

Color Theory



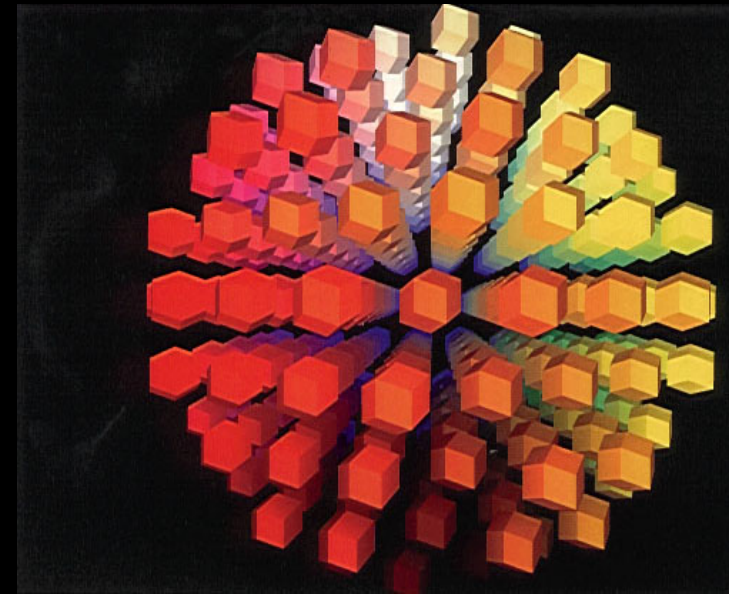
- Chapter 3c

Perceiving Color

- Color Blindness
- Animal Vision
- Simultaneous Contrast

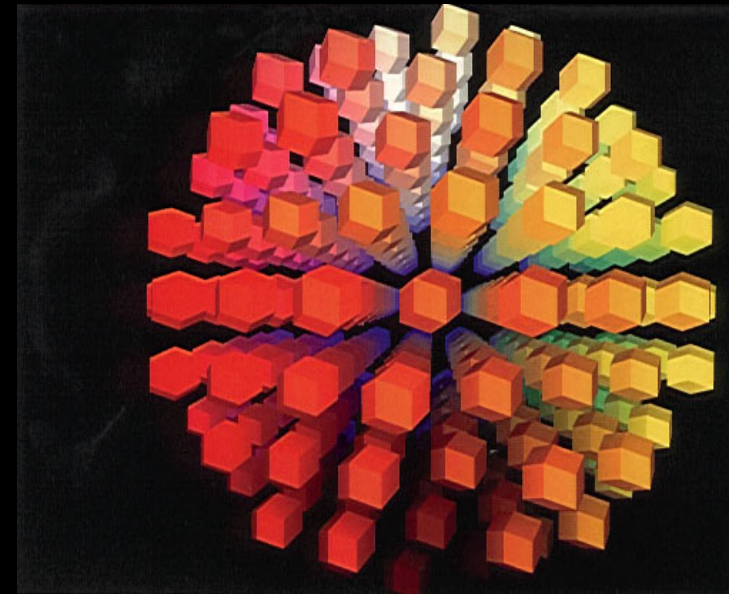
Color Theory

- Chapter 3 **Perceiving Color** (*so far*)
- Lens & Iris & Retina
- Rods & Cones x3
- Fovea & Optic Nerve
- Color Afterimage
- Iodopsin & Rhodopsin
- Color Constancy



Color Theory

- Chapter 3 **Perceiving Color** — *today*
- Northern Light
- Non-Human Color Vision — variations on a theme
- Hyper-Color Vision
- The *ONLY RULE* – Simultaneous Contrast

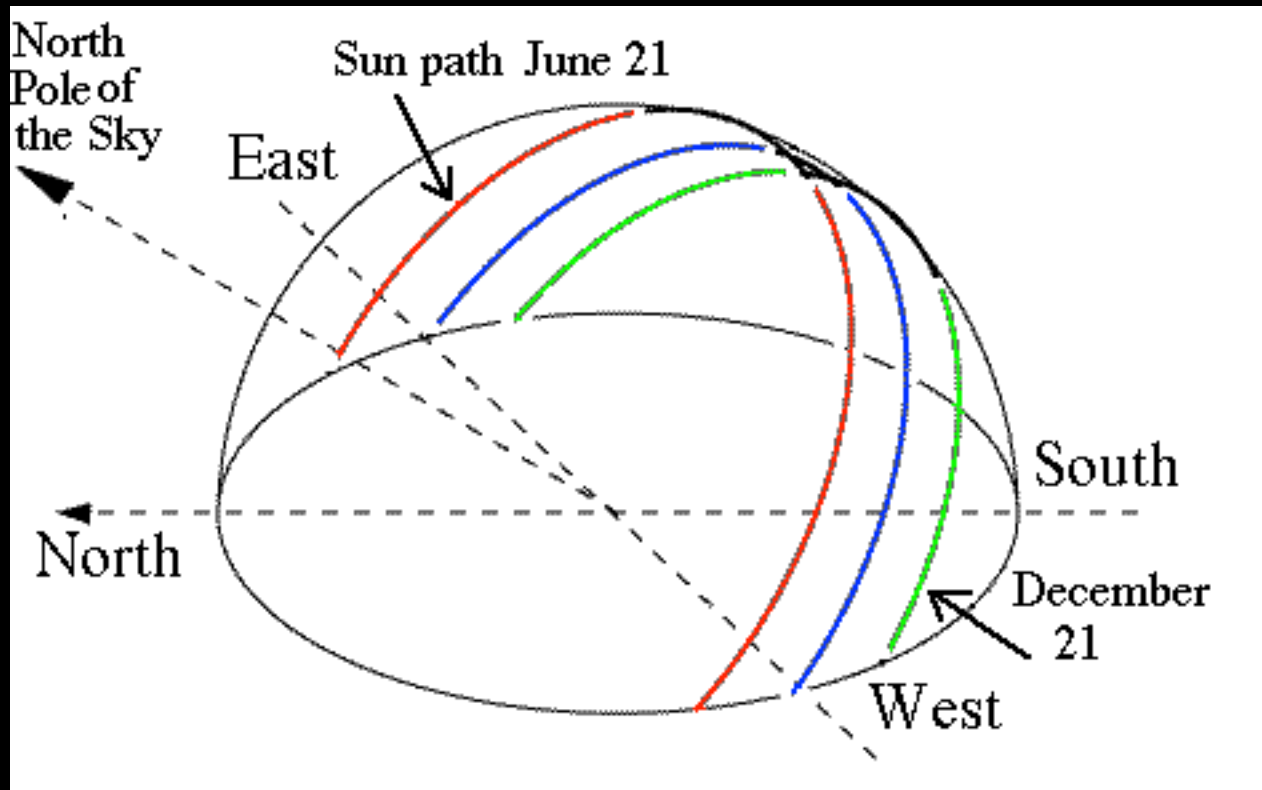


Northern light for the Painter's Studio

- Unlike Monet, most painter's want relatively consistent light as they work.
- Lighting in the studio needs to be similar to the lighting of viewing conditions, and relatively unchanging throughout the day. *That's* the goal.
- Light in the morning, mid-day and afternoon needs to be the same – otherwise the painter will continually adjust colors for changing light.

The path of the sun...

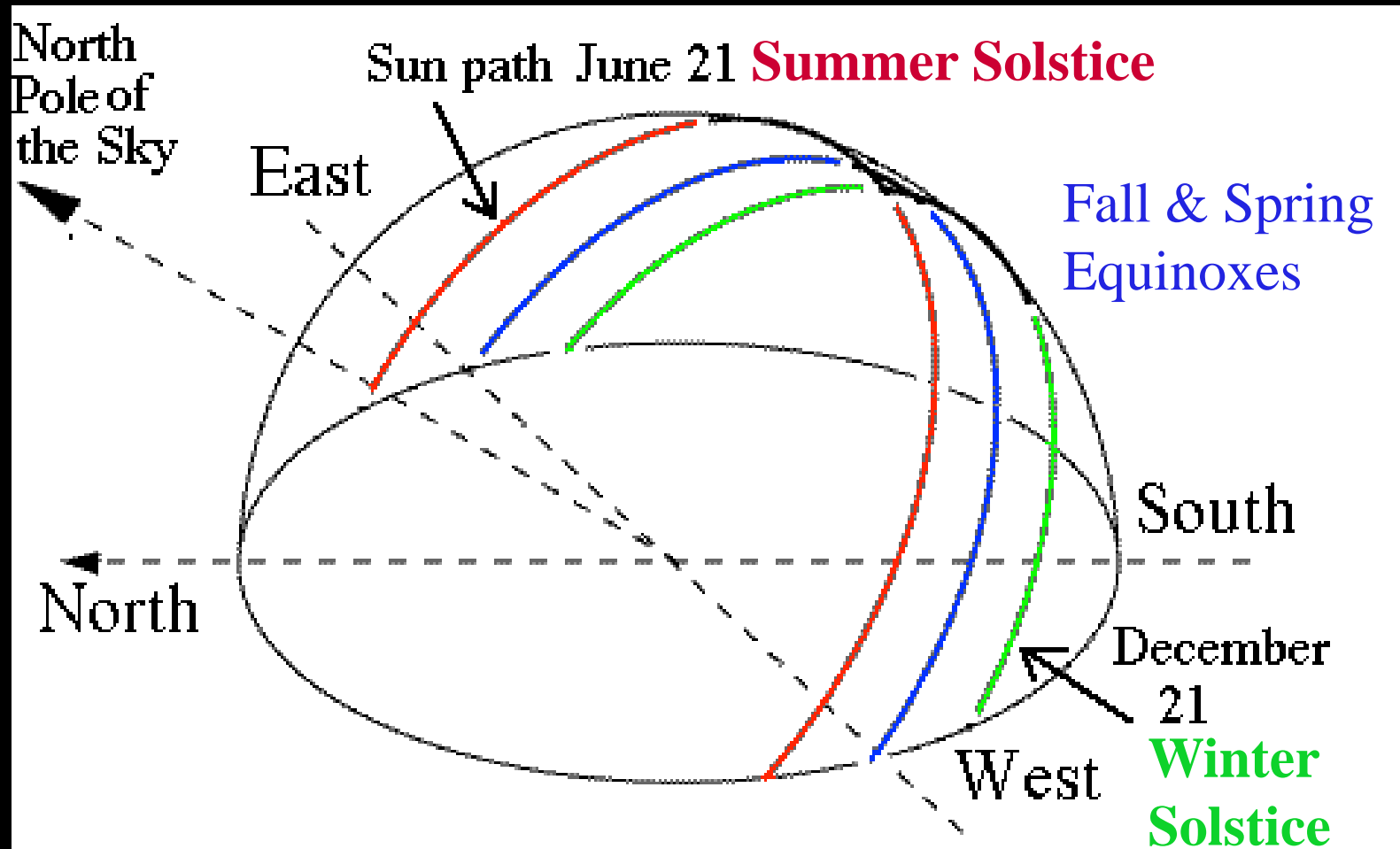
- Where is the sun at noon?
- Simple question?
- No.



what

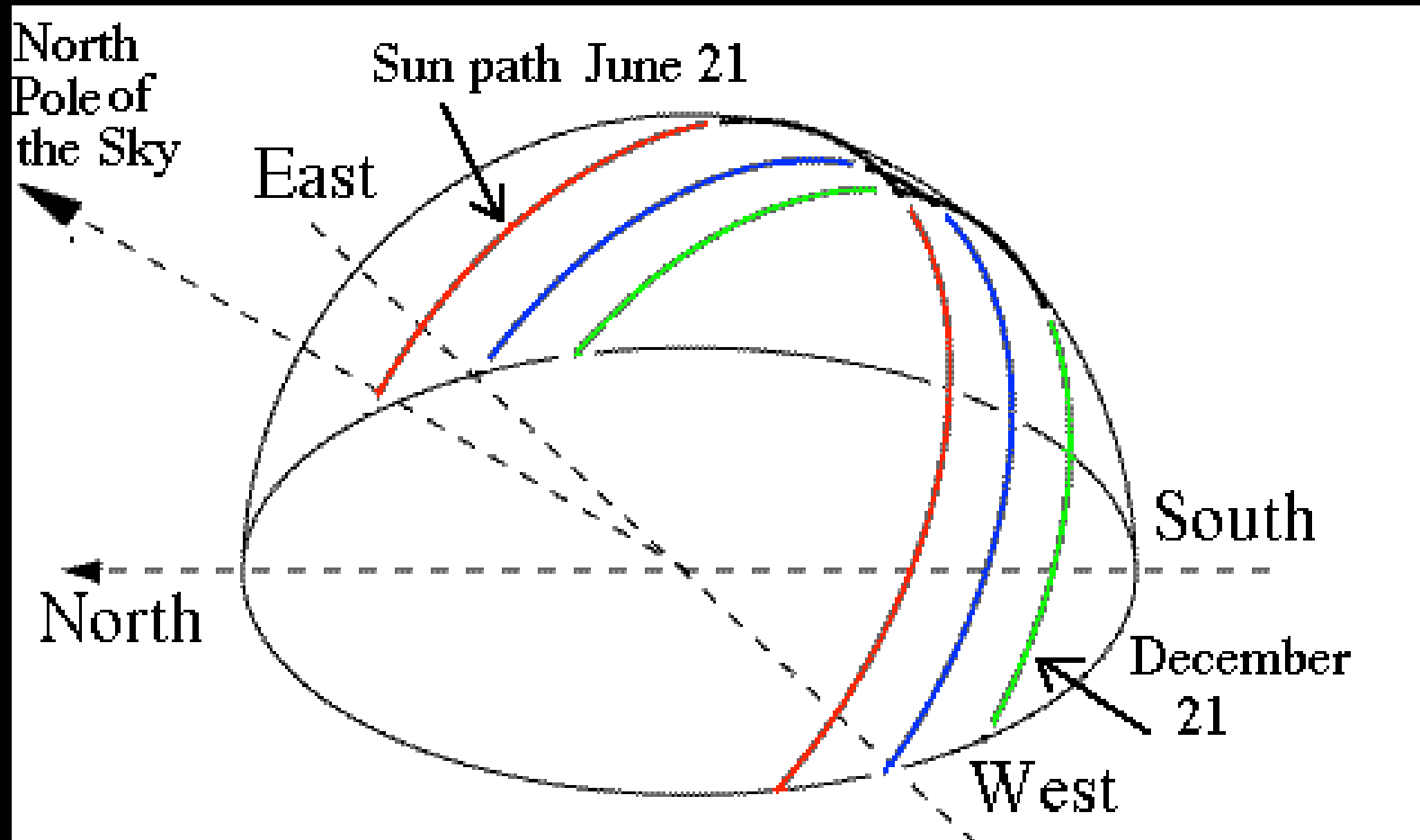
The path of the sun...

- Due to the earth's changing tilt throughout the year...
...in Summer, days get longer and noon sun is higher
- ...in Winter, days get short and the noon sun lower.



The path of the sun...

- But ALWAYS the sun's path is across the SOUTHERN sky...for those of us who live in the northern hemisphere...
...so light shines in southern windows directly, but never in northern windows.



Northern light for the Painter's Studio

- In the northern hemisphere, painters prefer NORTH-FACING windows so that the movement of the sun – across the southern sky – does not cause shadows and the level of illumination to vary as severely as it otherwise would.

Northern light for the Painter's Studio

- “In the northern hemisphere, artist's studios have for centuries been built with windows only on the northern side, to let only north light in, because it's such a constant light and good measure of general indoor light.

North light is a silvery type light that brings out the cools, purplish, greenish atmospheric colors.

- The plus of north light in a studio is that you can paint all day and the subject won't change.”

http://painting.about.com/od/paintingforbeginners/a/JFresiaLight_2.htm



Northern light for the Painter's Studio

Light from a southern window produces shadows that change constantly...

...moving across the room as the sun moves across the sky.

That creates visual interest...

...but not a steady subject for a painter.



Northern light for the Painter's Studio

- This north-facing skylight allows plenty of soft, reflected light... diffuse, with little directionality or harshness in shadows.



Exploring what other creatures see

- “Although we know that *sight differs* among animals, we do not know what animals actually perceive.
- “There is an important distinction between having light illuminate the retina, and understanding *what* is being seen.
- “Color vision and perception across the animal kingdom is the **subject of much ongoing research**, as we have a very limited understanding of the many ways animals see.”
- <http://www.webexhibits.org/causesofcolor/17.html>



Figuring out color perception among our furry friends

- We have limited means to figure out what animals see. Tests have been devised (e.g. select the correct color, and get a treat) ...
...and eyes *have been* studied in the lab.
- But we only *deduce* what they see, rather than *knowing* what they see.
- <http://www.webexhibits.org/causesofcolor/17.html>





Human Color Vision may be unique

- Animals apparently see a varied portion of the light spectrum — *they don't see what we see, or necessarily as we see.*
- Some are apparently color blind yet see detail quite well – though in black and white.





*If you're
the prey,*



*be still
be very, very still.*

- Many animals are *attuned to movement rather than color.* (remember Jurassic Park's T Rex...hold still...*very still*)
- “The Costa Rican red-eyed tree frog has a very limited visual pathway; its neural behavior and jumping reflex suggest it *only "sees" its prey if it is moving.*”

- Many predators, we believe, are color blind...

...as are bulls.

(a bullfighter doesn't taunt the bull to charge by the redness of his cape, but with *the twitching, swaying movement of that cape.*)

***Motion's
the thing***





Dogs & Cats

- “Dogs have two identified types of cones, suggesting they are **dichromats** with similar peak sensitivities to red-green colorblind humans.
- “Cats are **trichromatic**, but have a much lower proportion of cones to rods than humans. (thus they have great night vision.)
- “In addition, dogs and cats have a much more highly developed sense of smell than humans. While we rely primarily on sight, their perception of the world is far more reliant on olfactory stimuli.”
- <http://www.webexhibits.org/causesofcolor/17.html>



From the lowly worm to the mighty shrimp

- “Earthworms and caterpillars have “eye spots,” and see **only light and dark**, helping them stay out of the hot sun.
(above right — Tanzanian caterpillar)

Not 3 cones... 12... sort of.

- On the other hand, the mantis shrimp (top left) has complex eyes... with at least a **dozen distinct photoreceptors**.
A possible reason for the complexity of these eyes is that much of the **color processing occurs in the eye itself, rather than in the brain**. By contrast, our eyes send rather raw visual data to the brain, where it is then processed so that we can make sense of it.”

- <http://www.webexhibits.org/causesofcolor/17.html>

Color vision designed for Survival

- Some animals see **particular** color ranges well.
- Each family of insects and birds appears to be drawn to particular colors related to their primary food source.
-
- Red berries or violet flowers, may be a significant nutrition source for an insect, so those colors may be most “bright” to them – just as yellow is most bright to us.
(this is speculation...we've not asked them...or, rather, they've not answered.)



