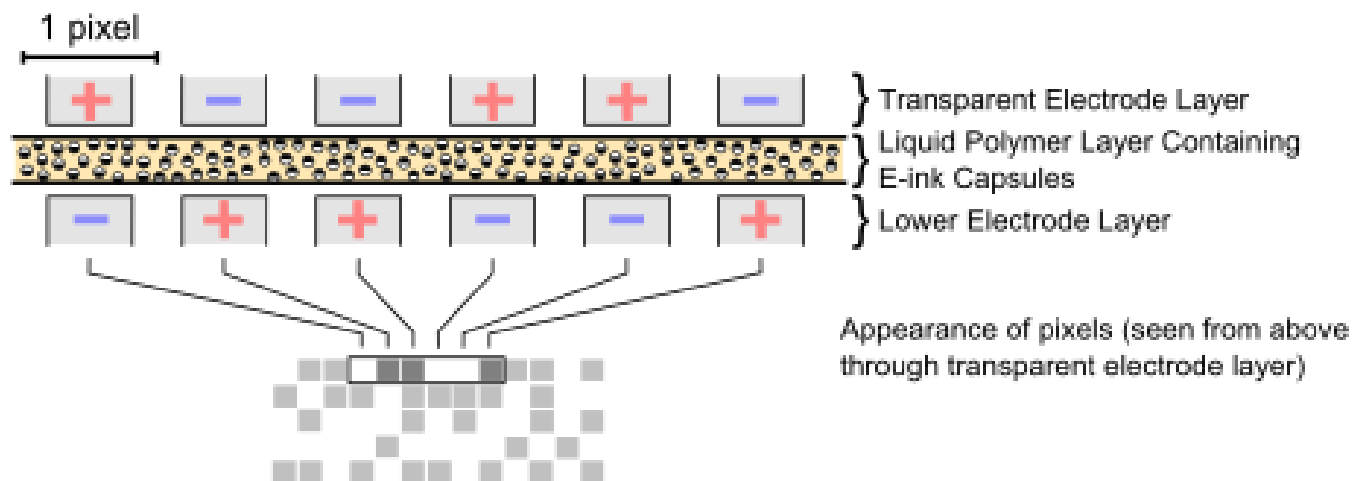
Top Transparent Electrode

Positively charged white pigment chips

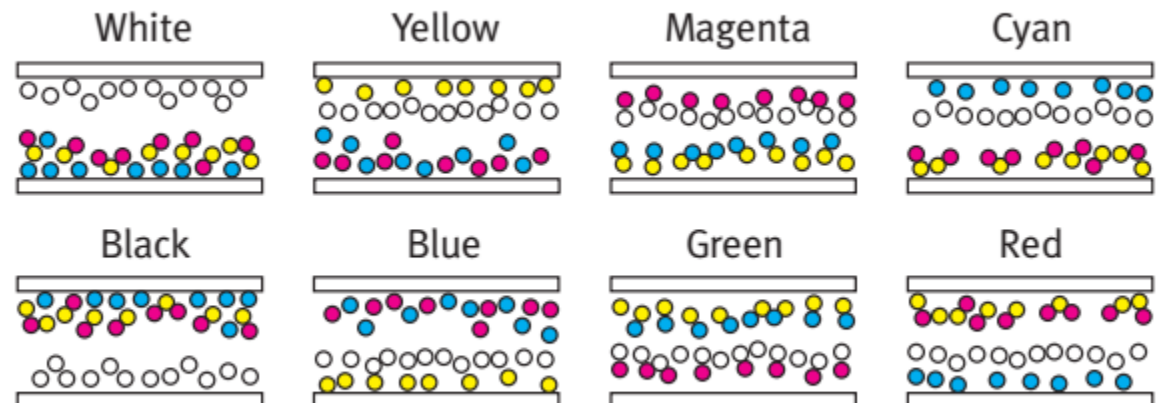
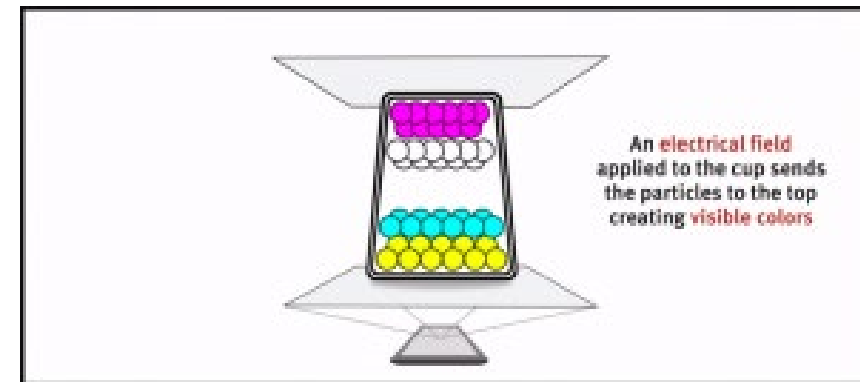
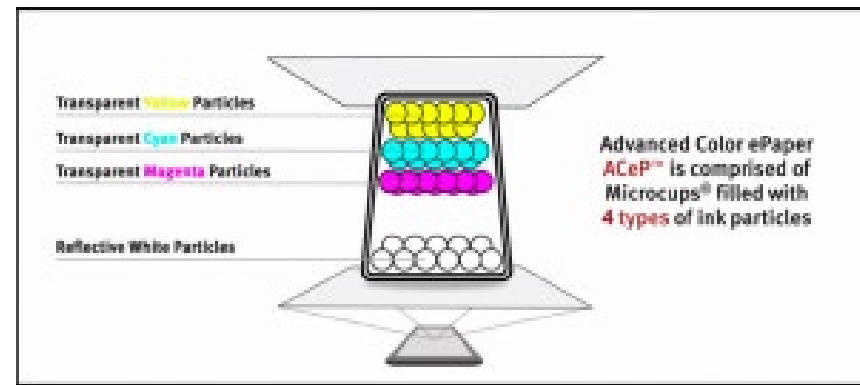


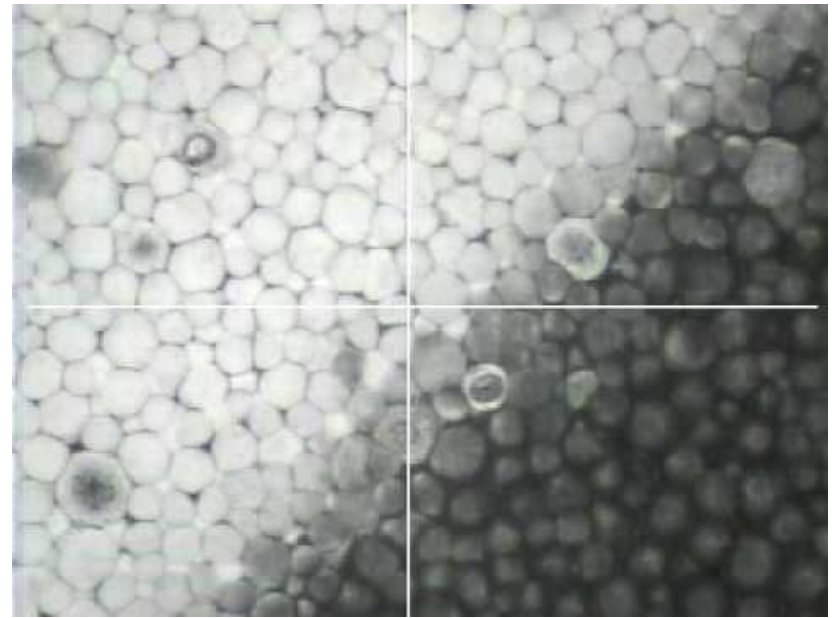


Electronic Ink is made up of millions of tiny microcapsules, about the diameter of a human hair. Each microcapsule contains positively charged white particles and negatively charged black particles suspended in a clear fluid.

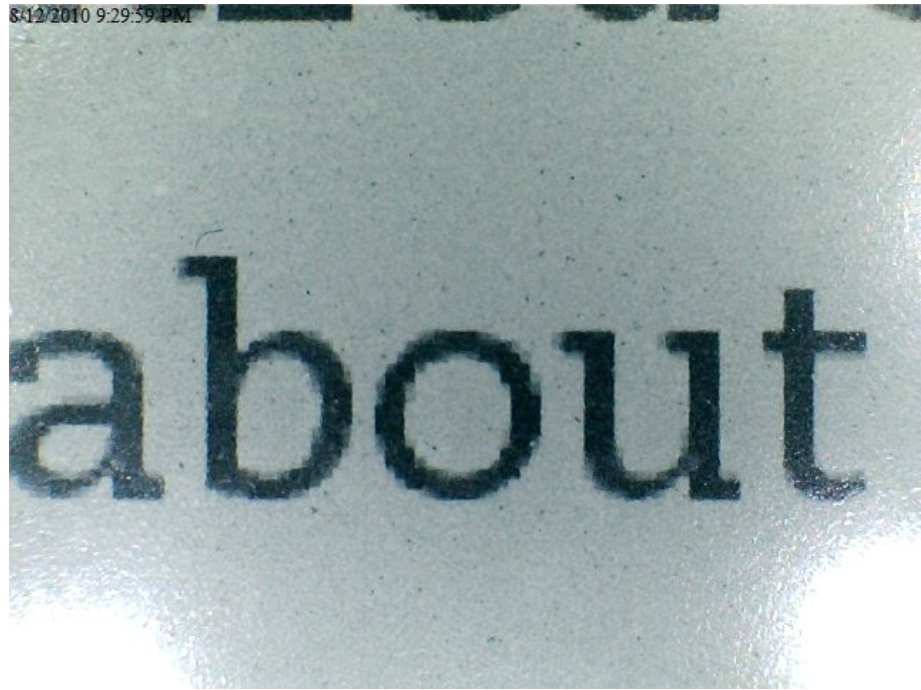


Color E-Ink



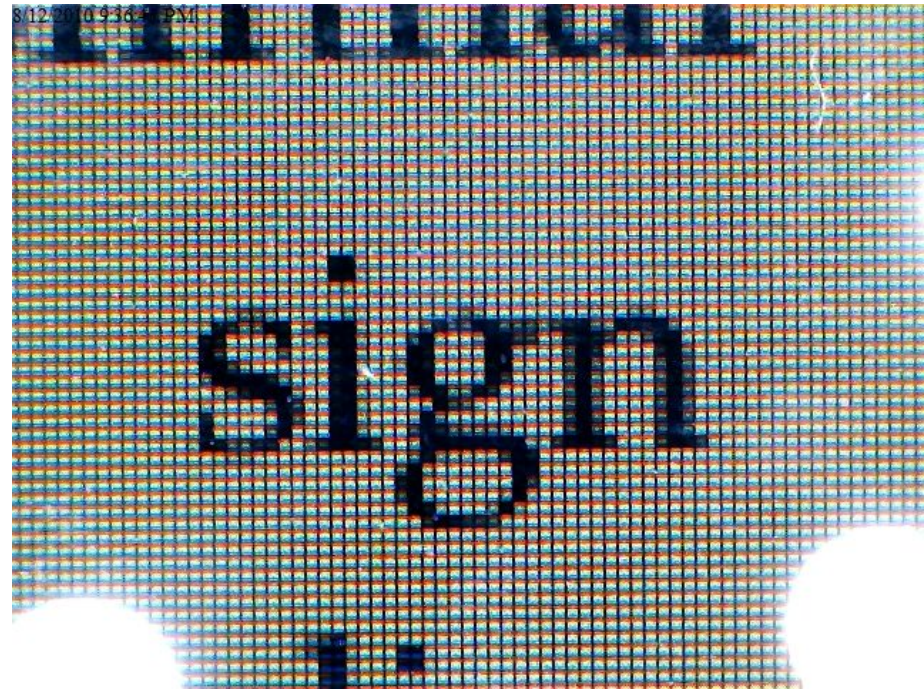


Kindle



At 26x

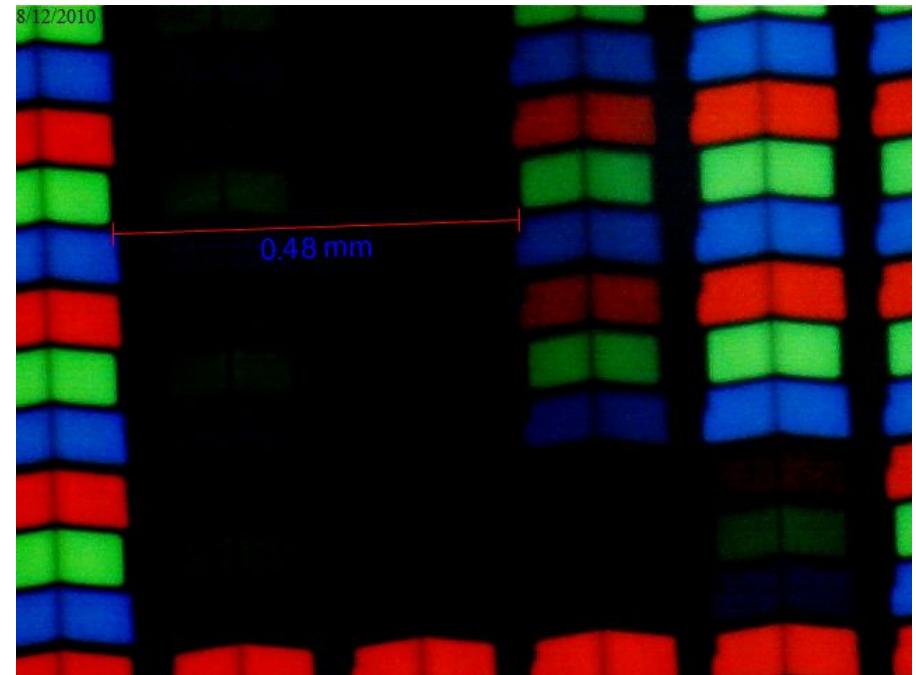
iPad



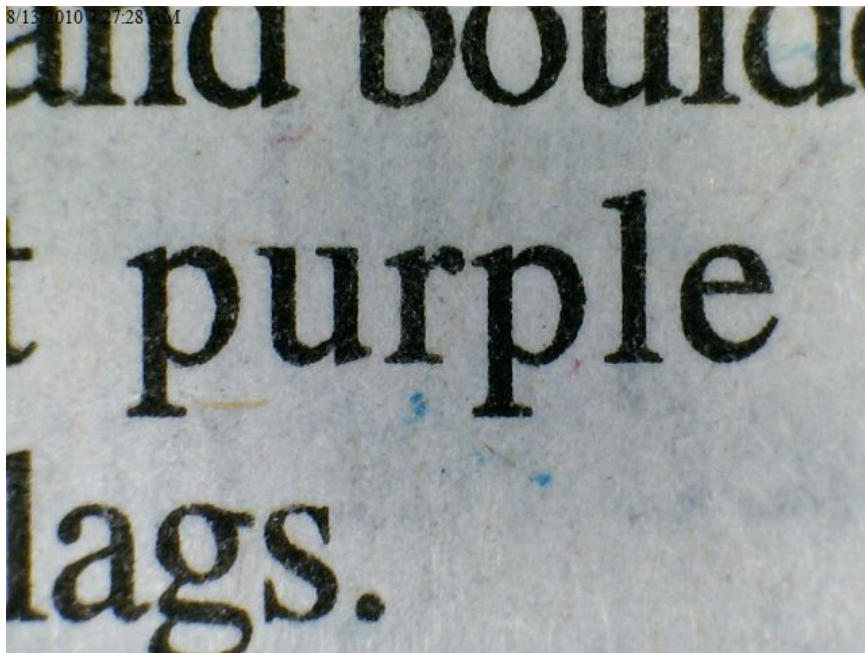
Kindle

At 400x

iPad



NewsPrint

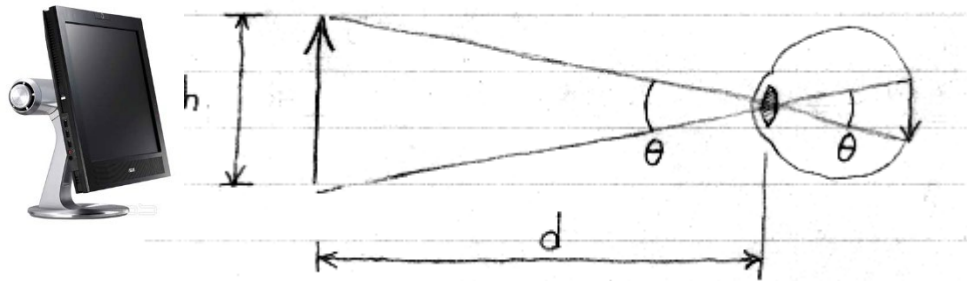
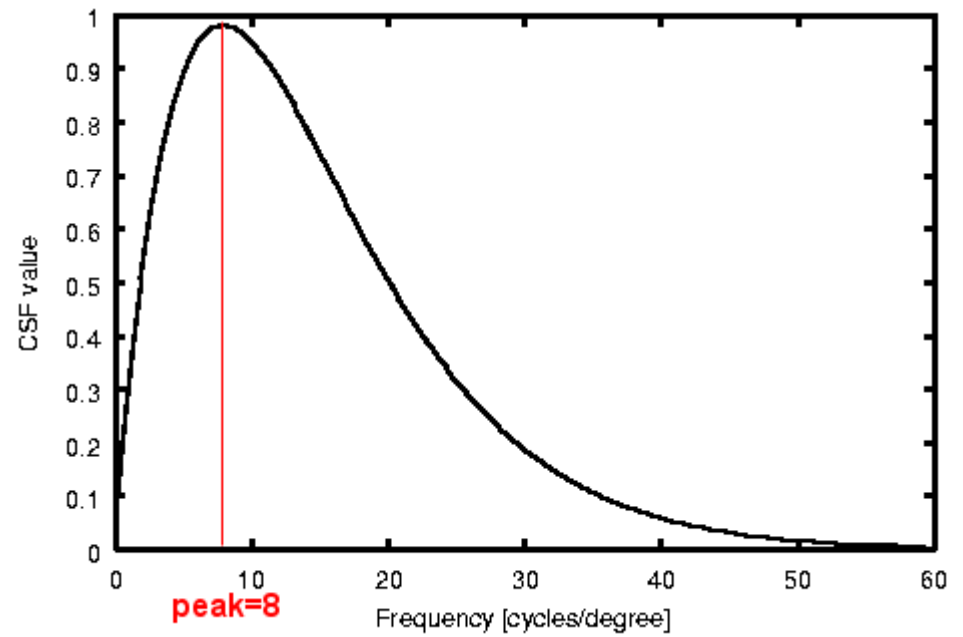