Advanced Color Vision

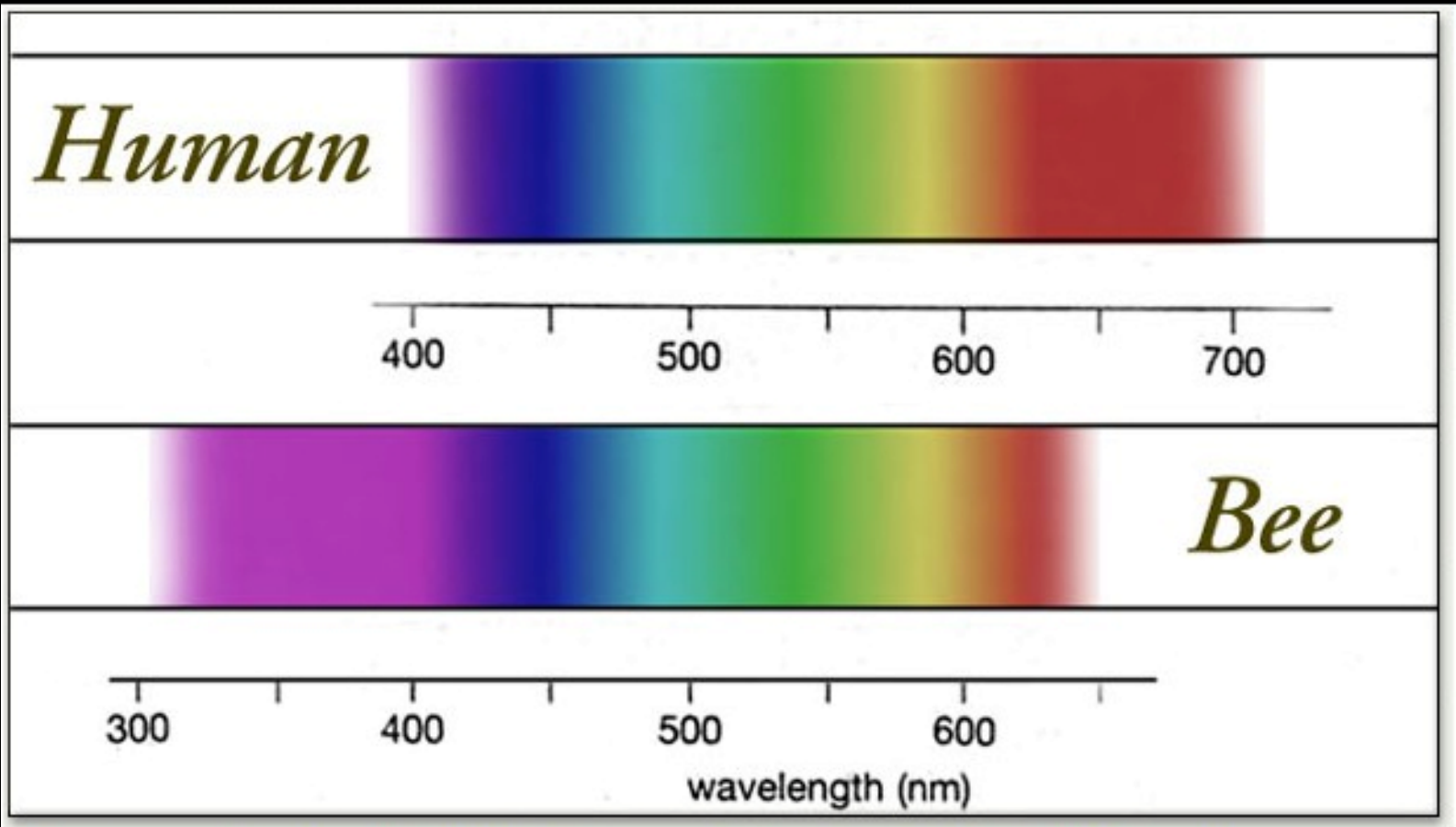


- “Of species studied so far, the best color vision appears to be found in birds, aquatic creatures, and certain insects.
- “Amongst insects, we know **that butterflies and honeybees have advanced color discrimination.**”
- <http://www.webexhibits.org/causesofcolor/17.html>

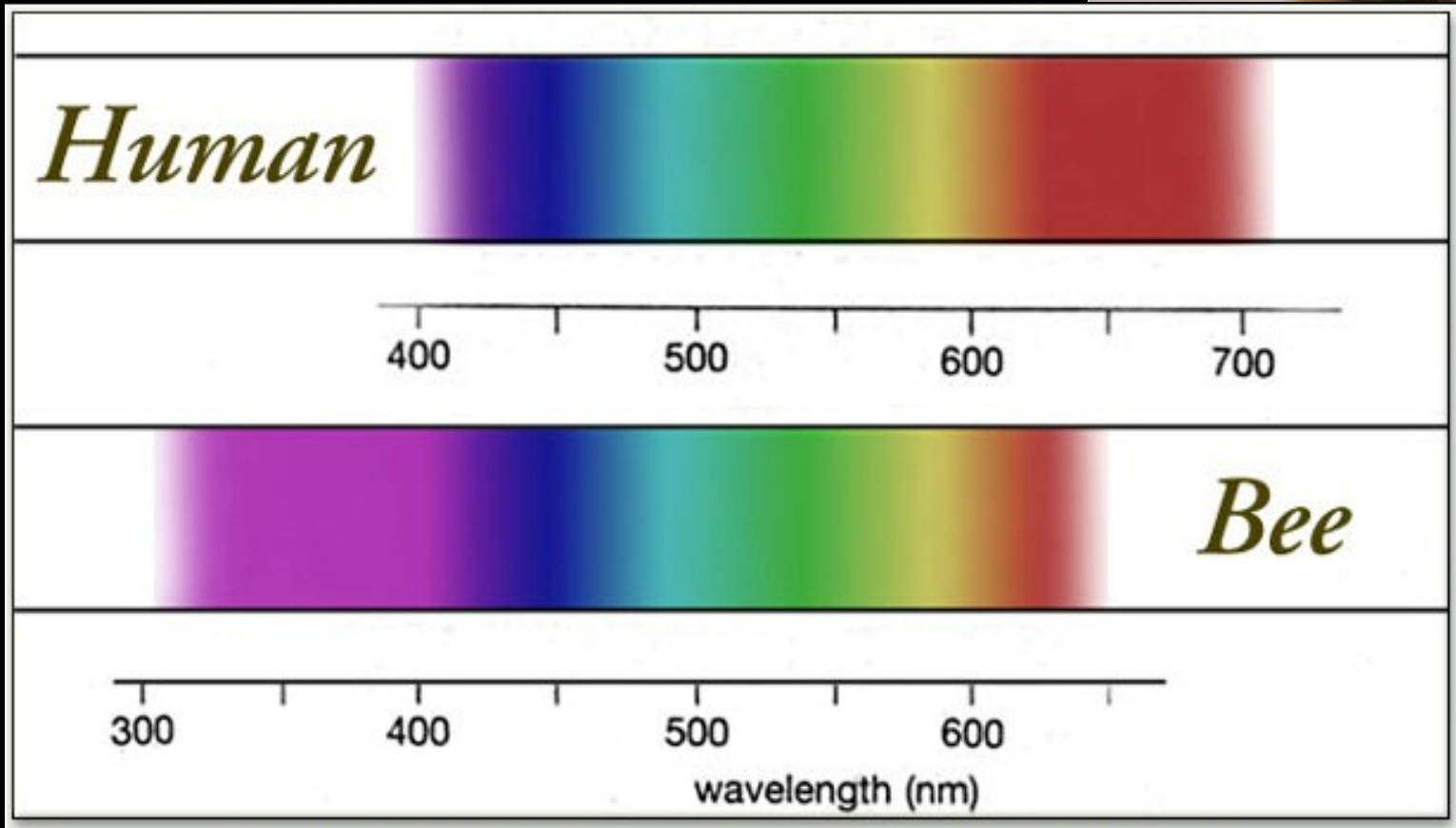
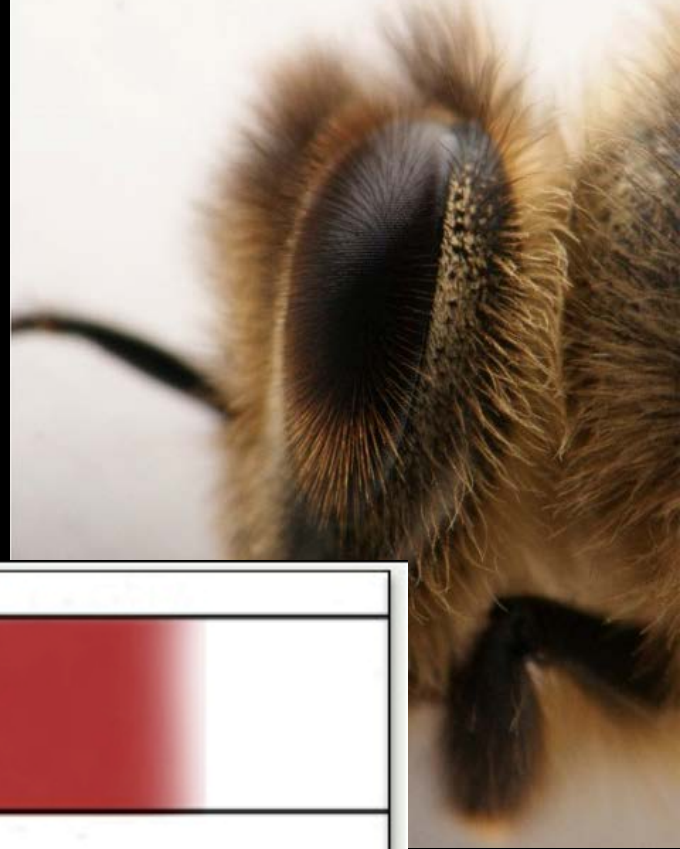
- Here human-visible spectrum is compared to a bee's. The bee has three types of colored-light-sensitive cells, similar to our three cones.

Human Color Spectrum vs. Honey Bee

While we see R - G - B, the bee “sees” Yellow-Green, Blue and an ultraviolet wavelength outside our visible spectrum.



- The bee can distinguish most of “our” colors, **except red** — and can see some colors that we can’t.
- On the other hand, we don’t know what any of these colors *look like* to the bee, we only believe that the bee can *distinguish* these wavelengths.



- “The range of vision for the bee and butterfly **extends into the ultraviolet.** “The petals of the flowers they pollinate have *special ultraviolet patterns* to guide the insects deep into the flower.”

Ultraviolet Honey Bees



...sort of like landing strips?

These patterns are made of “colors” in the ultraviolet range...

...just beyond what our eyes can see.

Guys, if 8%+ of us being colorblind weren't bad enough, try this...

*...about 2-3% of women may have **Tetrachromatic vision** enabling them to distinguish **100x as many hues** as we can.*



Tetrachromatic Women?

- That means their eyes appear capable of sensing 4 different wavelengths of light/color.

Assuming tetrachromatic vision works similar to trichromatic vision, **tetrachromats can distinguish 100 million hues**, while you and I can distinguish about 1 million. (100X *more hues...*)

These are not “new” hues beyond our color wheel, but finer and finer divisions within the color wheel... more nuance.

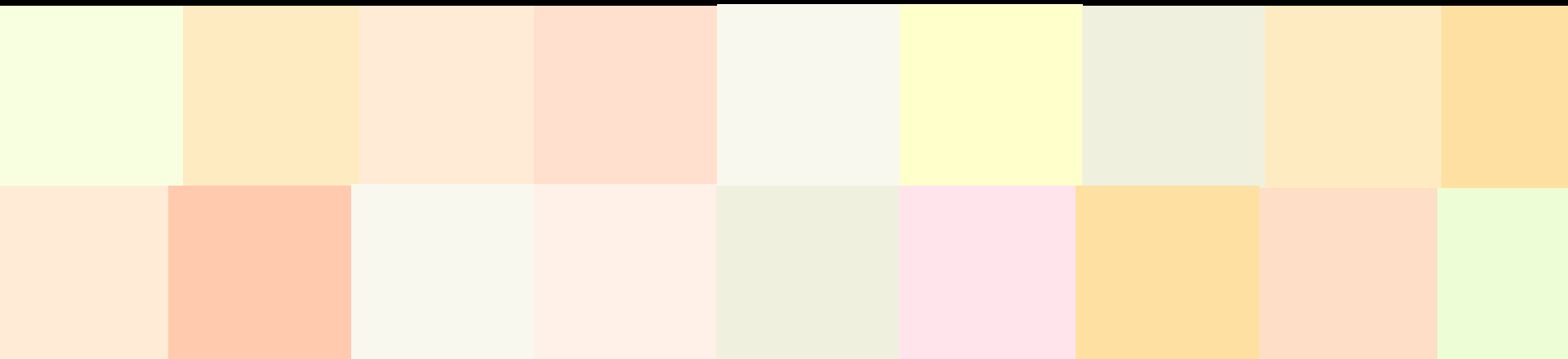
<http://www.post-gazette.com/pg/06256/721190-114.stm>

“A **tetrachromat** is a woman who can see *four distinct ranges of color, instead of the three* that most of us live with.”

That is, she has **four different types of cones**...instead of the usual 3 types.

Tetrachromatic Women?

- In one example, an interior decorator holds up three samples of beige wall paint, "*and I can see gold in one and gray in another and green in another, but my clients can't tell the difference.*””

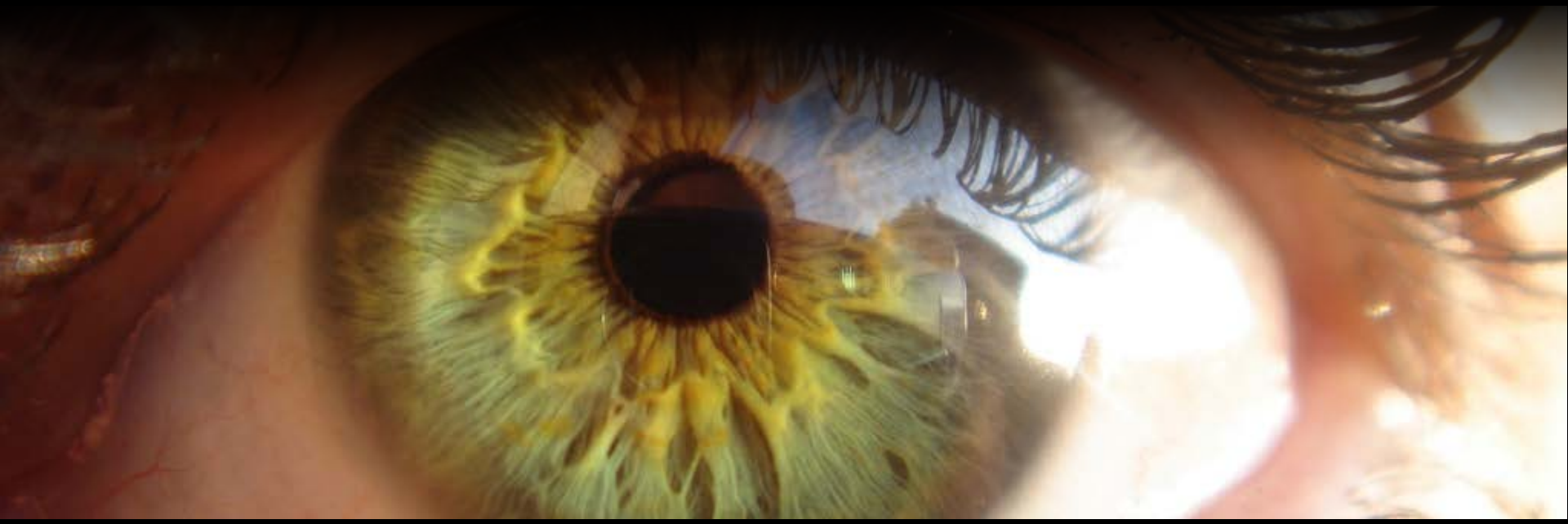


<http://www.post-gazette.com/pg/06256/721190-114.stm>

“Each of the three standard color-detecting cones in the retina -- blue, green and red -- can pick up about 100 different gradations of color, Dr. Neitz estimated. But the brain can combine those variations exponentially, he said, so that *the average person can distinguish about 1 million different hues.*

Tetrachromatic Women?

“A true tetrachromat has another type of *cone in between the red and green -- somewhere in the orange range* -- and its 100 shades theoretically would allow her to *see 100 million different colors.*

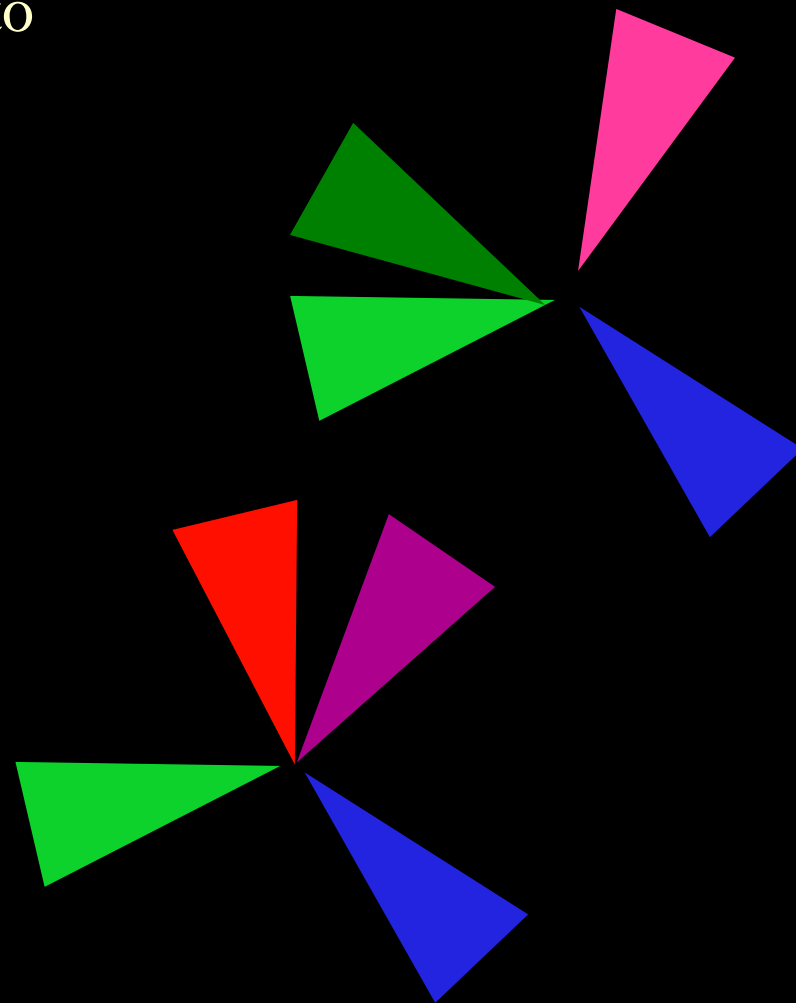
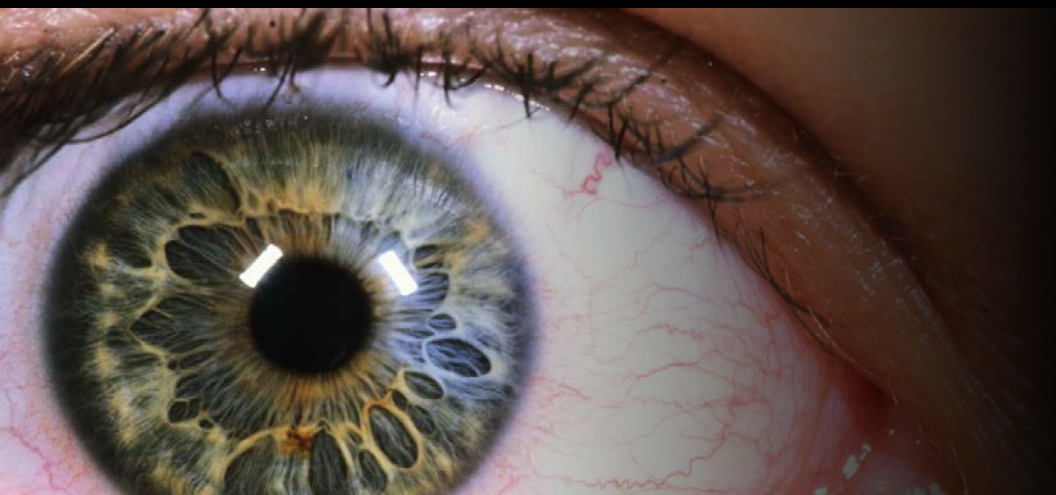


<http://www.post-gazette.com/pg/06256/721190-114.stm>

Some women with 4-types of cones have only slightly expanded color discernment • due to the particular hue-sensitivity of that 4th cone — sometimes its very similar to our “regular” green-sensing cone, or to our red-sensing cone.