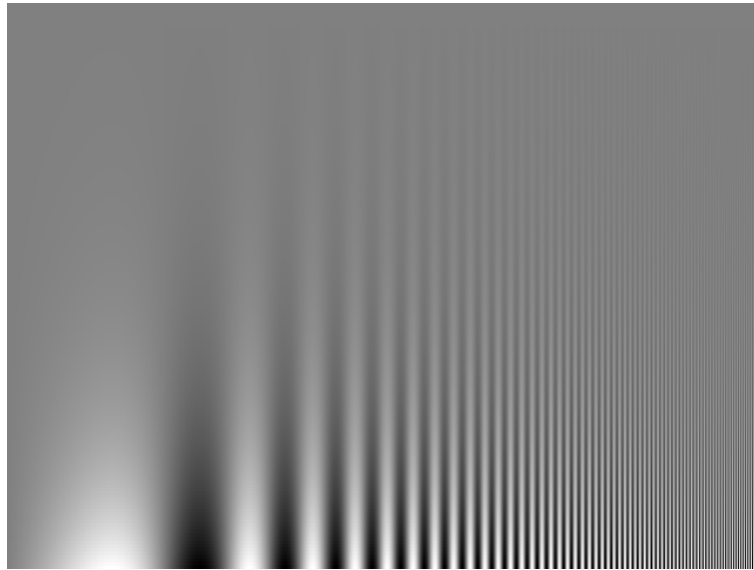


Perception

How much spatial resolution (pixels) do we need?



How much spatial resolution (pixels) do we need?



How much temporal resolution (frames per second) do we need?

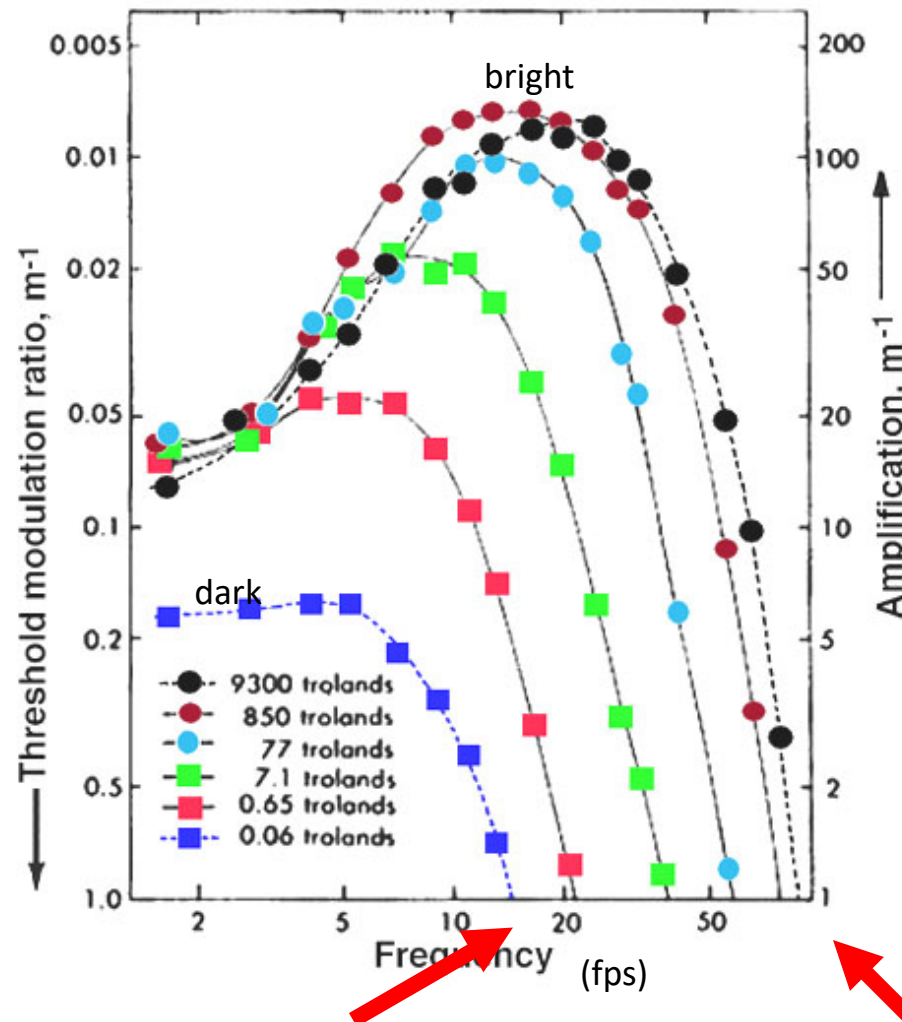
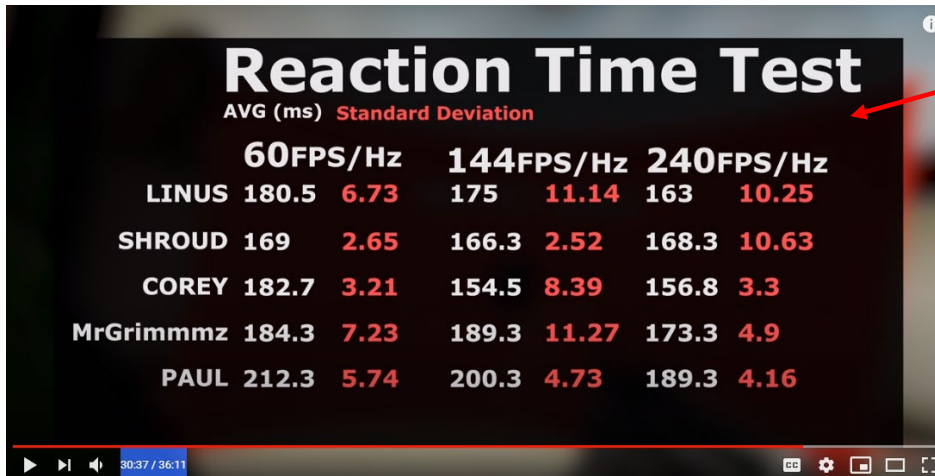