Tetrachromatic Women?

In a few cases, women may have two distinct green cones on either X chromosome.”



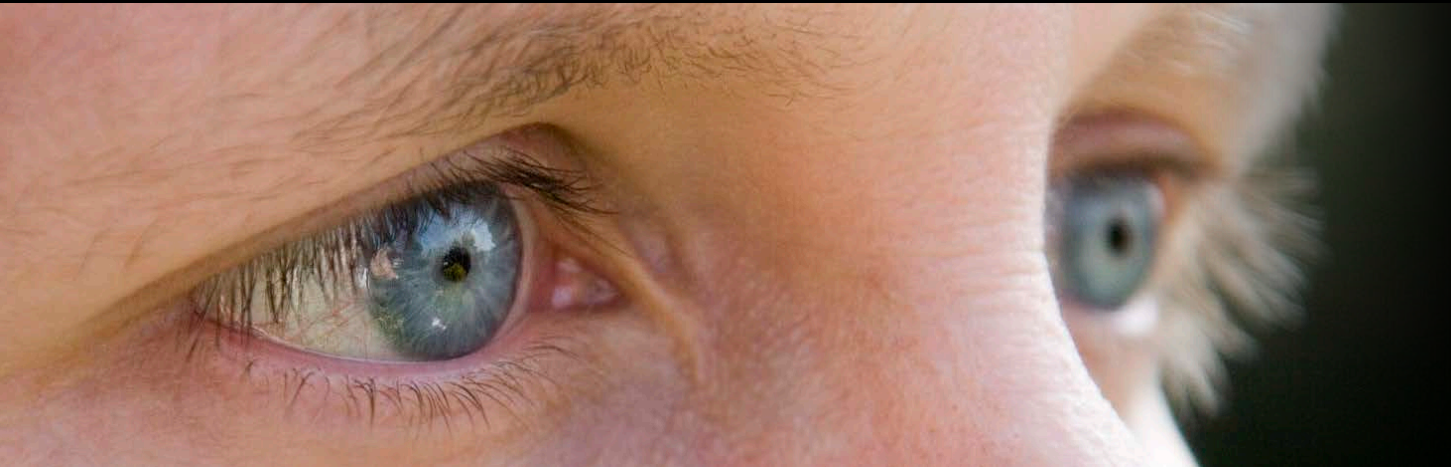
“...**only women have the potential for super color vision...**

because **the genes for the pigments in green and red cones lie on the X chromosome**, and **only women have two X chromosomes**, creating the opportunity for one type of red cone to be activated on one X chromosome and the other type of red cone on the other one.

Tetrachromatic Women?

- ...also, the fact that **men have only 1 X chromosome** is why we are so vulnerable to color blindness.

Women are much more likely to have all of the needed color-sensing genes on at least one of their two X chromosomes.



Hexachromatic Women?

“It is suspected that a human female could inherit multiple alleles for color blindness as protanomaly, deuteranomaly, and/or tritanomaly leading to the phenotypic expression of *at least four and possibly as many as six types of color-sensing cones*, although the red-, green-, and blue-deficient cones would have degenerate spectral sensitivity.

- <https://en.wikipedia.org/wiki/Pentachromacy>



But ladies, if you think tetrachromatic vision trumps all, pigeons have you beat...

“Some birds (notably pigeons) and butterflies have **five or more kinds of color receptors** (i.e. cones) in their retinæ...

Pentachromatic Pigeons?

- ...and are therefore believed to be **pentachromats**, [though psychophysical evidence of functional **pentachromacy** is lacking.]”

(<http://en.wikipedia.org/wiki/Pentachromat>)



“Some birds (notably pigeons) and butterflies have five or more kinds of color receptors in their retinæ, and are therefore believed to be pentachromats, though psychophysical evidence of functional pentachromacy is lacking.”

<http://en.wikipedia.org/wiki/Pentachromat>

Pigeons & Butterflies Pentachromats

Pentachromats have 5 different types of cones.

(you and I are Trichromats.)

Each cone specializing in a different range of hue.



That means their eyes appear capable of sensing 5 different wavelengths of light/color, but we really don't know what a pigeon's mind *does* with what the eye senses — thus, **we really don't know what they “see.”**

(<http://en.wikipedia.org/wiki/Pentachromat>)

Pentachromatic Pigeons?

Assuming pentachromatic vision works similar to our trichromatic vision, **they can distinguish 10 billion hues**, while you and I can distinguish about 1 million.

- (10,000X more hues than us...*maybe*)



Simultaneous Contrast

We'll eventually be exploring **Chevreul's Laws** of color perception.

He arrived at 13 laws, or general rules of thumb, to help color designers anticipate what colors will do when composed – when colors are placed side by side in images and designs.

All those rules come down to **Simultaneous Contrast**.

Color & Context

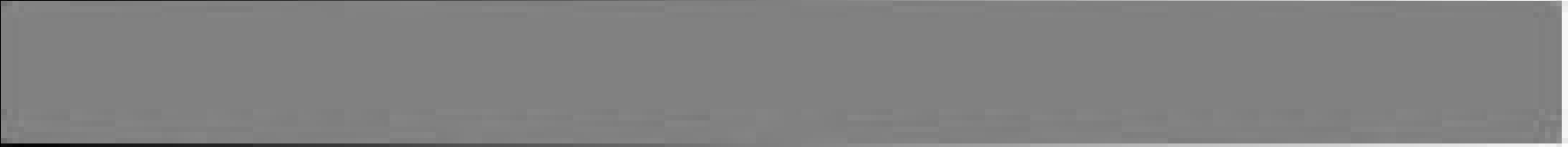
Simultaneous Contrast is the most influential color-perception-altering phenomena.

It alters what you see, all the time.

To design color well, you must anticipate the impact of this everyday, all-the-time perceptual phenomena.

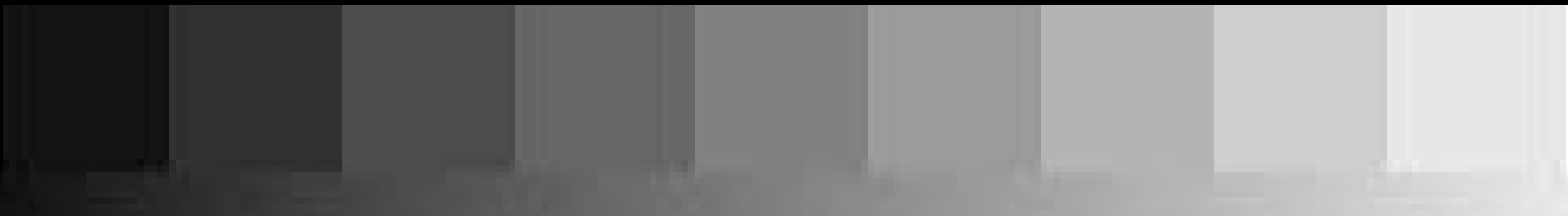
Color & Context



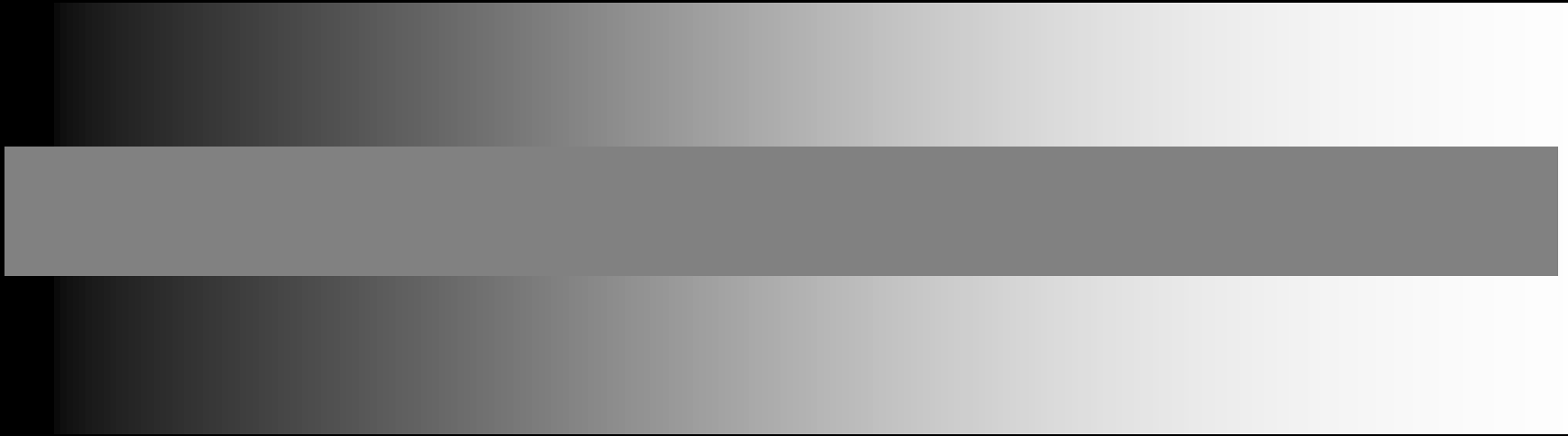


Simultaneous contrast -- each value changes appearance in response to the colors/values around it.

Notice the scalloped, curved-like appearing of these squares.



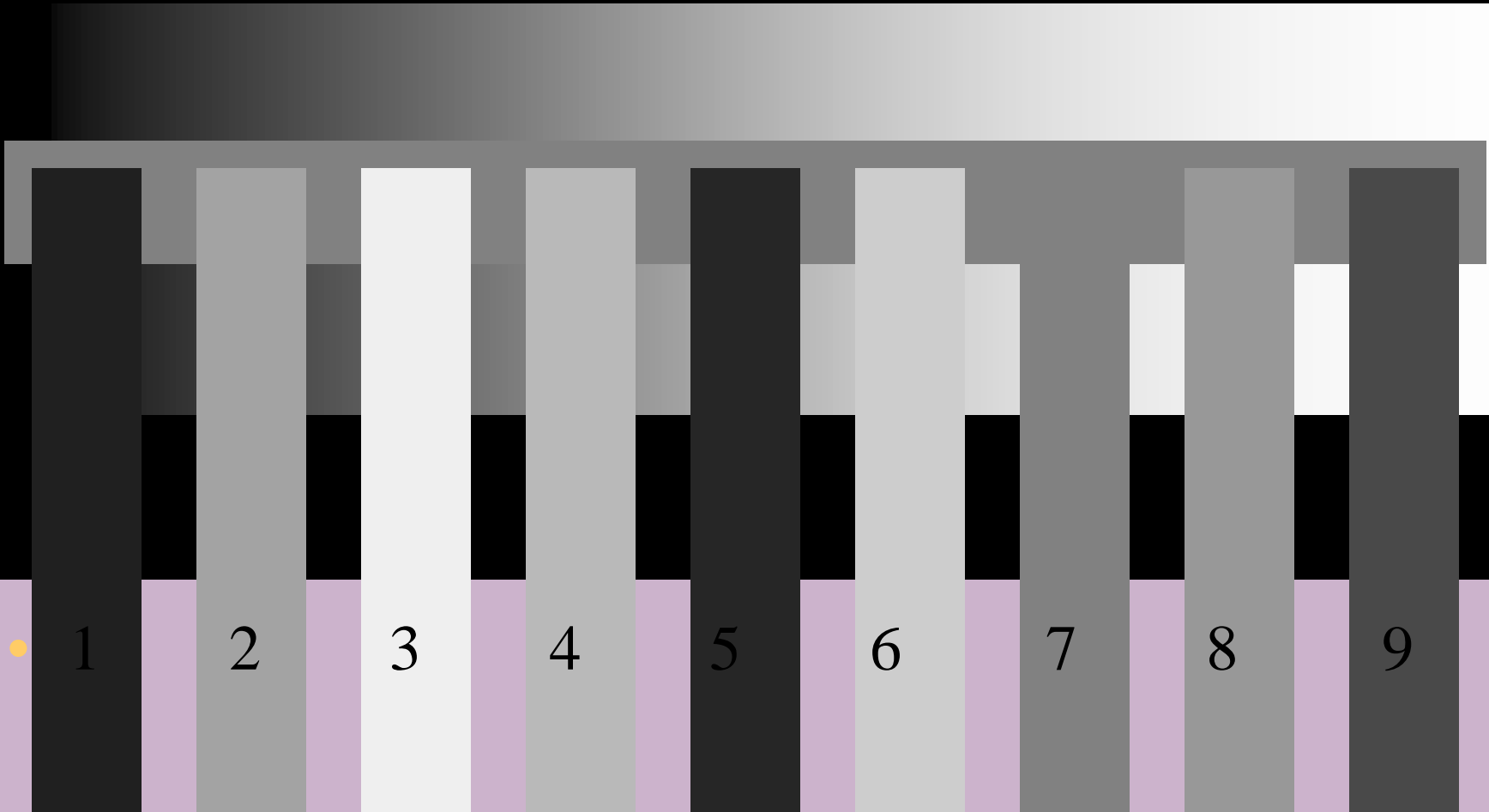
Color & Context



- 1 2 3 4 5 6 7 8 9
-
- A row of nine square color swatches. Swatch 1 is black. Swatches 2, 3, 4, 5, 6, 7, 8, and 9 are various shades of gray, ranging from light to dark, corresponding to the gradient bar above.

- Which color is the center band?

Color & Context

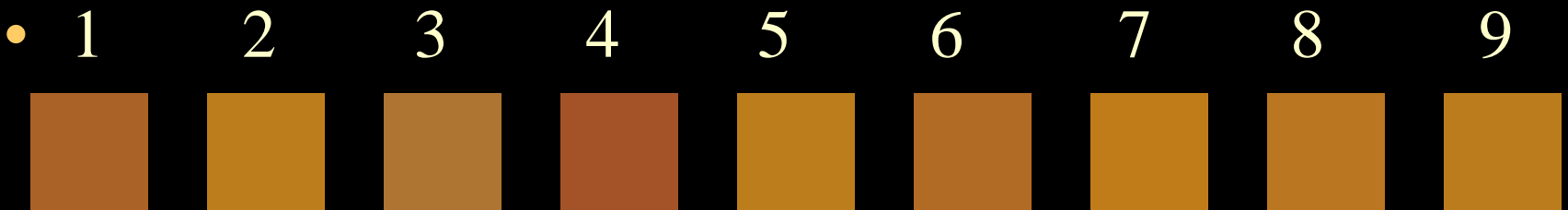


- Which color is the center band?

Color & Context

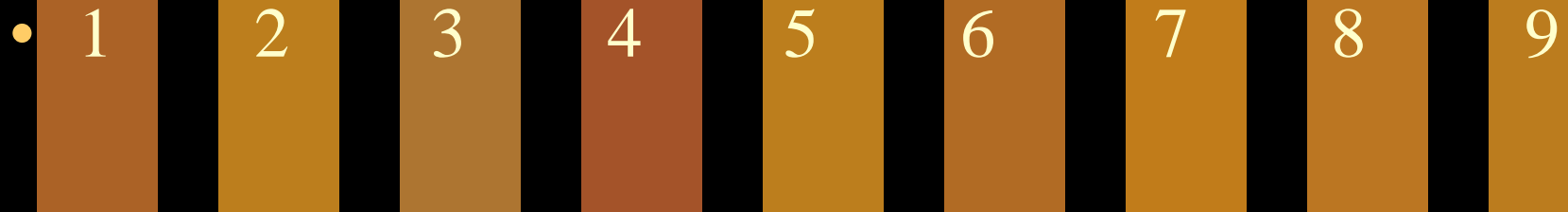


Color & Context



- Which color is the center band?

Color & Context

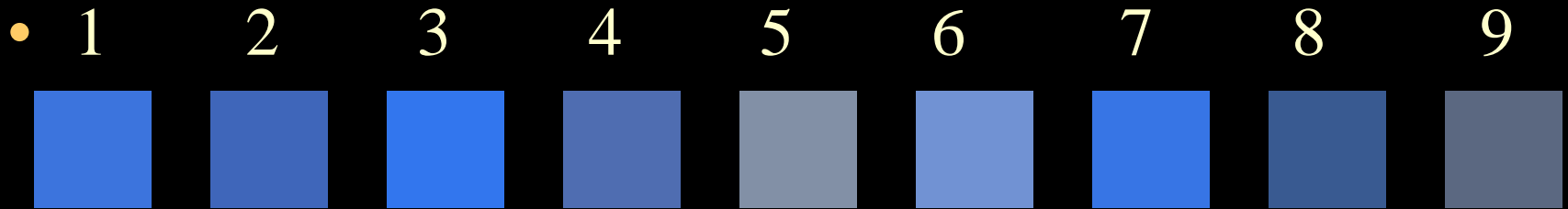


- Which color is the center band?

Color & Context

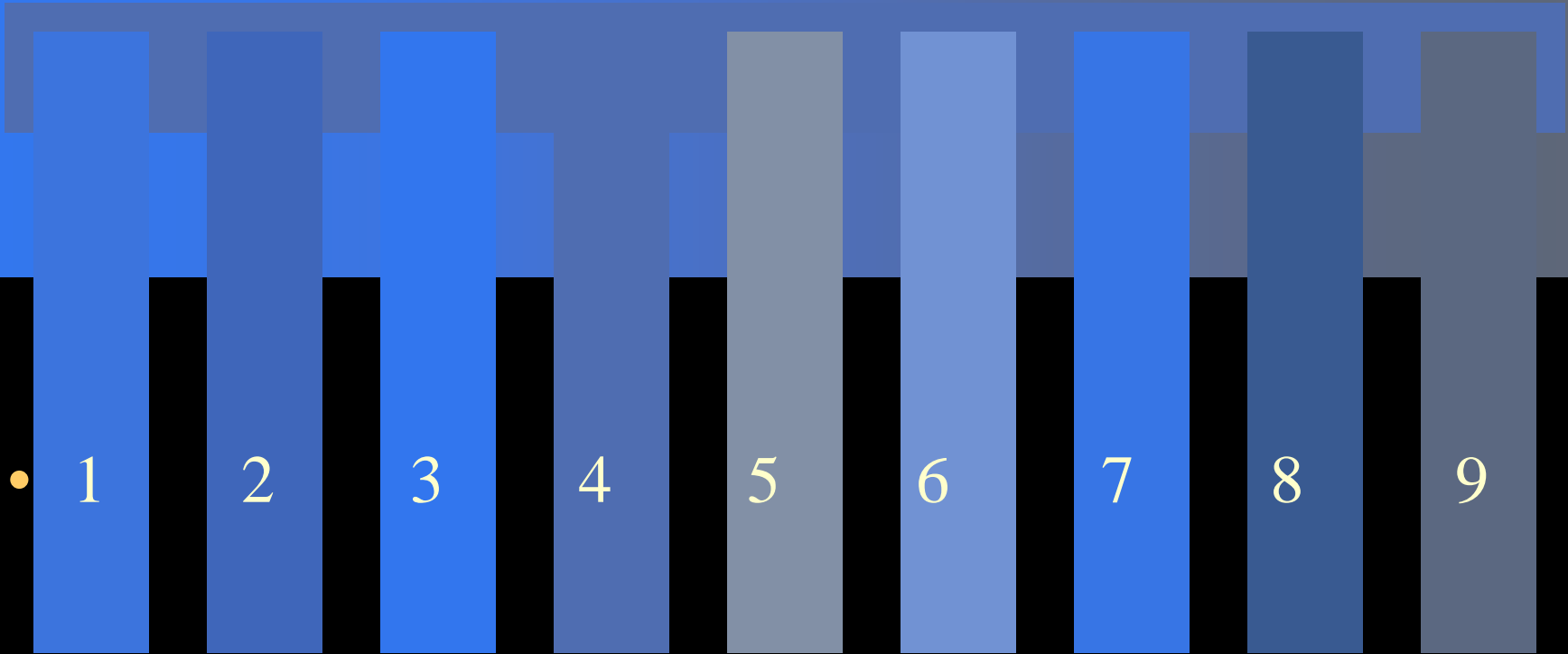


Color & Context



- Which color is the center band?

Color & Context

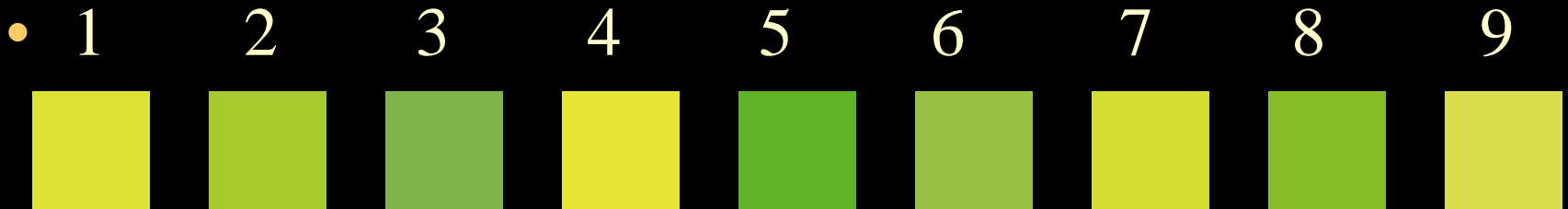


- Which color is the center band?

Color & Context

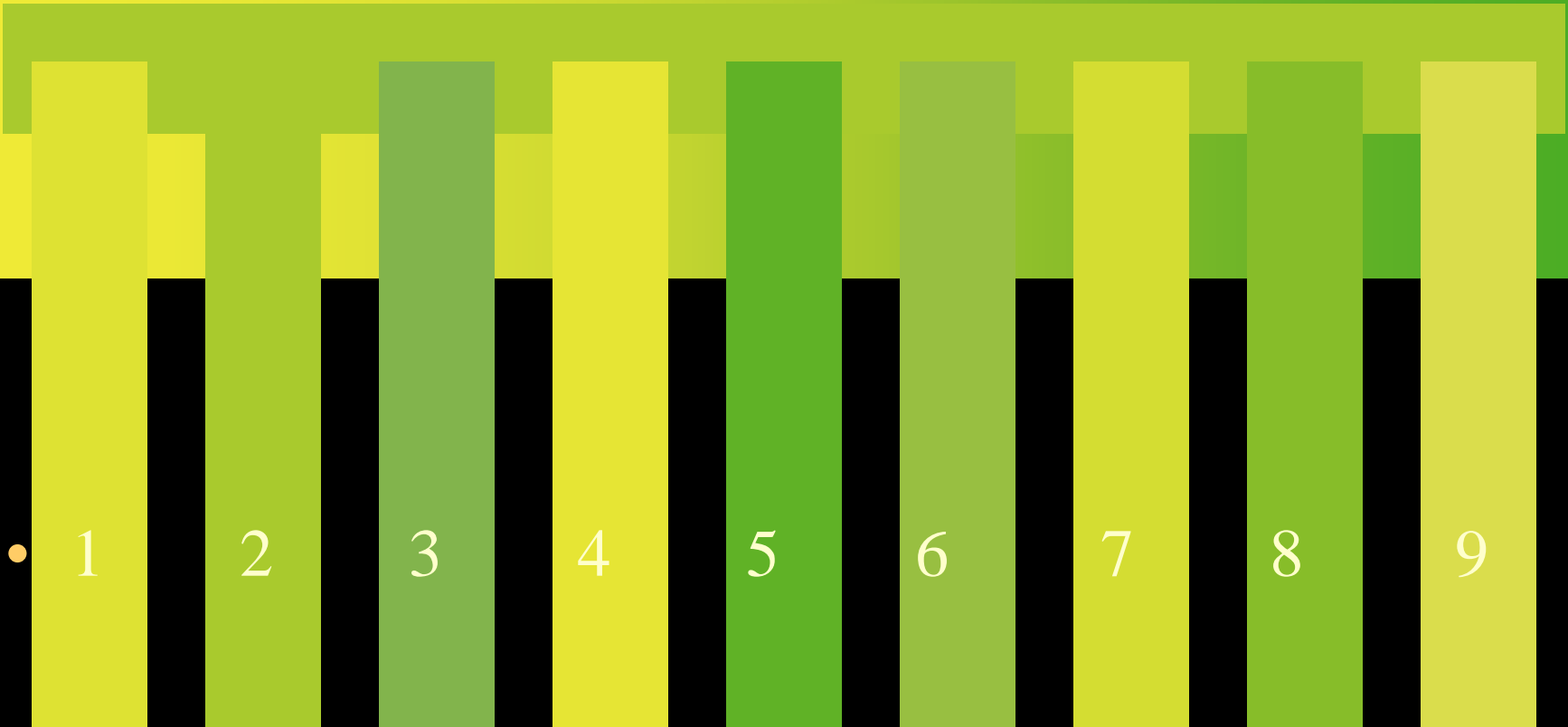


Color & Context



- Which color is the center band?

Color & Context

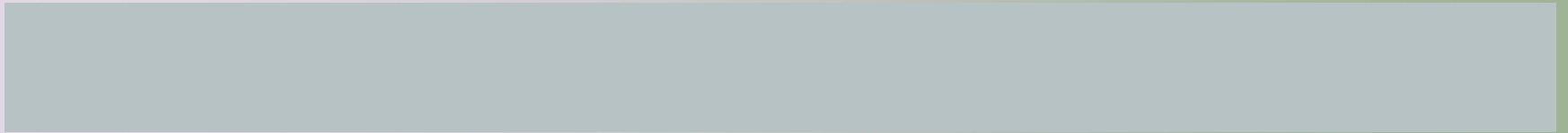


- 1 2 3 4 5 6 7 8 9
- Which color is the center band?

Color & Context



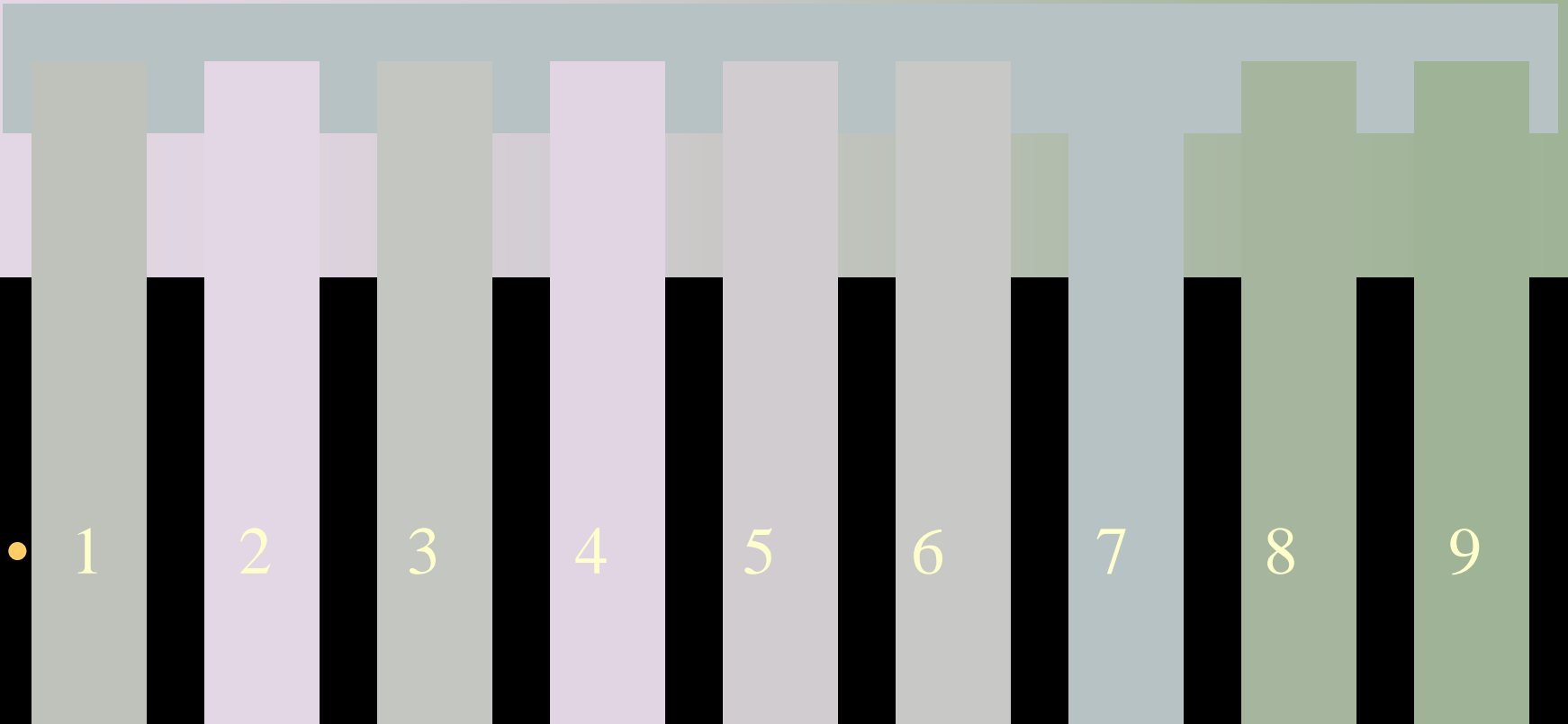
Color & Context



- 1 2 3 4 5 6 7 8 9
-
- A row of nine colored squares corresponding to the numbers 1 through 9. The colors are: 1 (teal), 2 (light purple), 3 (teal), 4 (light purple), 5 (light grey), 6 (light grey), 7 (light blue), 8 (teal), 9 (teal).

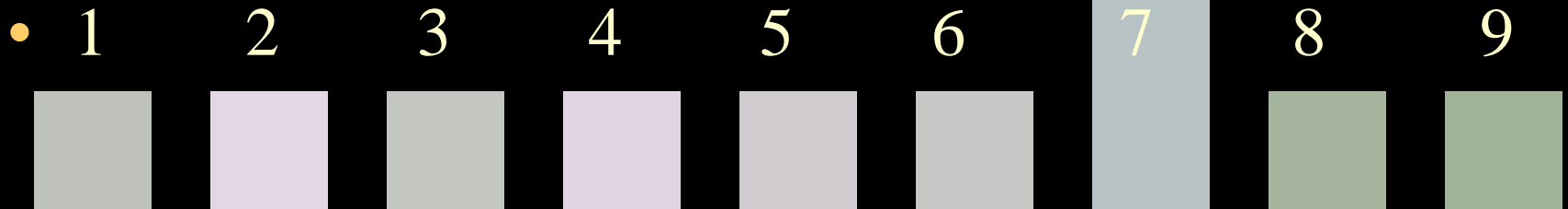
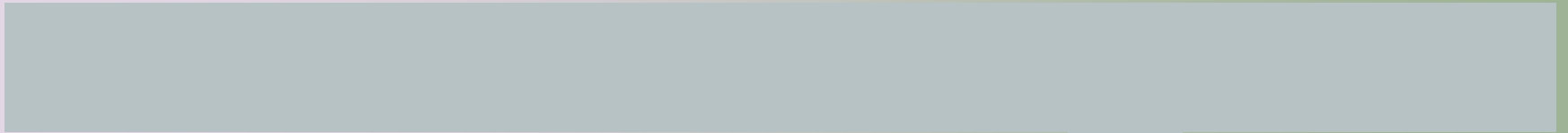
- Which color is the center band?

Color & Context



- 1 2 3 4 5 6 7 8 9
- Which color is the center band?

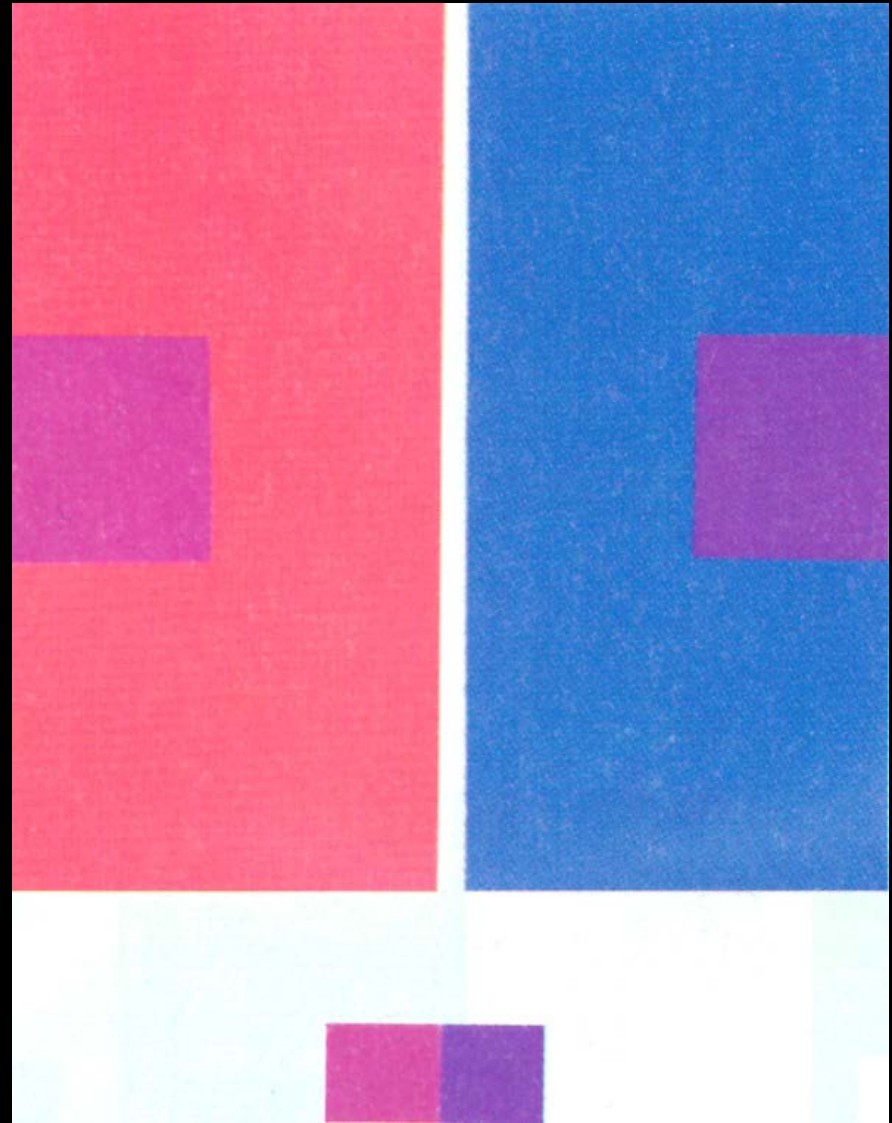
Color & Context



- Which color is the center band?