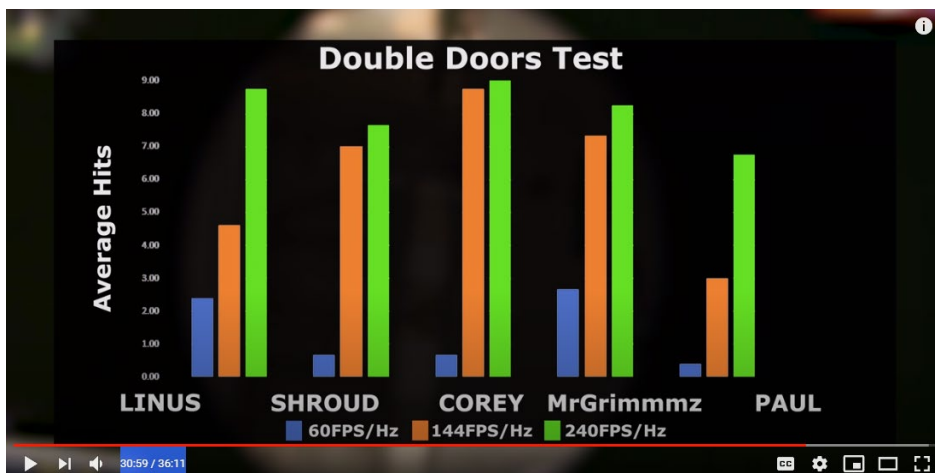
Fig. 11. Temporal Contrast Sensitivity Function (TSF) for various adapting fields. Kelly's data from Hart Jr, W. M., *The temporal responsiveness of vision*. In: Moses, R. A. and Hart, W. M. (ed) *Adler's Physiology of the eye, Clinical Application*. St. Louis: The C. V. Mosby Company, 1987.

Will an expensive GPU and monitor help you game?



15ms reaction time difference

Game State → Render Time (1/fps ms) → Display Time (1/Hz ms) → Data into your eye



60fps/Hz = 16ms
120fps/Hz = 8ms
240fps/Hz = 4ms
480fps/Hz = 2ms

2*12ms difference

An excellent 30 minutes if you are a gamer → <https://www.youtube.com/watch?v=OX31kZbAXsA&feature=youtu.be>

Participation Survey

- <http://tiny.cc/160-1119>

Participation May 19

Form description

This form is automatically collecting email addresses for UC Santa Cruz users. [Change settings](#)

I was in class May 19

- ☐ Yes
- ☐ No

Roughly how long did you spend on HW4 (Viewing+Projection+Lighting)

- ☐ 0-1 hours
- ☐ 1-2 hours
- ☐ 2-4 hours
- ☐ 4+ hours

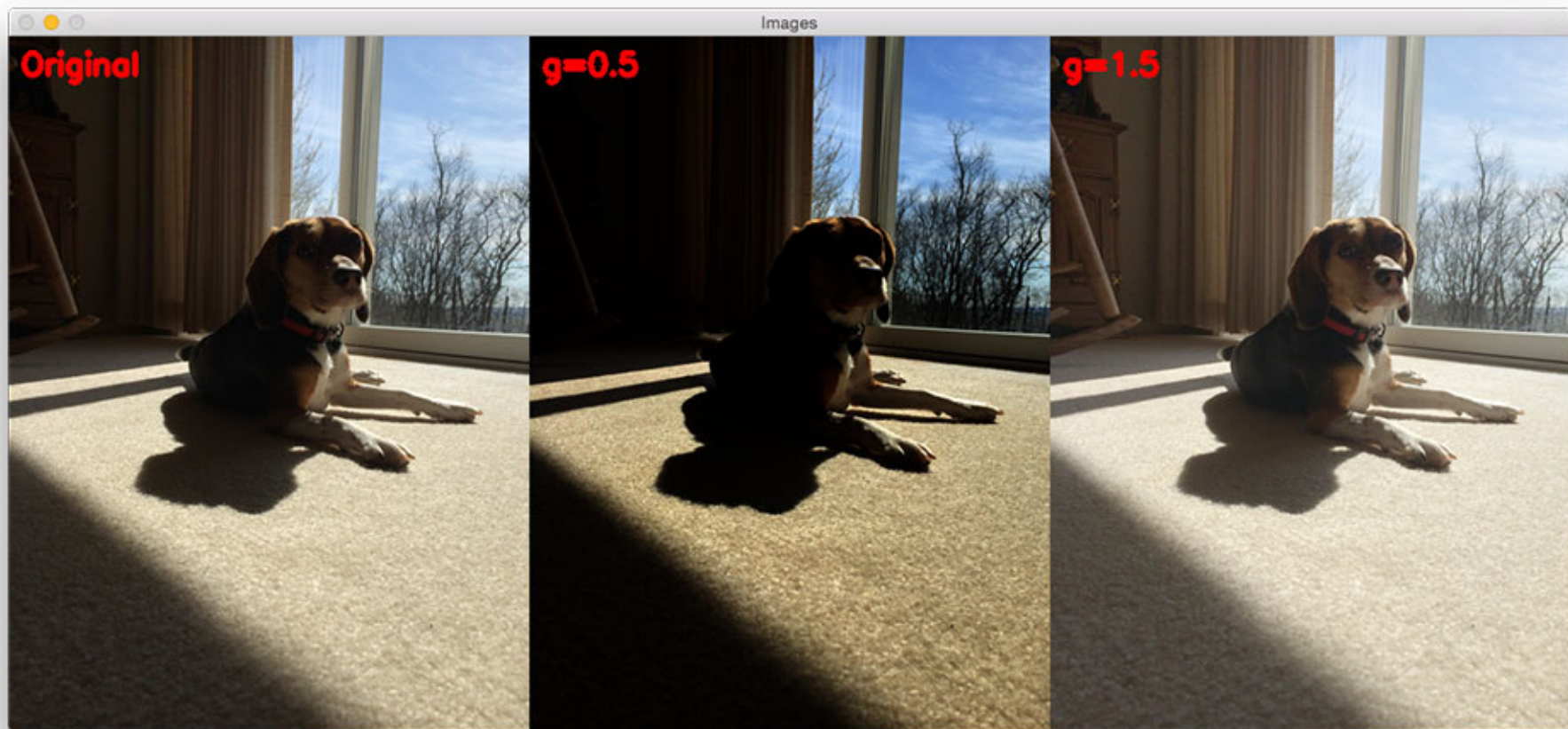
There are videos from Lucas introducing Lab 4

- ☐ I didn't watch it, I just started the assignment
- ☐ I watched it, but its NOT helpful
- ☐ I watched it, and it IS helpful
- ☐ Other...