Color Context: Simultaneous Contrast

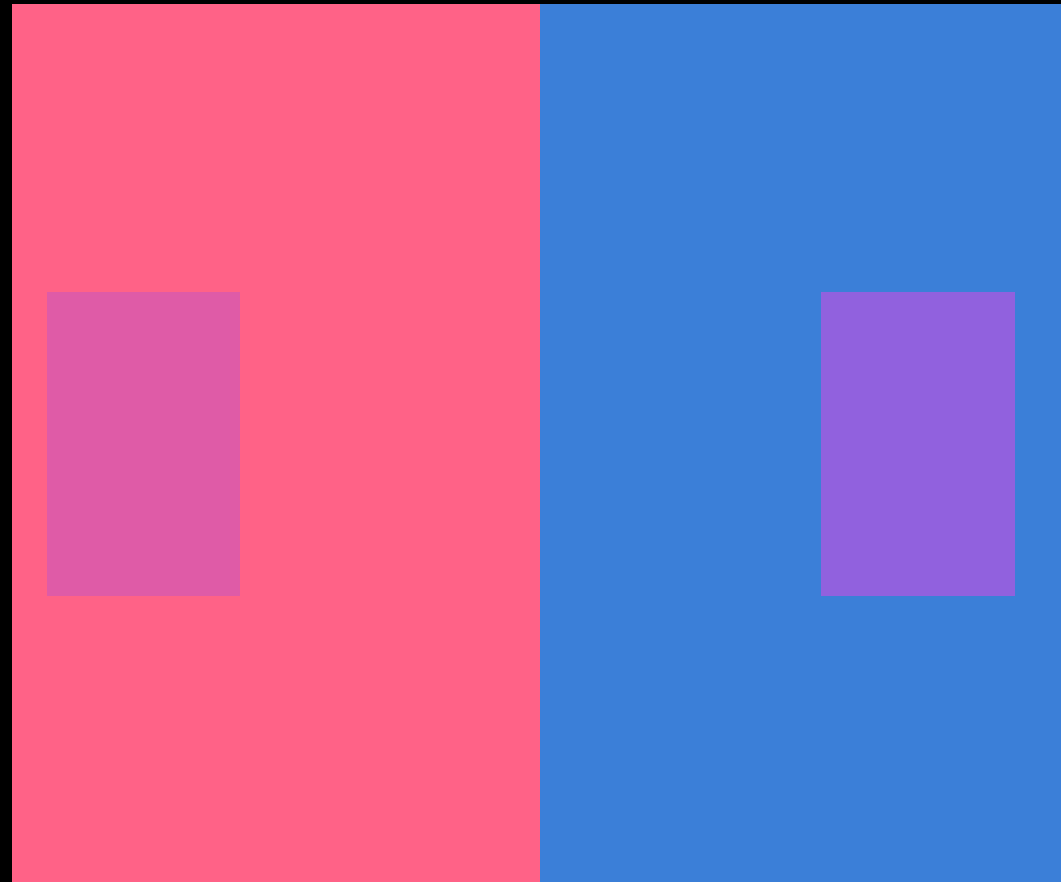
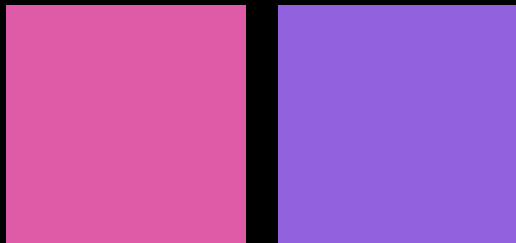
- “The only hard and fast rule that can be applied is the *all colors are affected by the colors around them.*” (Color, p. 27-28)

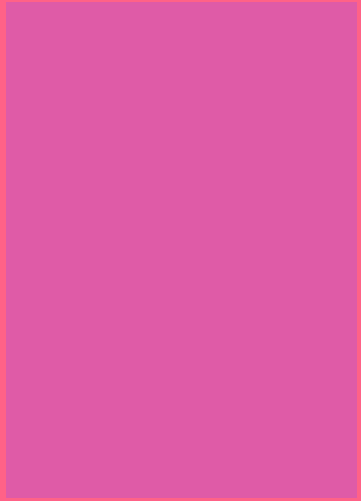


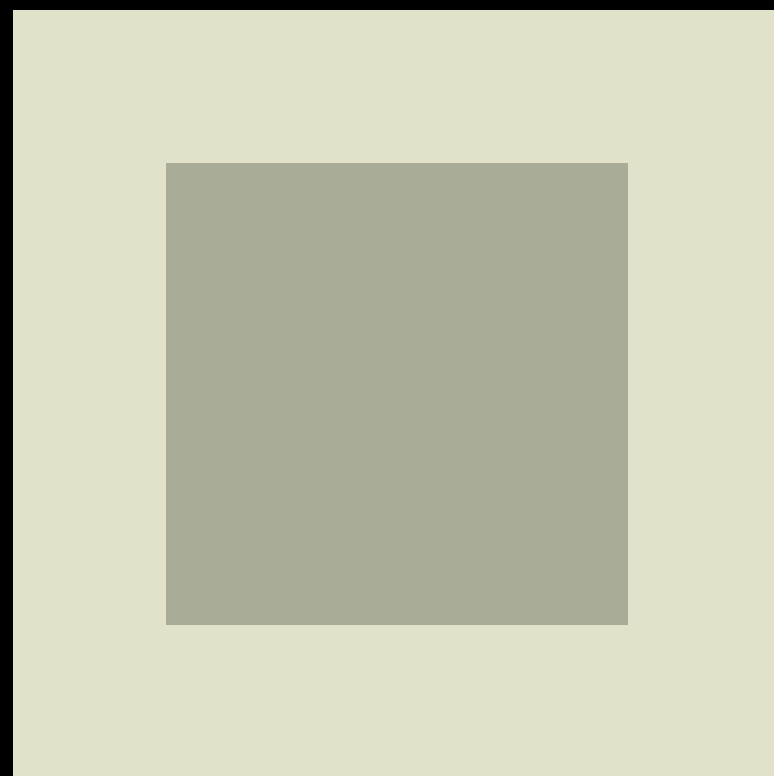
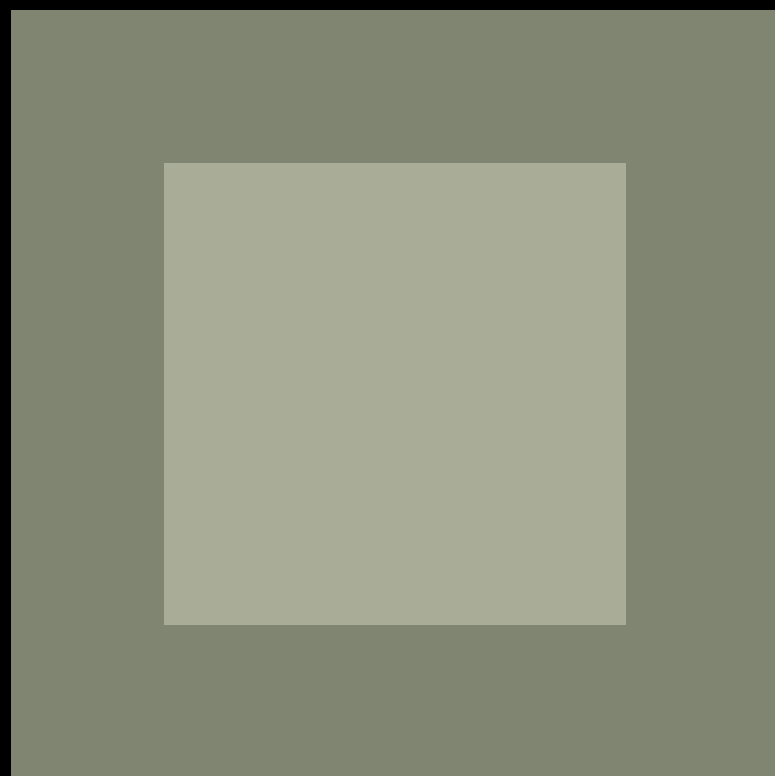
Color & Context: Simultaneous Contrast

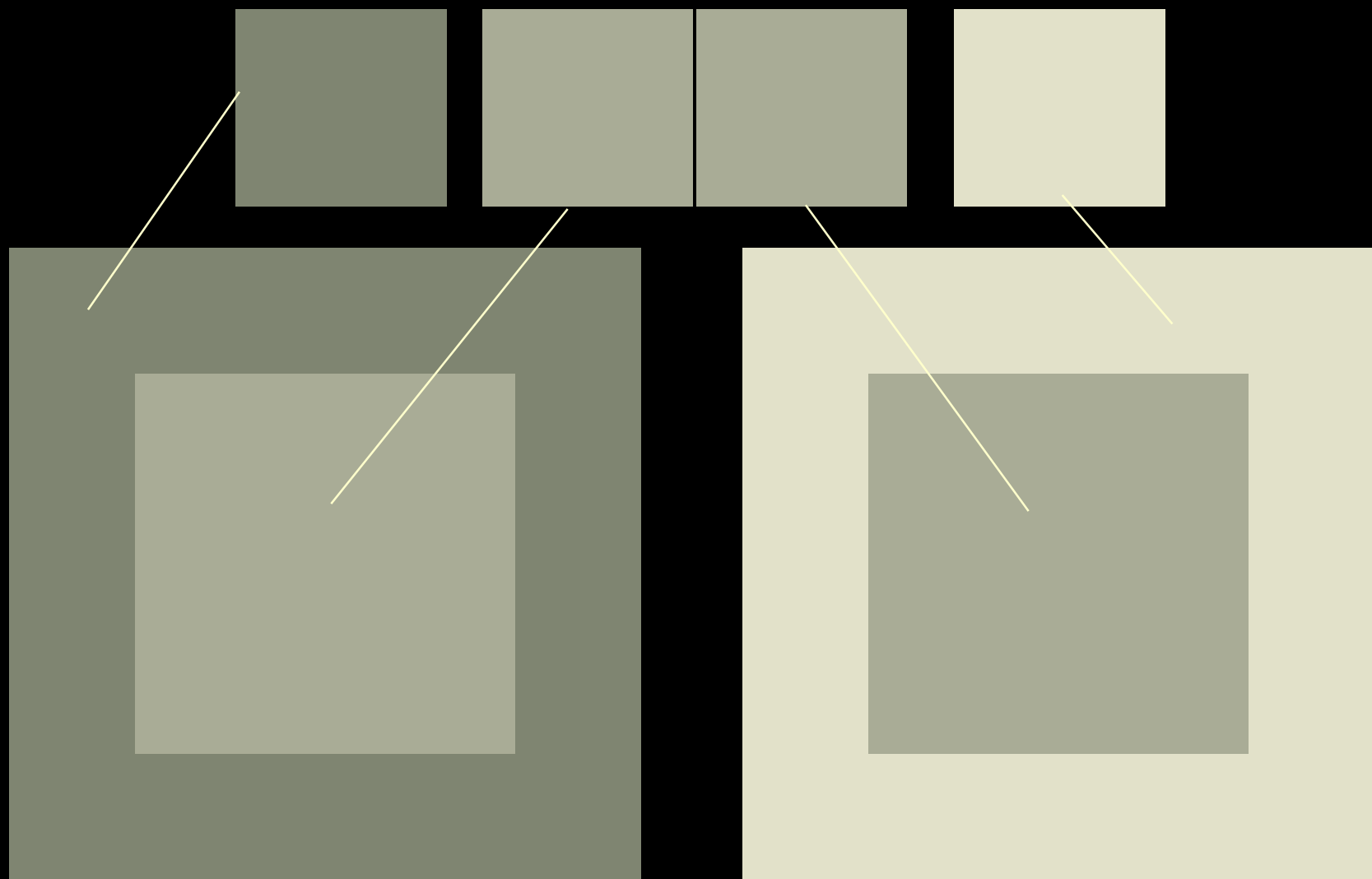
- All colors are altered by the colors around them.
(see Chevreul's Laws)

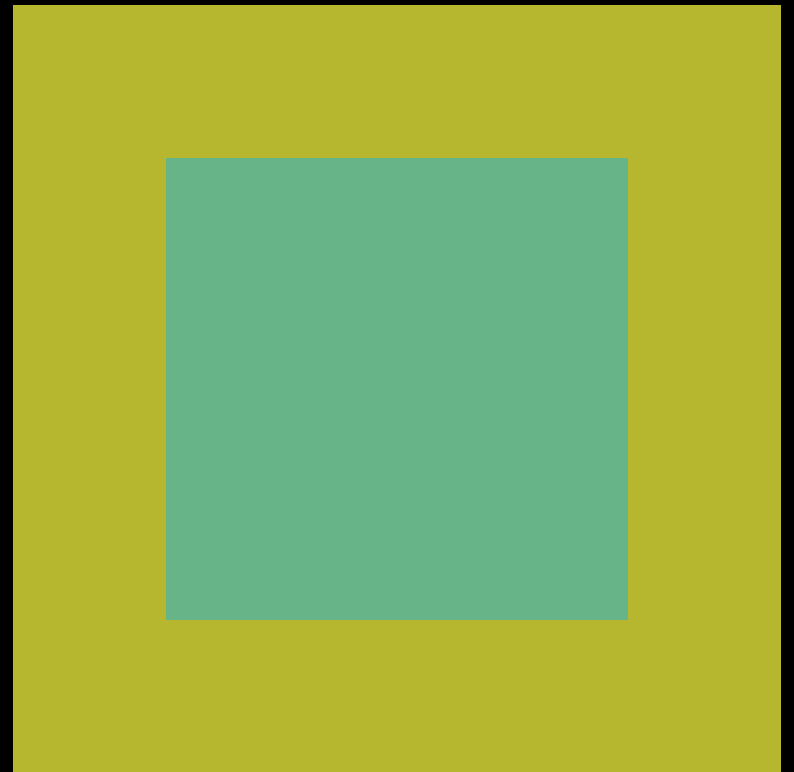
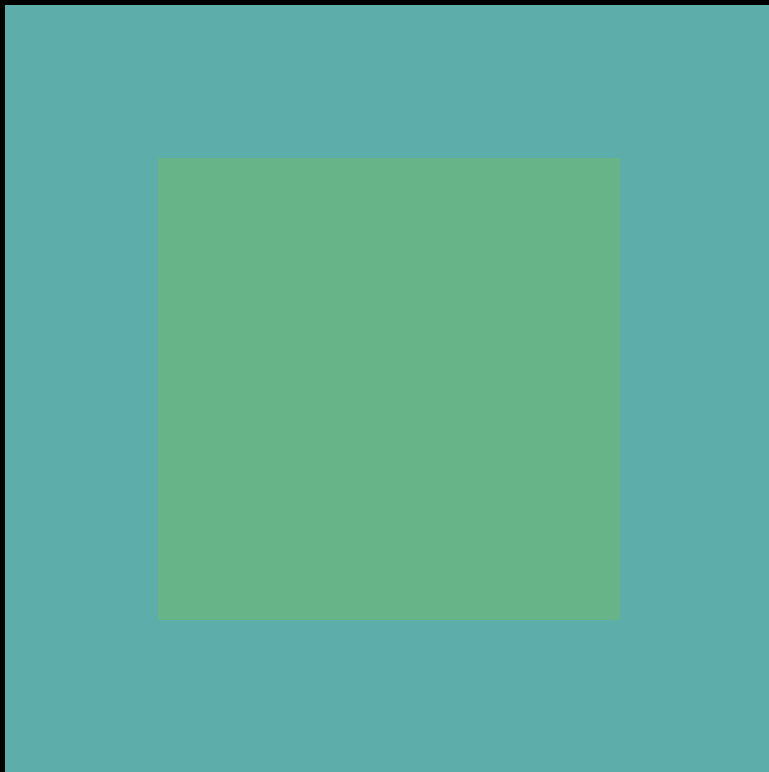
- Here, two very different colors appear the same.









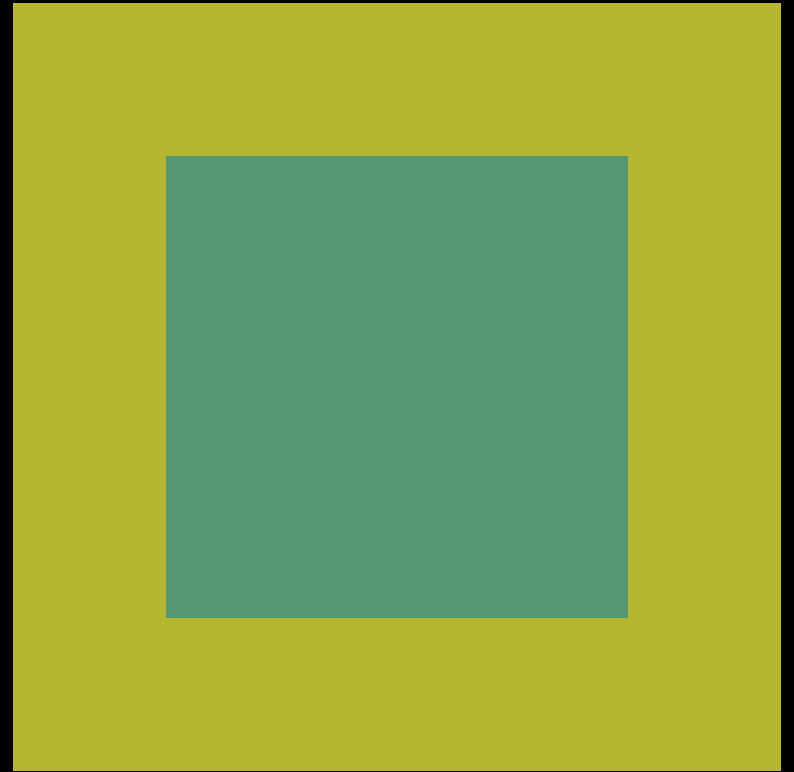
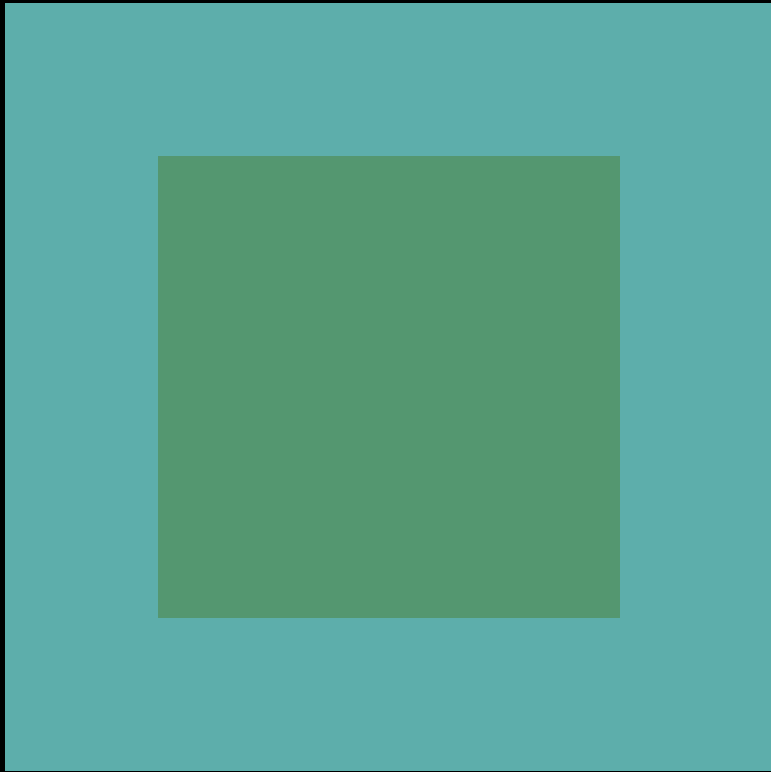


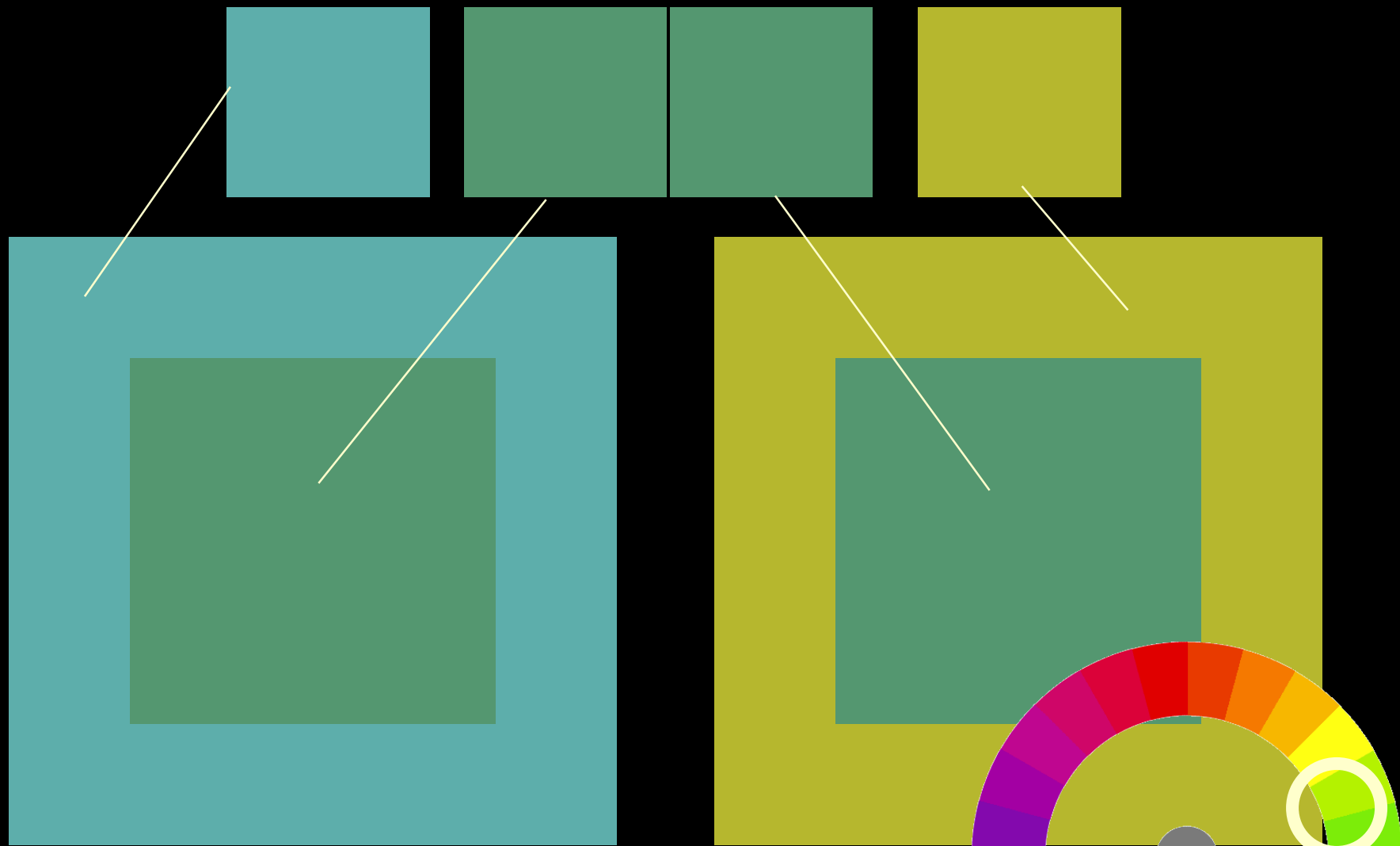


Note that the hues are roughly symmetrical — there are even intervals between the BBG—GBG, and the GBG—YG.

Also, chroma is roughly equal (medium) and values are quite close.

These traits help the hue (of the GBG) shift successfully.



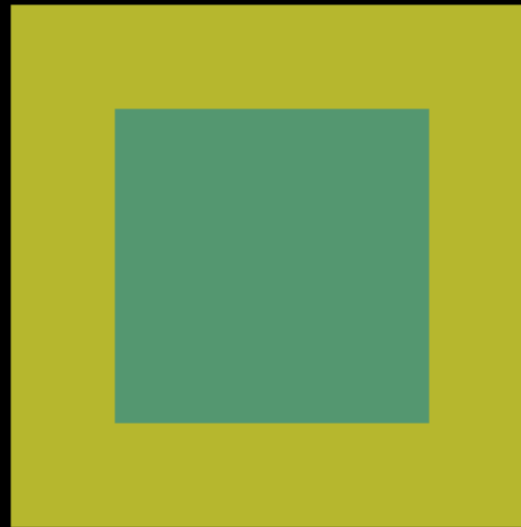
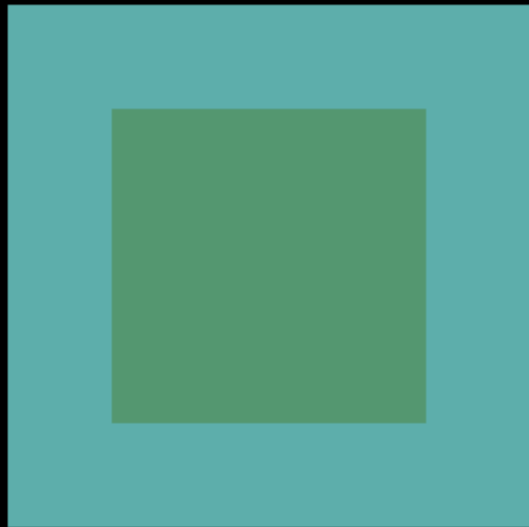
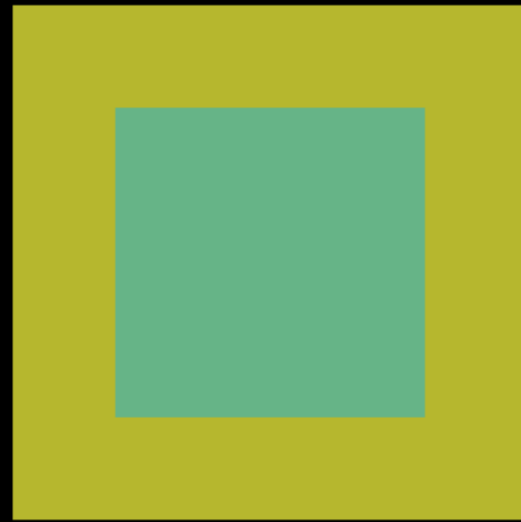
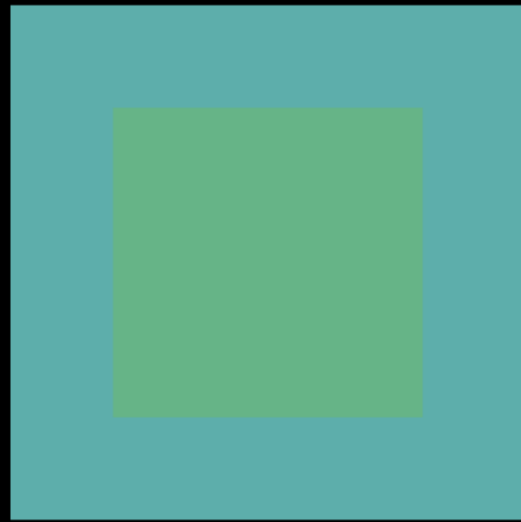


Note that the hues are again roughly symmetrical — there are even *intervals* between the BBG—GBG, and the GBG—YG.

However, values are just a bit more distinct.

The hue (of the GBG) shifts less than in the prior example— however, the value of the GBG shifts more.

Joseph Albers, especially, explored how some colors are more vulnerable to simultaneous contrast than others – that is, the perception of some colors tend to change noticeably, while other colors “hold” their appearance moreso.

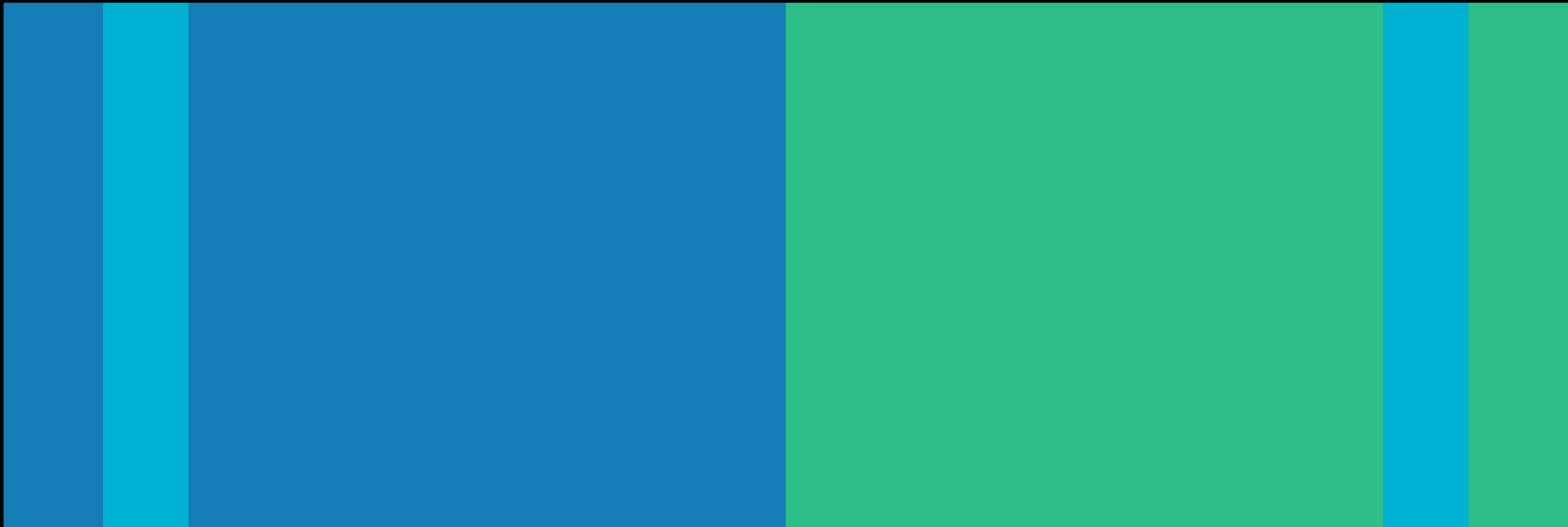


Such vulnerability to change depends, in part, on the nature of the relationship with surrounding colors, as well as the traits of the color itself.

***Color & Context: Simultaneous
Contrast***

Color Context

- (here, one color appears as two)



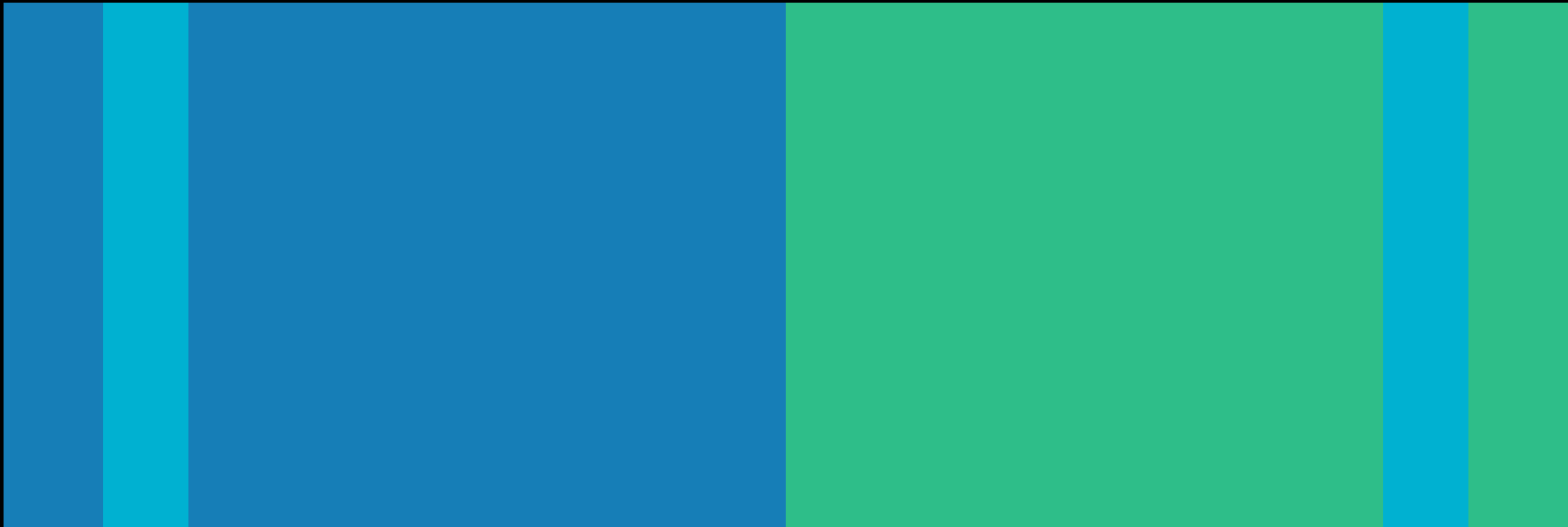
Color Context

- (here, one color appears as two)



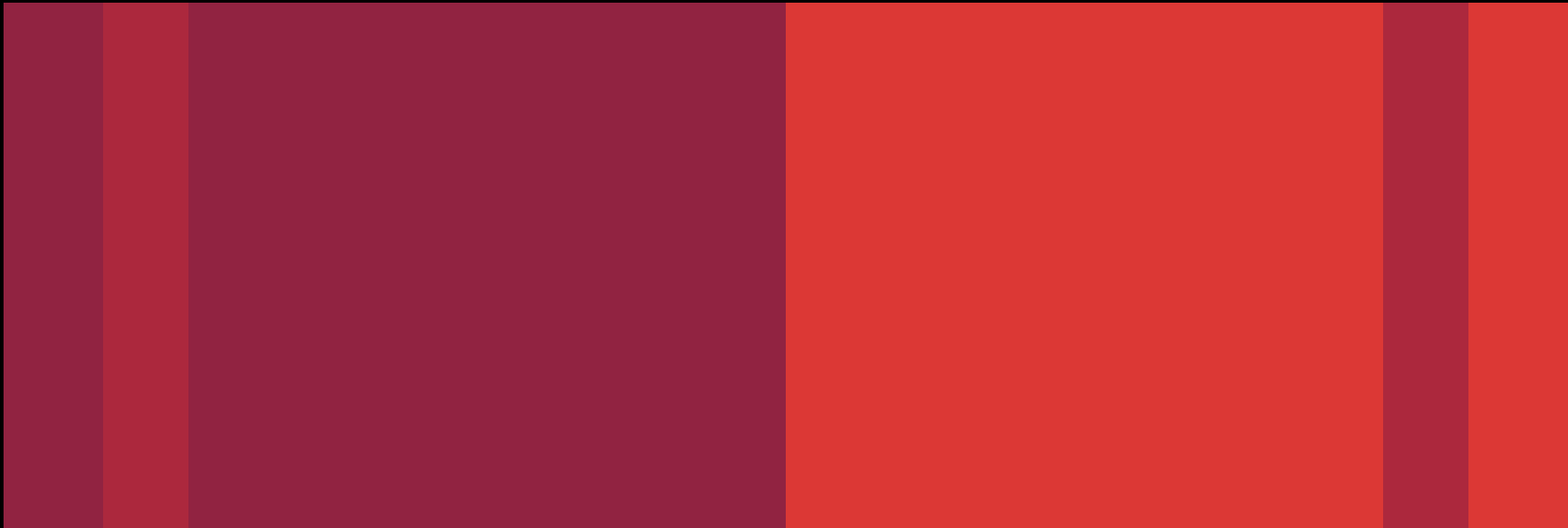
Color Context

- (here, one color appears as two)



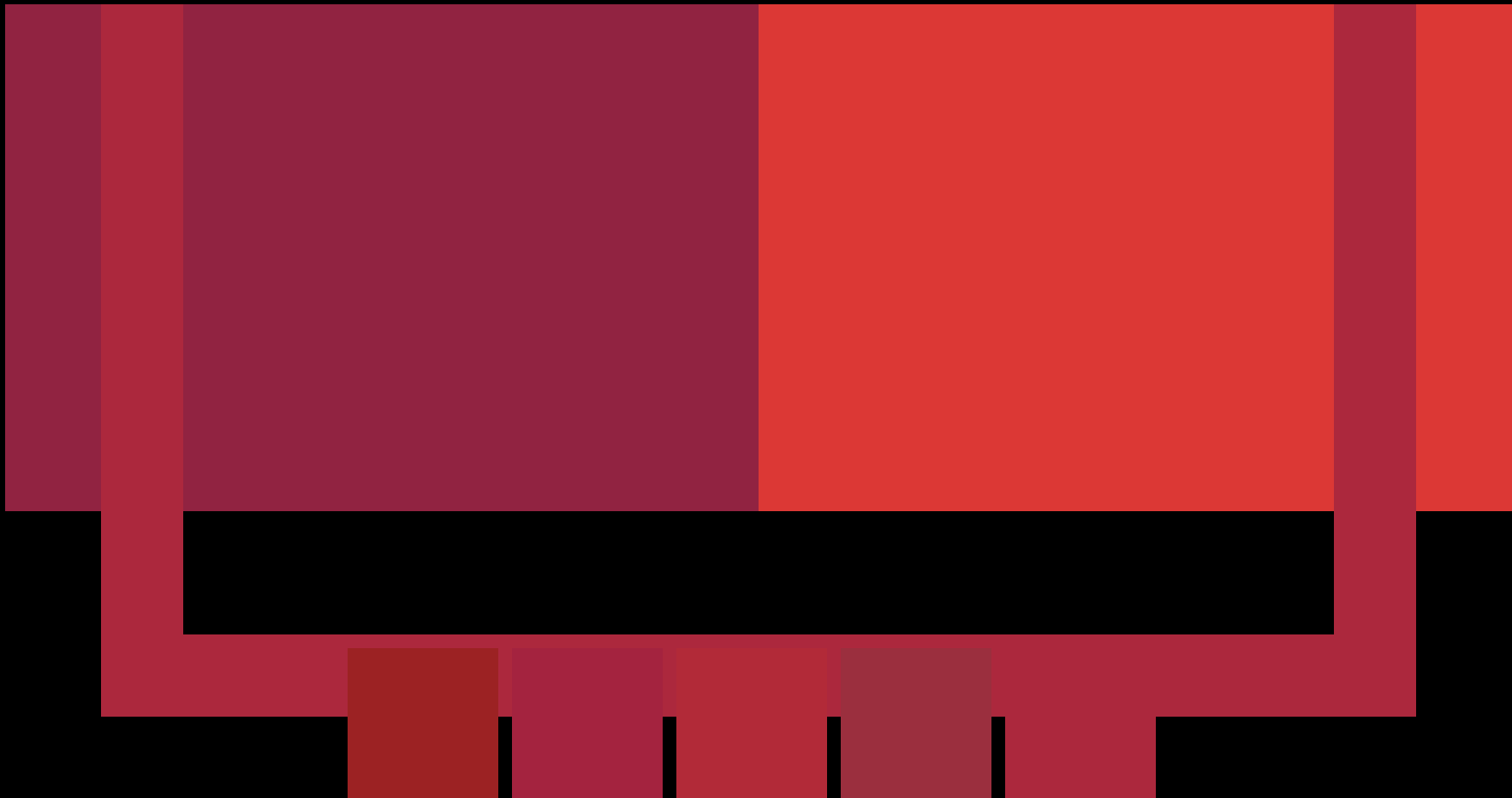
Color Context

- (here, one color appears as two)