There are videos from James introducing Lab 4

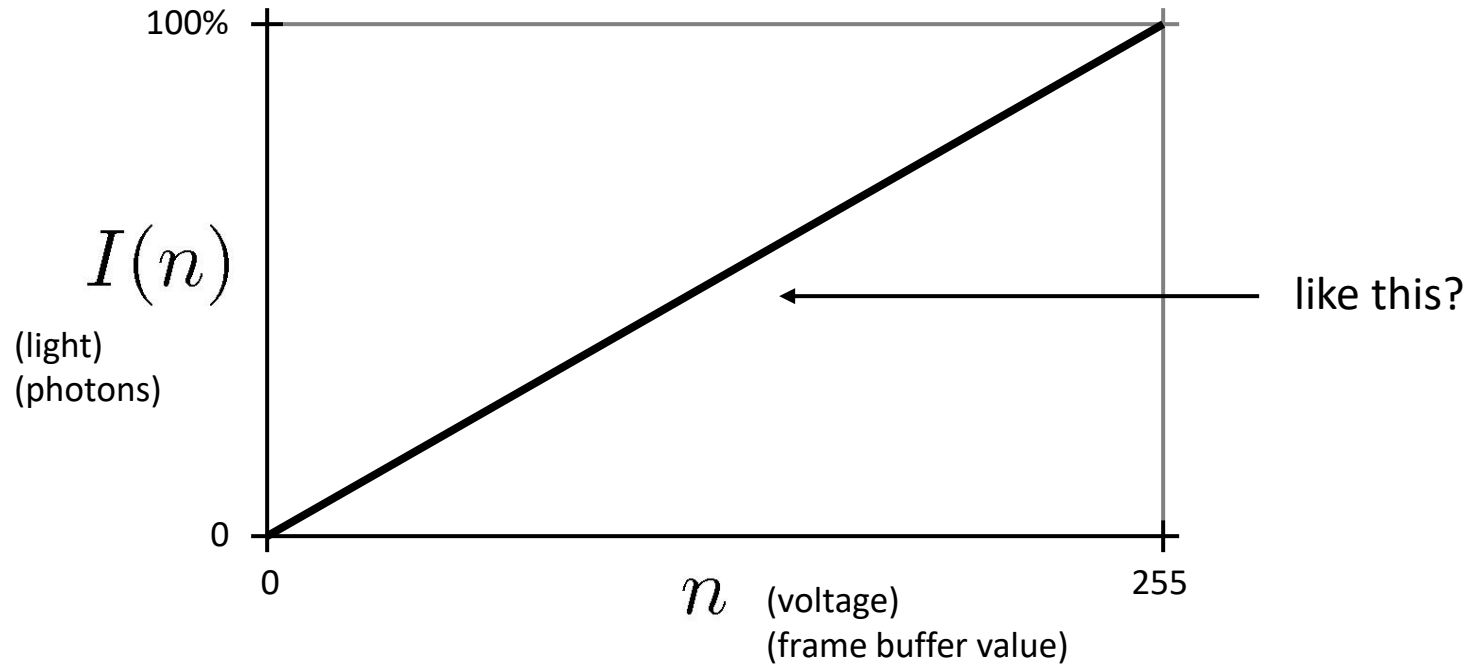
- ☐ I didn't watch them, I just started the assignment
- ☐ I watched them, but its NOT helpful
- ☐ I watched them, and it IS helpful
- ☐ Other...

Gamma

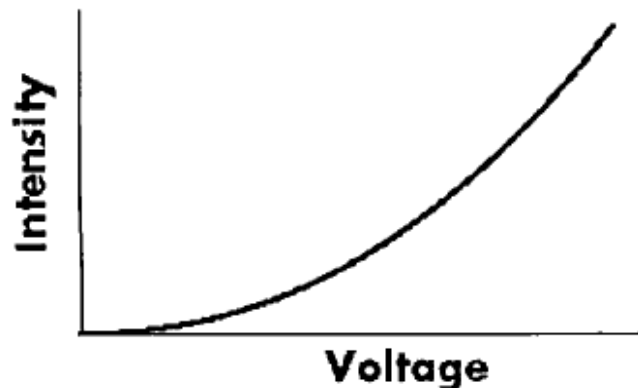


Transfer function of display

- Say pixel value is 123
 - this means the intensity is 123. 123 what?



Monitor Gamma



$$I = g \cdot (V - V_b)^\gamma$$

Monitor
 $\gamma=2.5$

Two knobs

Black Level (Brightness): V_b

Picture (Contrast): g

Adjustments

1st adjust to full black

Picture 0, adjust black-level

2nd adjust brightness

Perception of Intensities

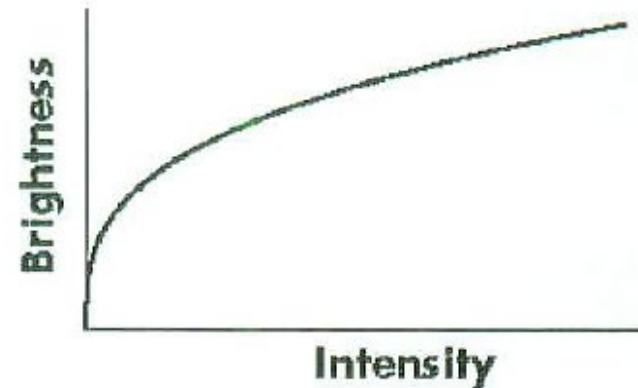
Steven's Law:

Sensation (S) vs. Intensity (I)

$$S = I^p$$

Experiments

Sense	Exponent
Brightness	0.33
Smell	0.55
Loudness	0.60
Taste	0.80
Length	1.00
Heaviness	1.45

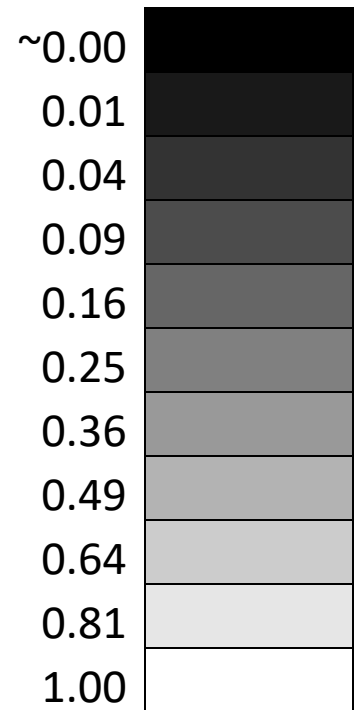
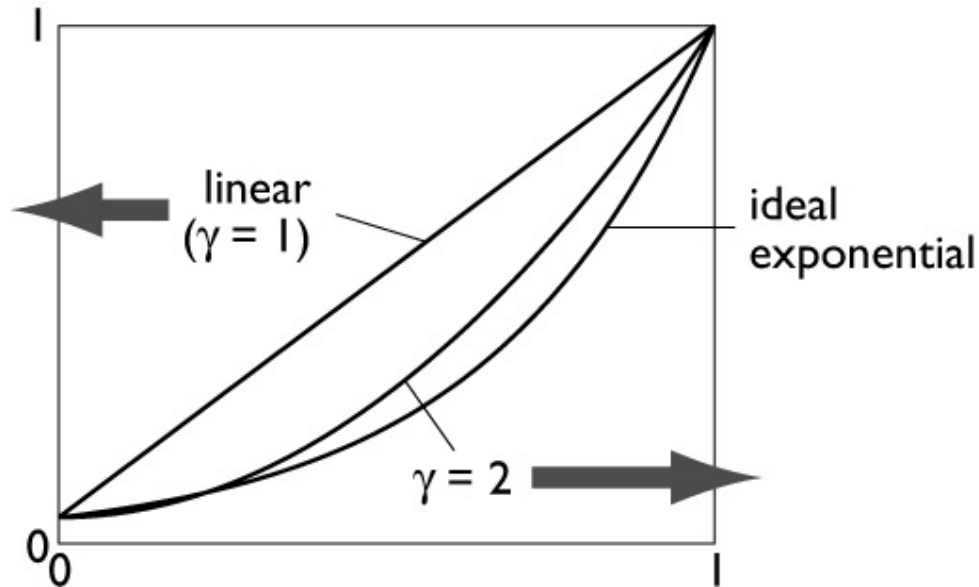
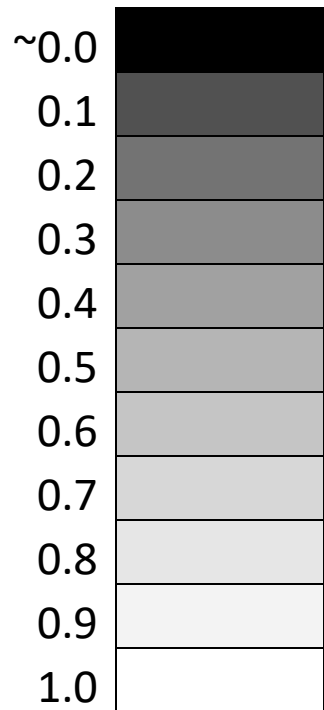


Stevens $B = I^{1/3}$

Weber $JND = \frac{\Delta I}{I} \approx 0.01$

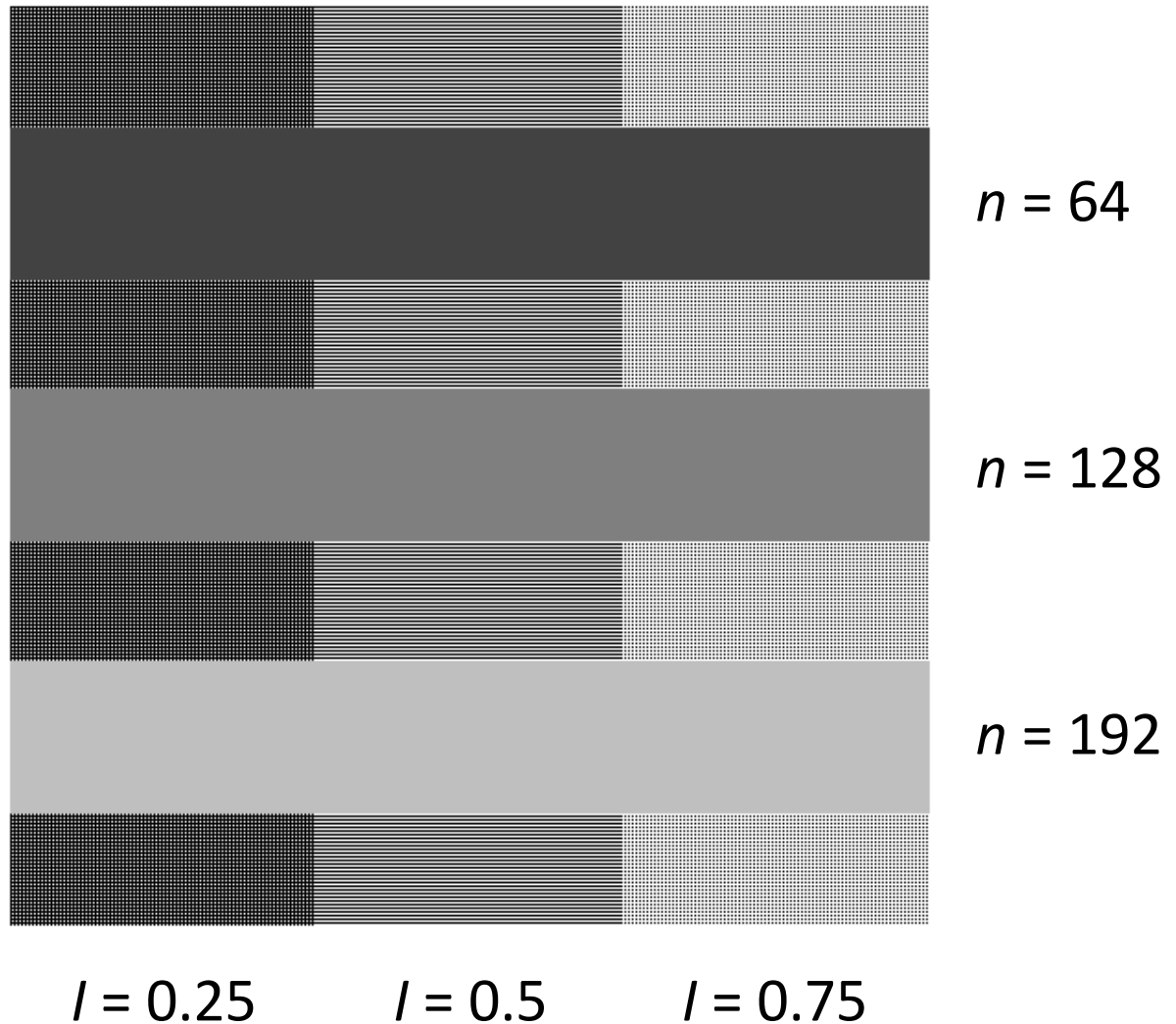
Fechner $B = k \log I$

Why nonlinear intensity?



- Closer to ideal perceptually uniform exponential

Checkerboard test



Gamma Correction

Goal: Operate in linear intensity space

How: Gamma correction table

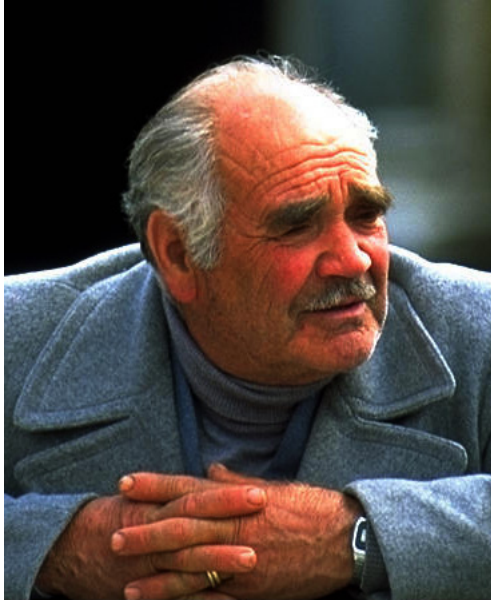
$$I = V^\gamma$$

$$V = P^{1/\gamma}$$

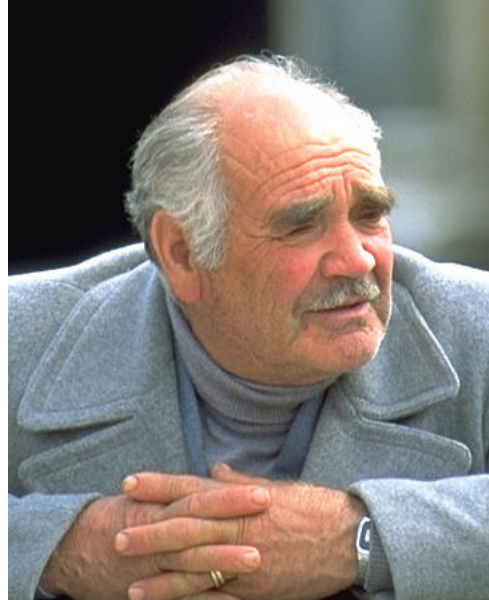
$$I = V^\gamma = (P^{1/\gamma})^\gamma = P$$

Input	Output
0	0
1	16
2	23
3	28
4	32
...	...
...	...
251	253
252	253
253	254
254	254

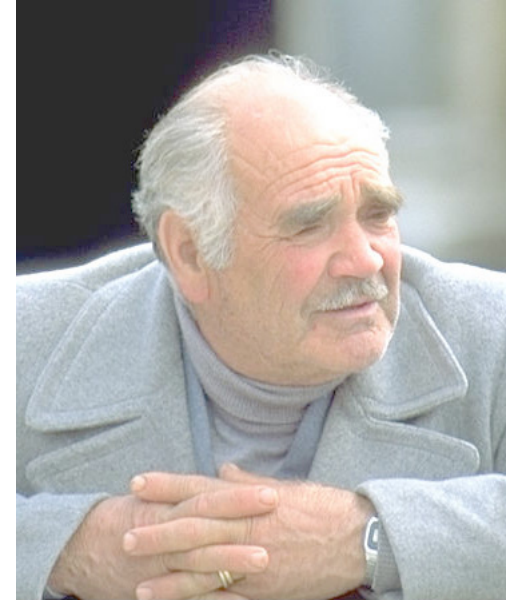
Gamma correction



corrected for
g lower than
display



OK



corrected for
g higher than
display

[Philip Greenspun]