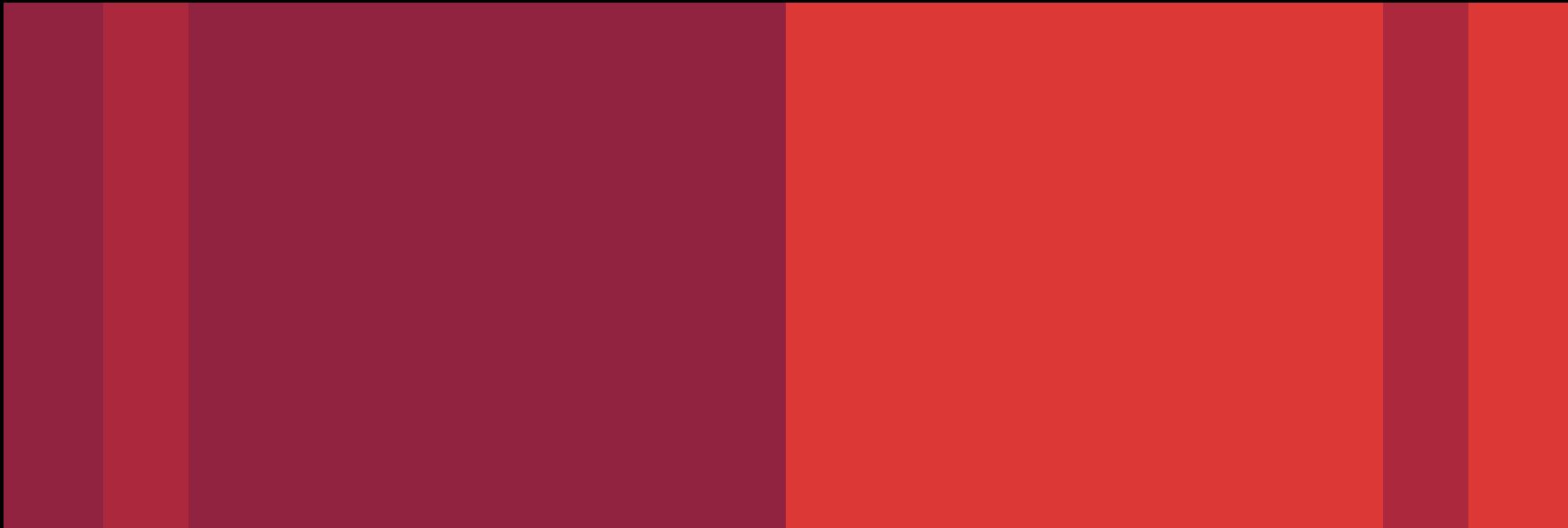
Color Context

- (here, one color appears as two)



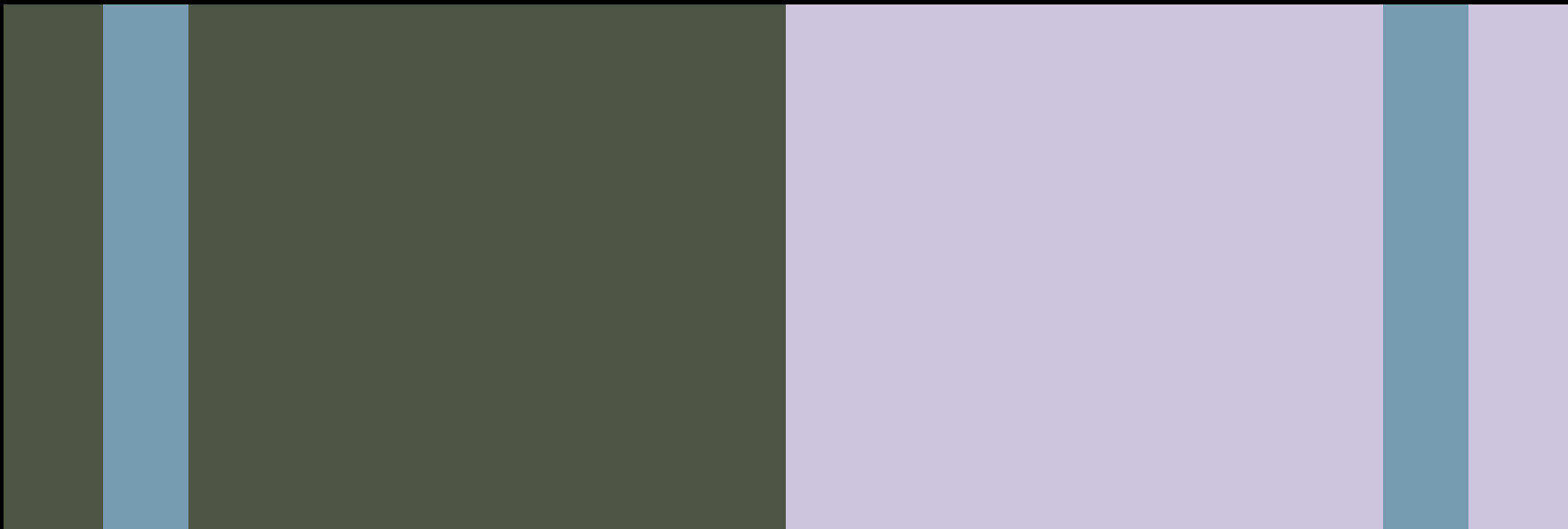
Color Context

- (here, one color appears as two)



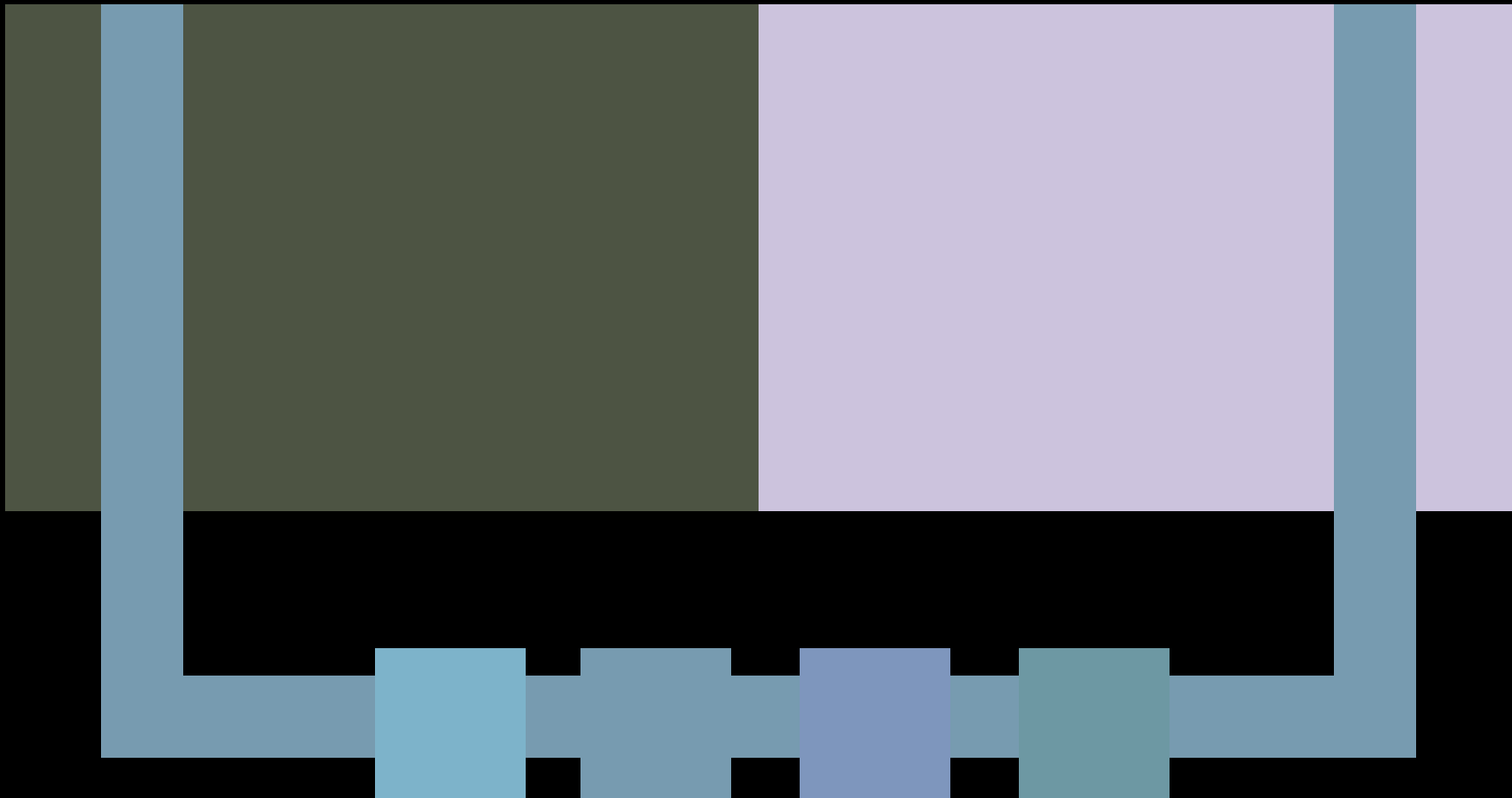
Color Context

- (here, one color appears as two)



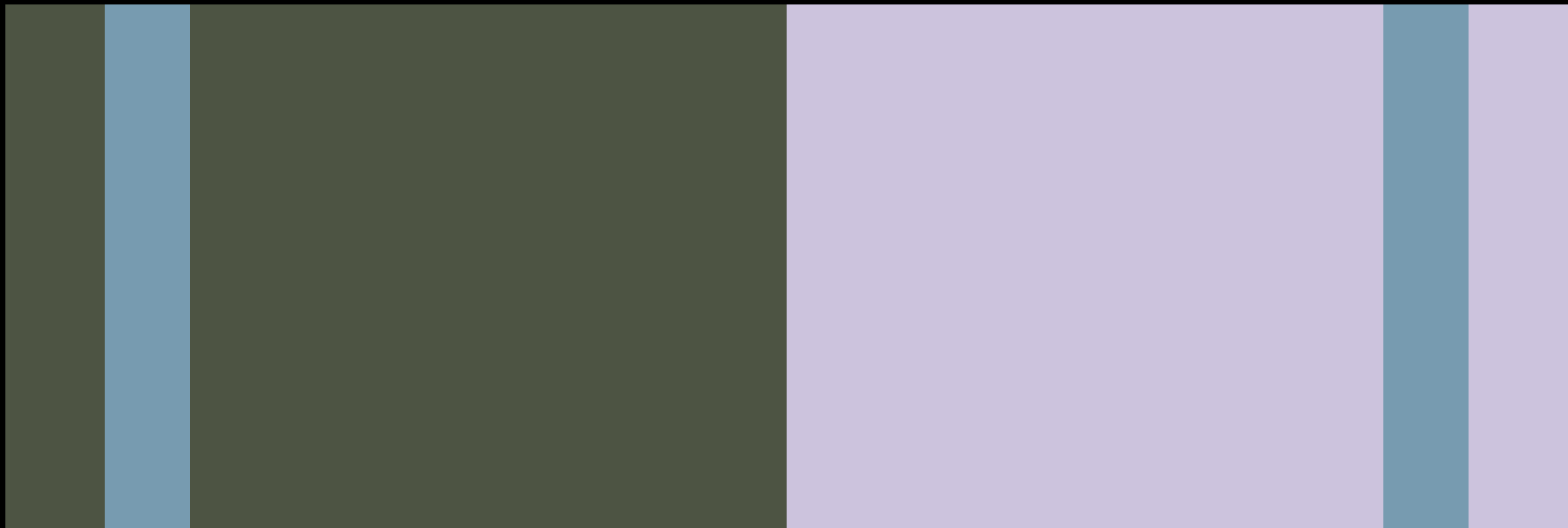
Color Context

- (here, one color appears as two)



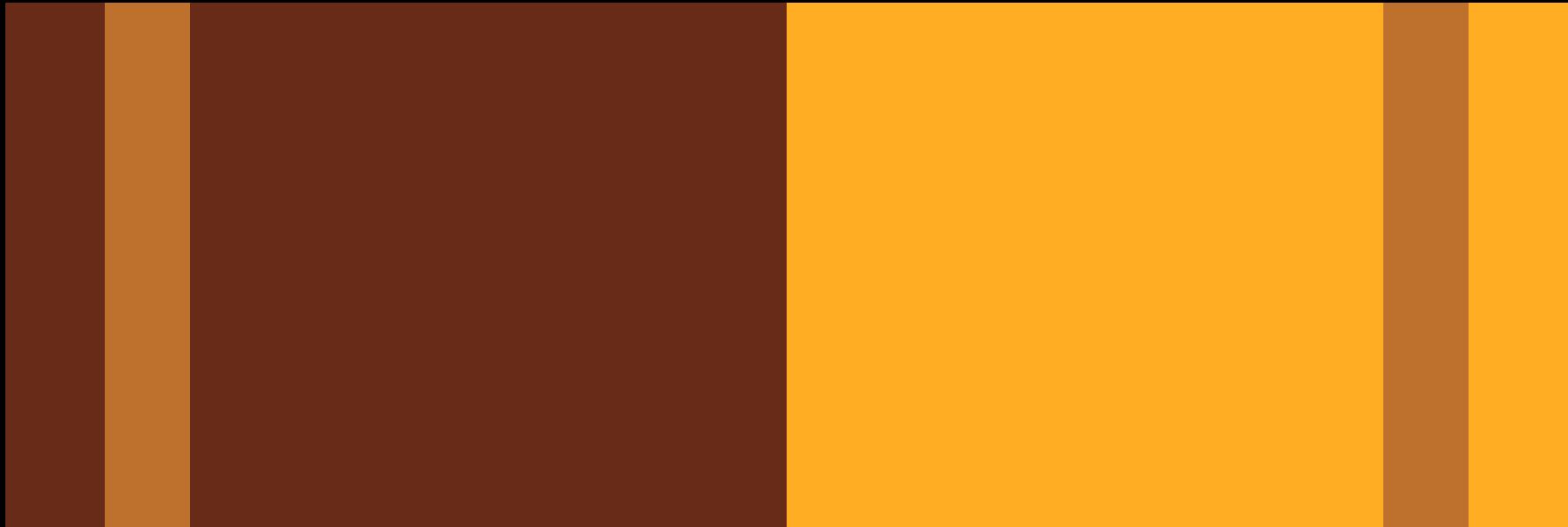
Color Context

- (here, one color appears as two)



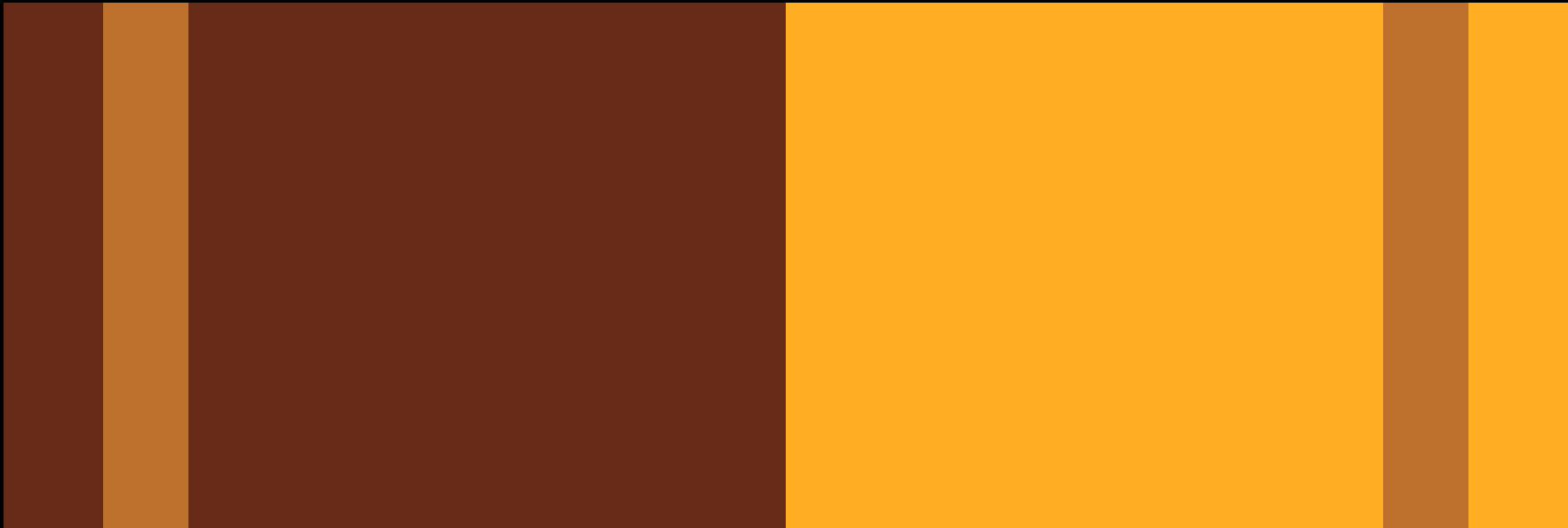
Color Context

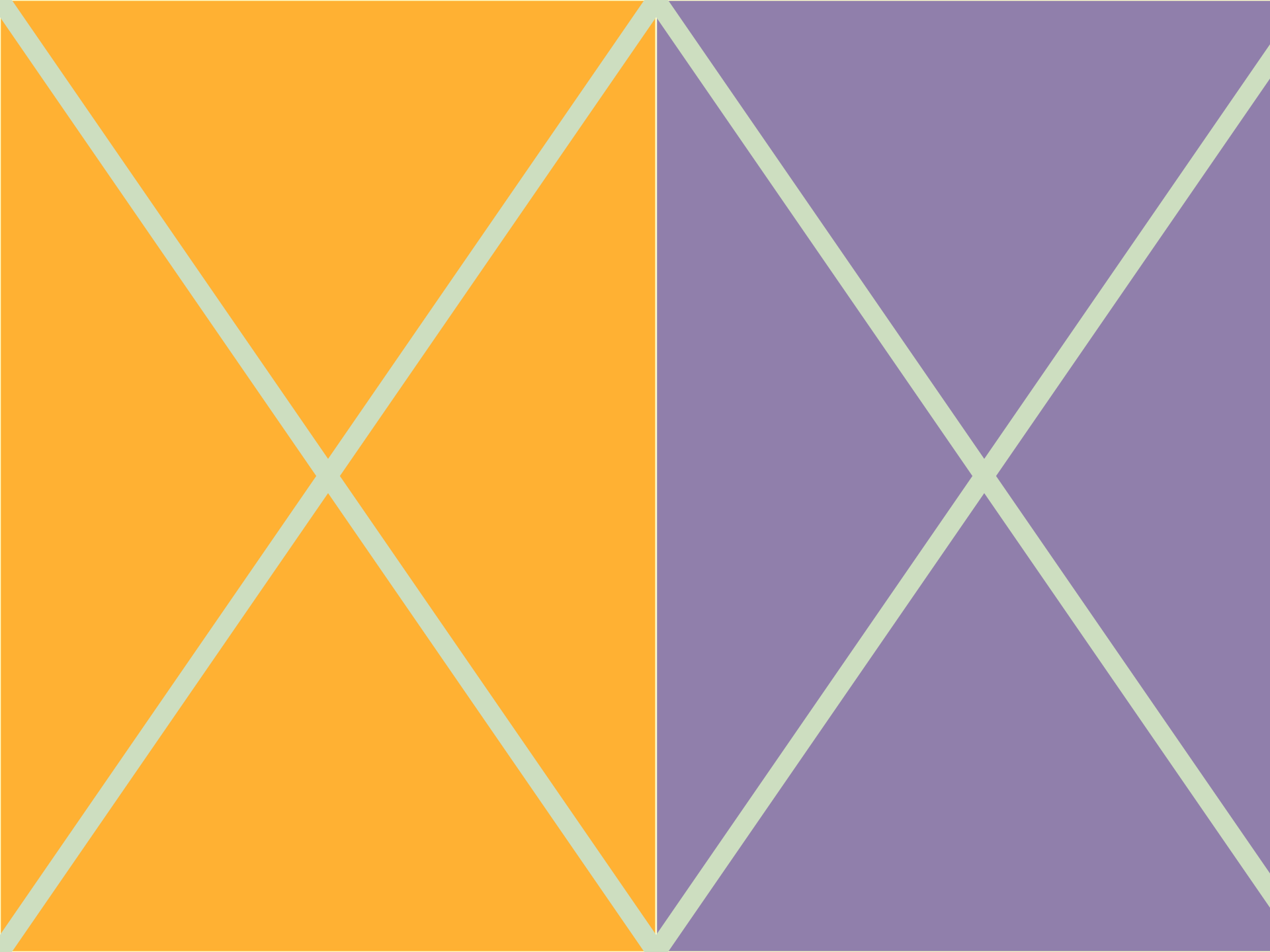
- (here, one color appears as two)