Dithering

Quantization



1 bpp (2 grays)

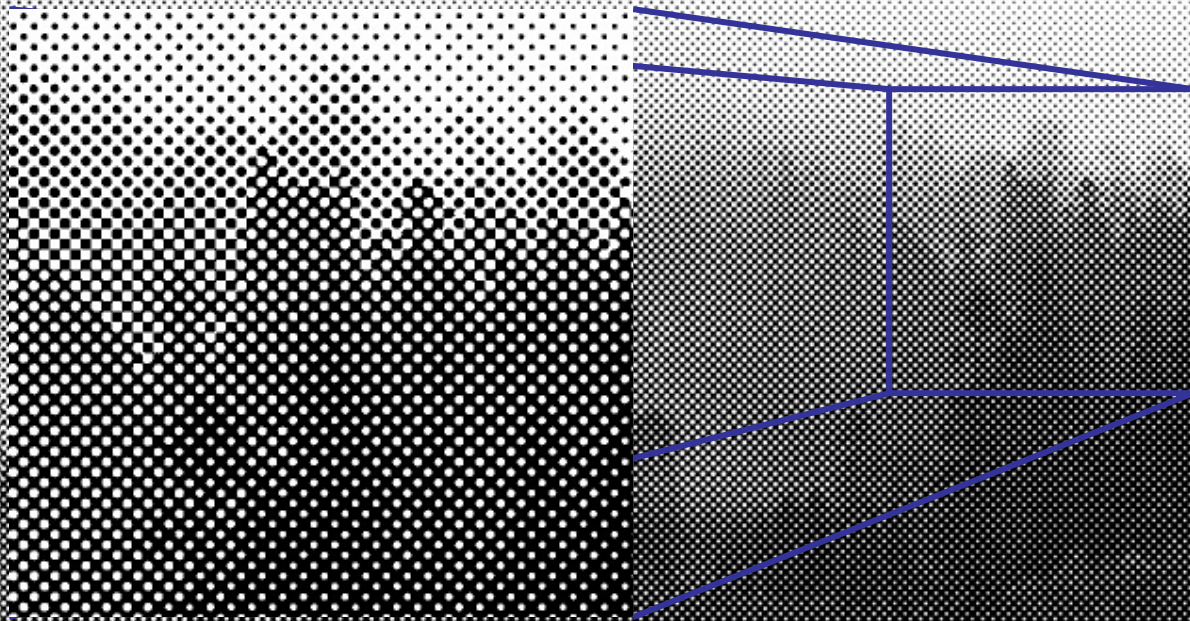
[Philip Greenspun]

- You make a black and white printer. You don't want your pictures to come out like this. Design a system for converting grayscale images to black/white that will look better than this. (You can only use black/white, what value goes in each pixel?)



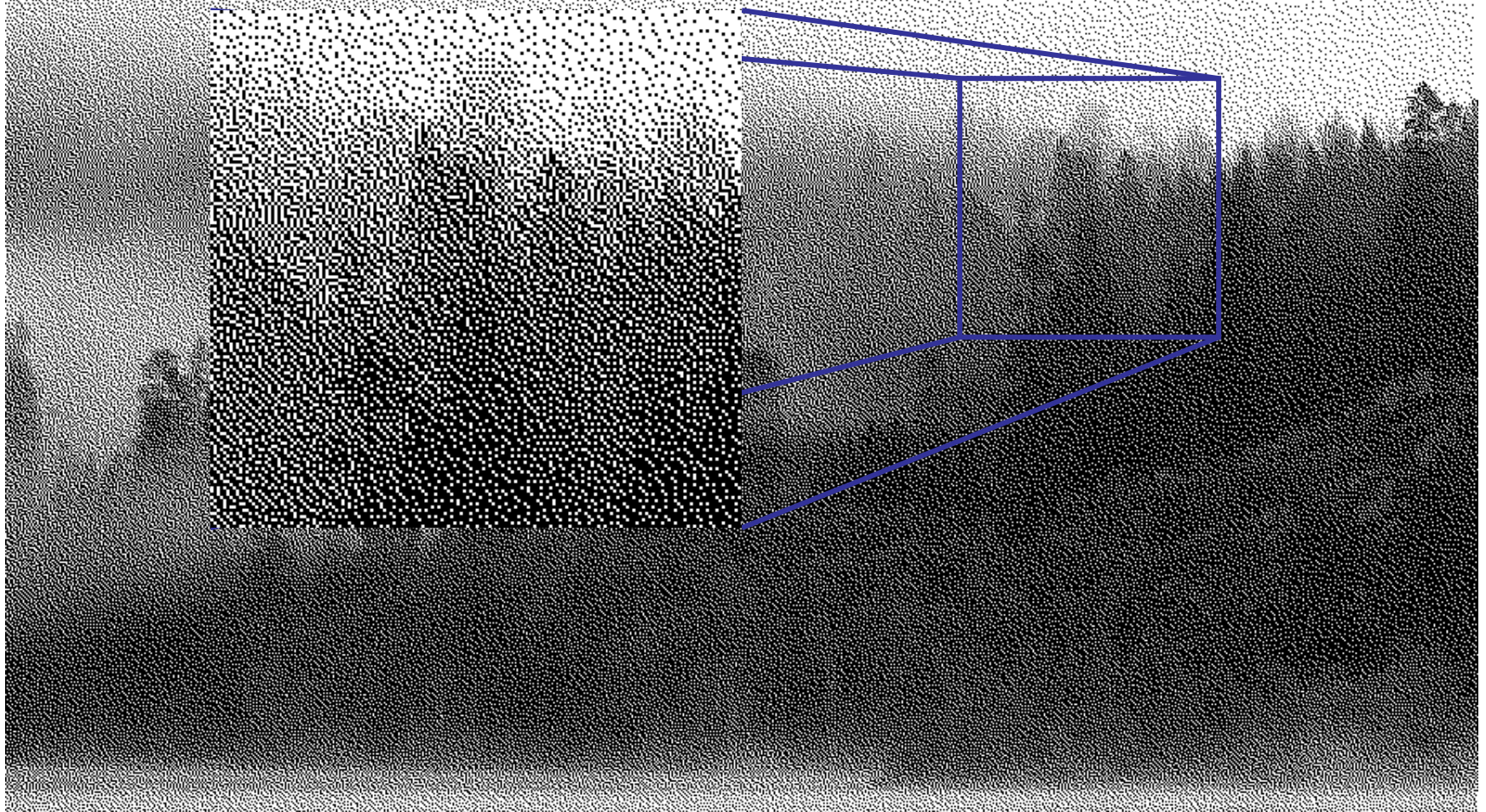
Ordered dither example

- Produces regular grid of compact dots



Diffusion dither

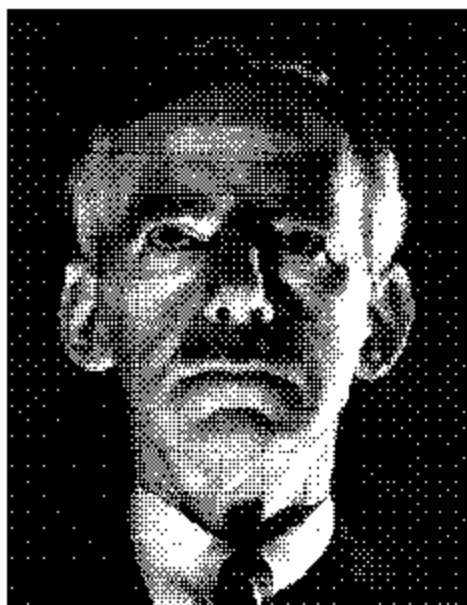
- Produces scattered dots with the right local density



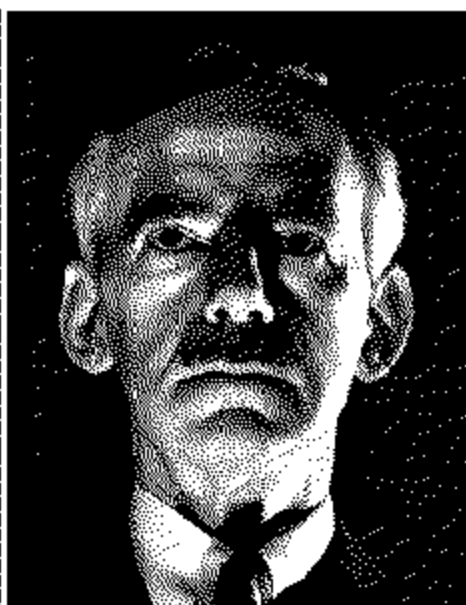
Comparison



Blue Noise



Bayer Dither



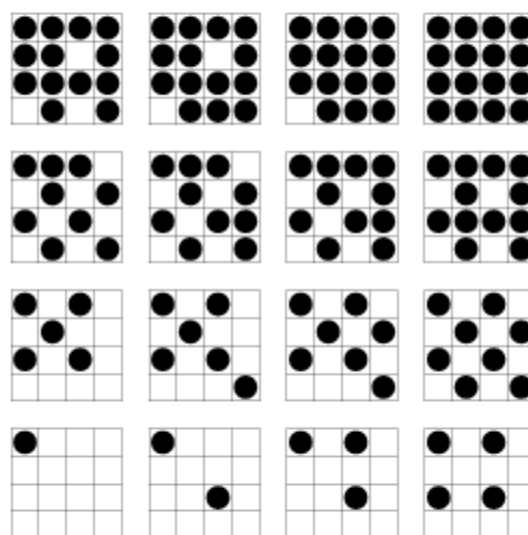
Floyd-Steinberg

Bayer Ordered Dither Patterns

$$D_2 = \begin{bmatrix} 0 & 2 \\ 3 & 1 \end{bmatrix}$$

$$D_n = \begin{bmatrix} 4D_{n/2} + 0 & 4D_{n/2} + 2 \\ 4D_{n/2} + 3 & 4D_{n/2} + 1 \end{bmatrix}$$

$$D_4 = \begin{bmatrix} 0 & 8 & 2 & 10 \\ 12 & 4 & 14 & 6 \\ 3 & 11 & 1 & 9 \\ 15 & 7 & 13 & 5 \end{bmatrix}$$



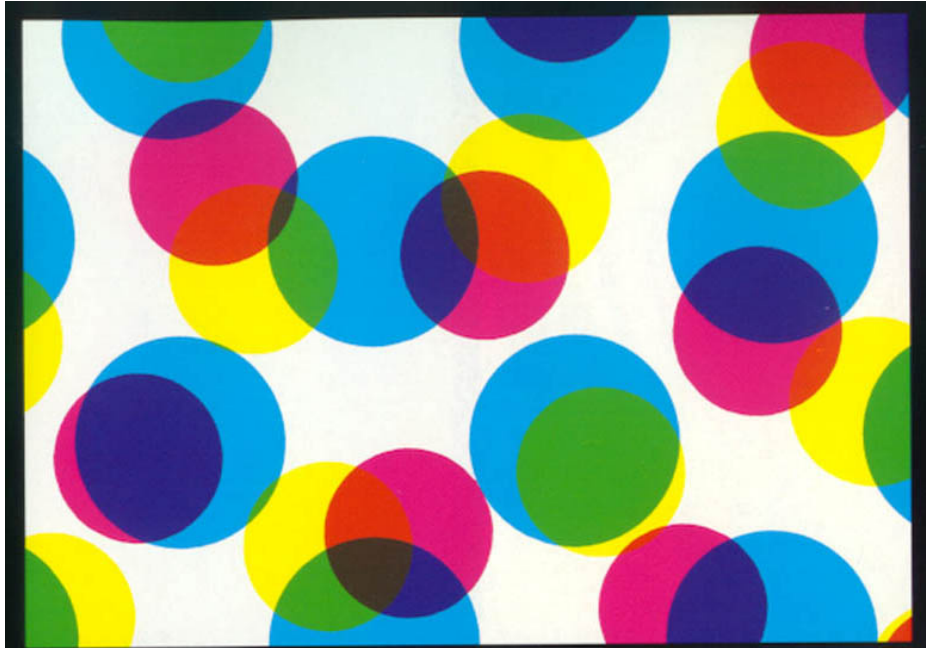


Plate 6 Magnified view of the magenta, cyan, and yellow dots used in color printing.
(Courtesy of Hammermill Papers Group, Division of Hammermill Paper Company)

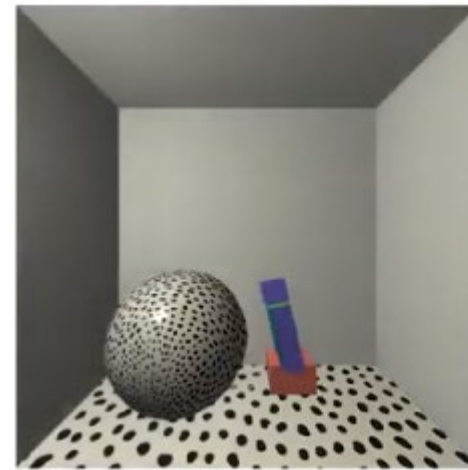
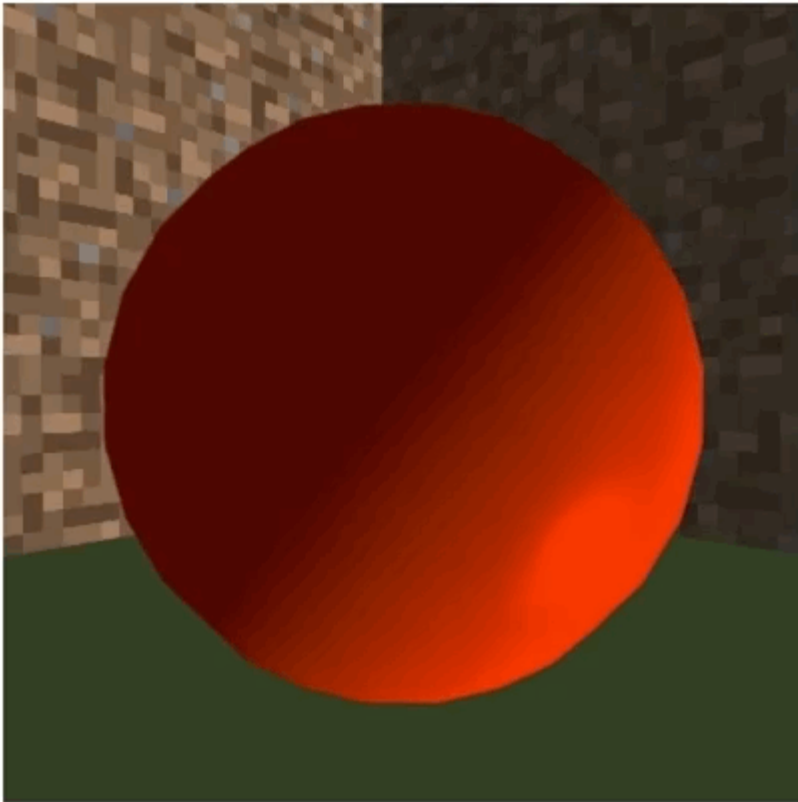


Administrative

Due Dates

- Due Monday
 - HW4 (Viewing, Projection, Lighting, Visibility)
- Due Wed
 - Quiz4
- Due next Monday
 - A4 (Lighting)

Lab4 - Lighting



ms: 7 fps: 138.6

Normal On Normal Off X

X X X Light: ON OFF

Light X Light Y Light Z

Magenta Animation: ON OFF

Yellow Animation: ON OFF

Camera Angle

Q&A

End