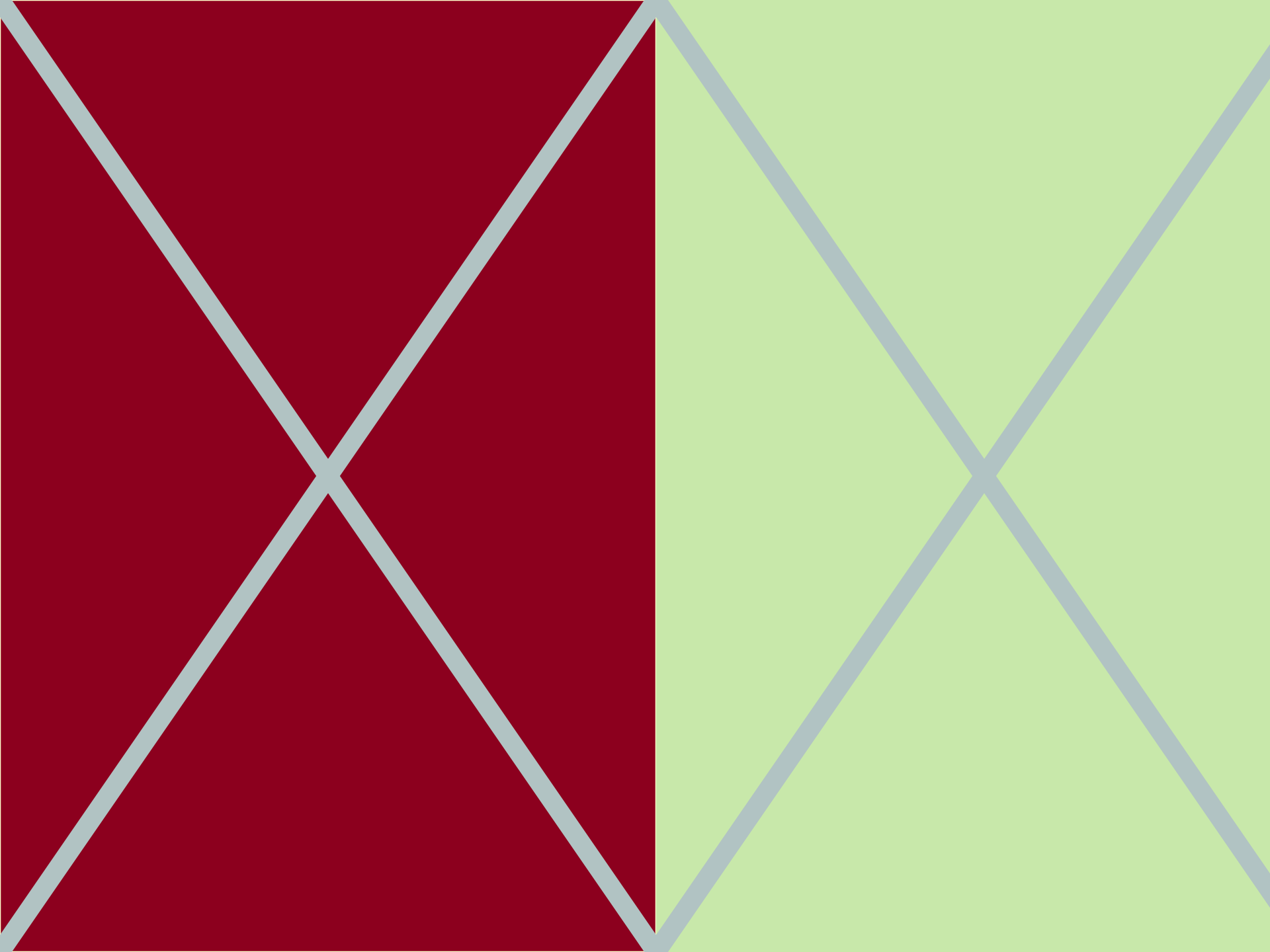


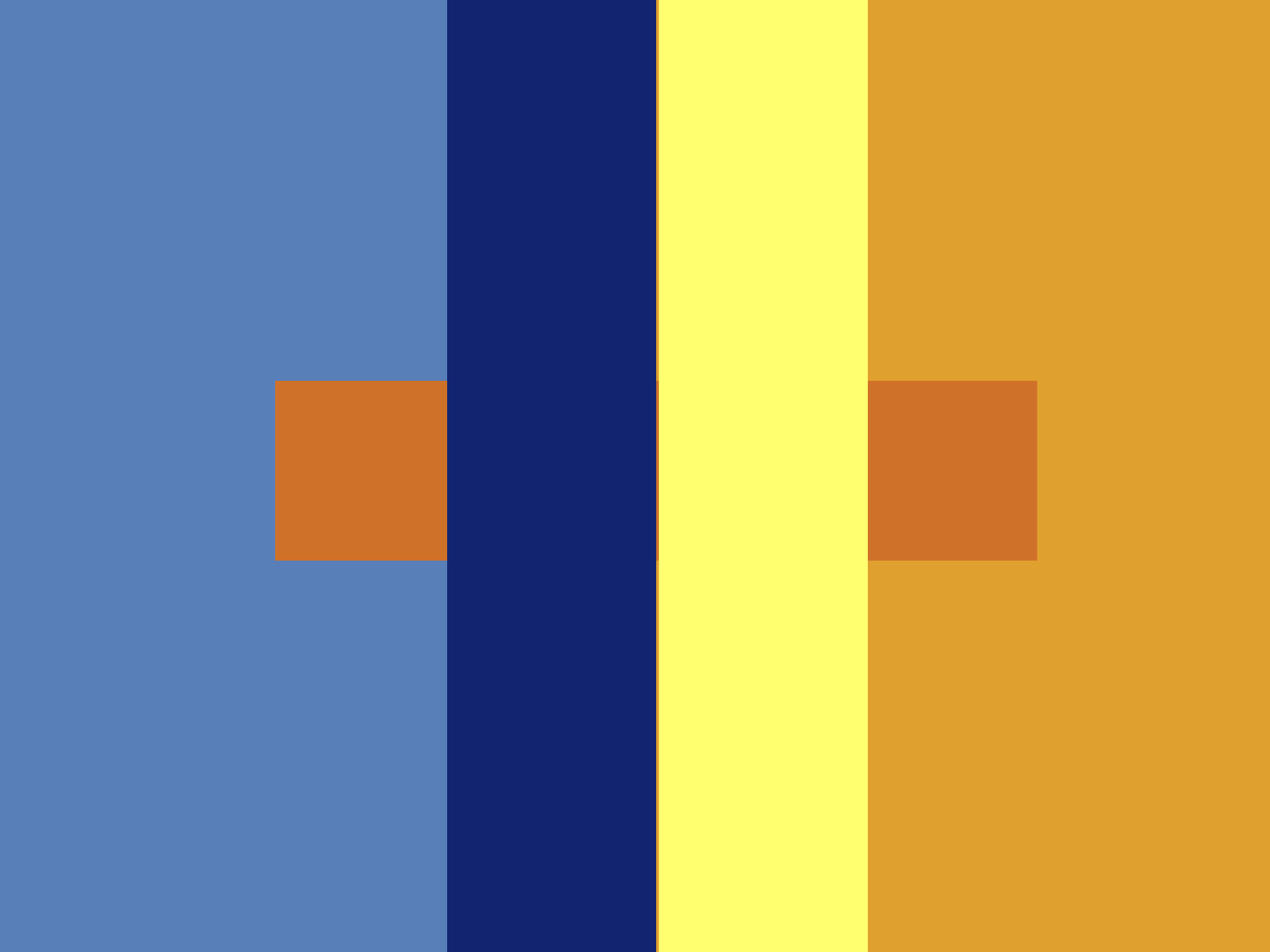
Color Context

- (here, one color appears as two)





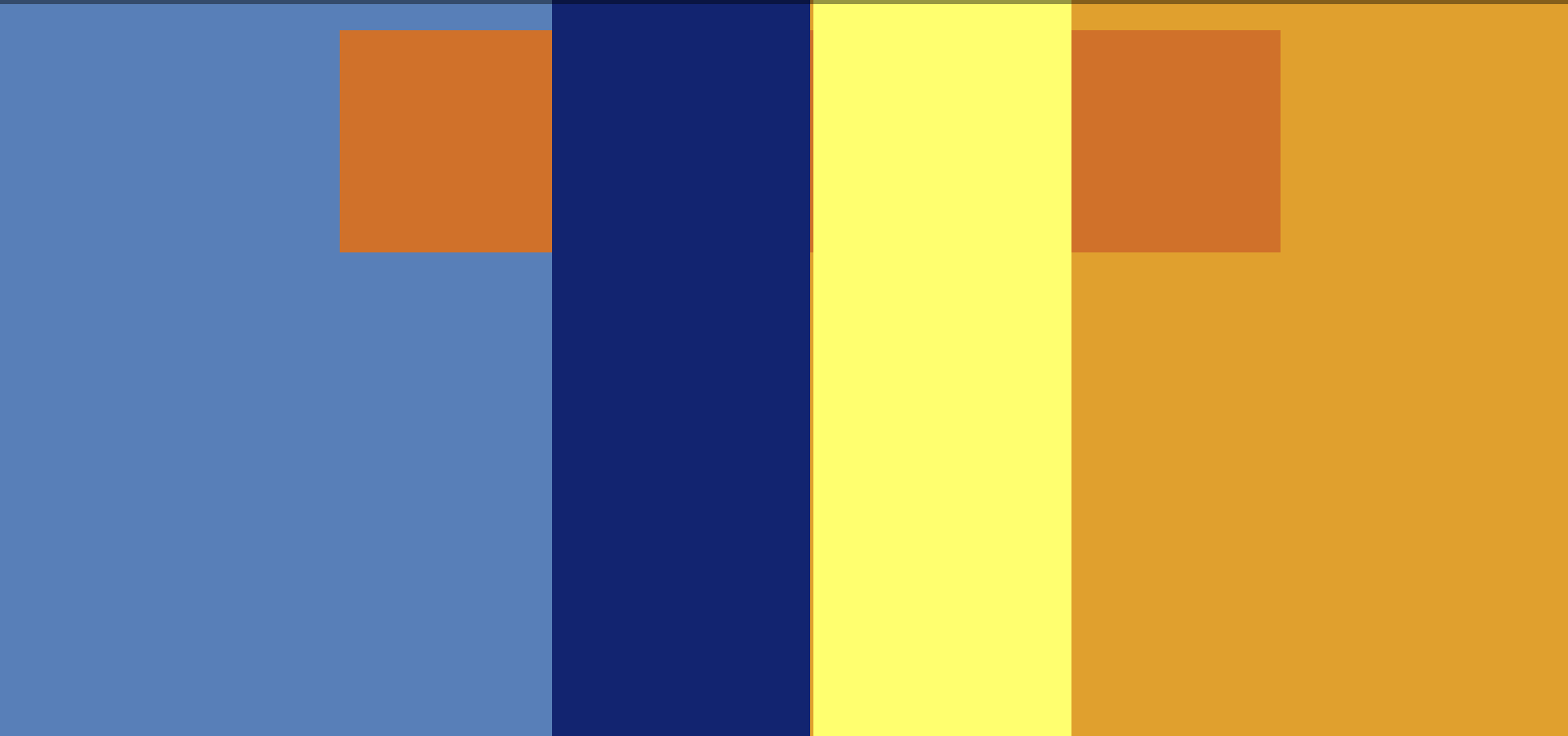




Based on Joseph Albers *Interaction of Color*

“A color has many faces, and 1 color can be made to appear as 2 different colors” Here, the left and right small squares are the same shape.

“...and no normal human eye is able to see both squares—alike.”

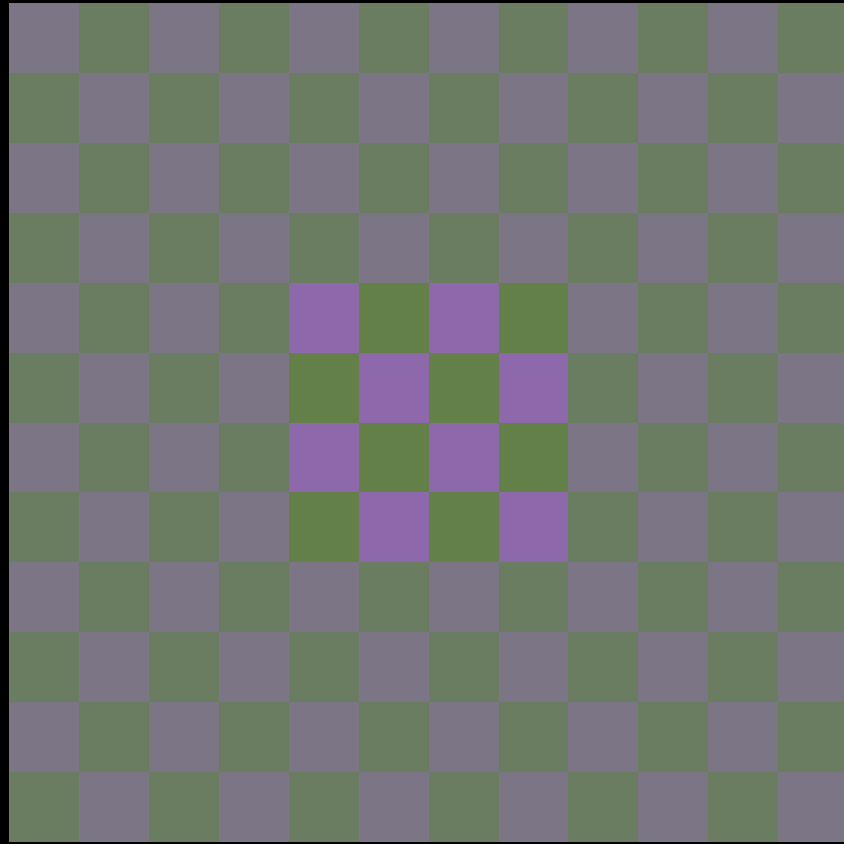
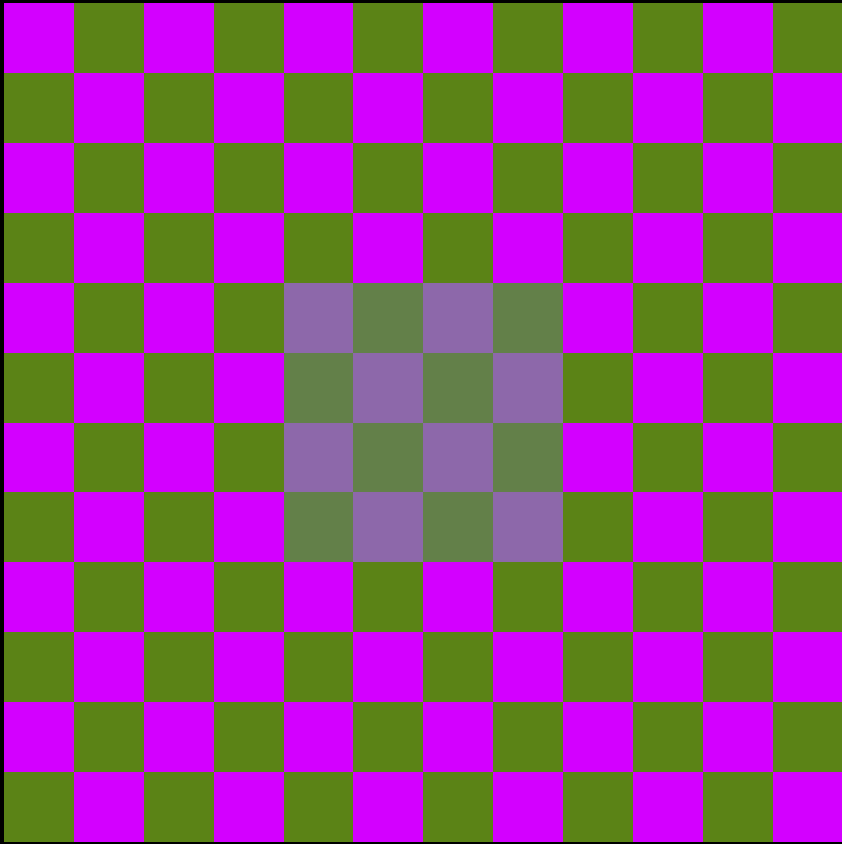


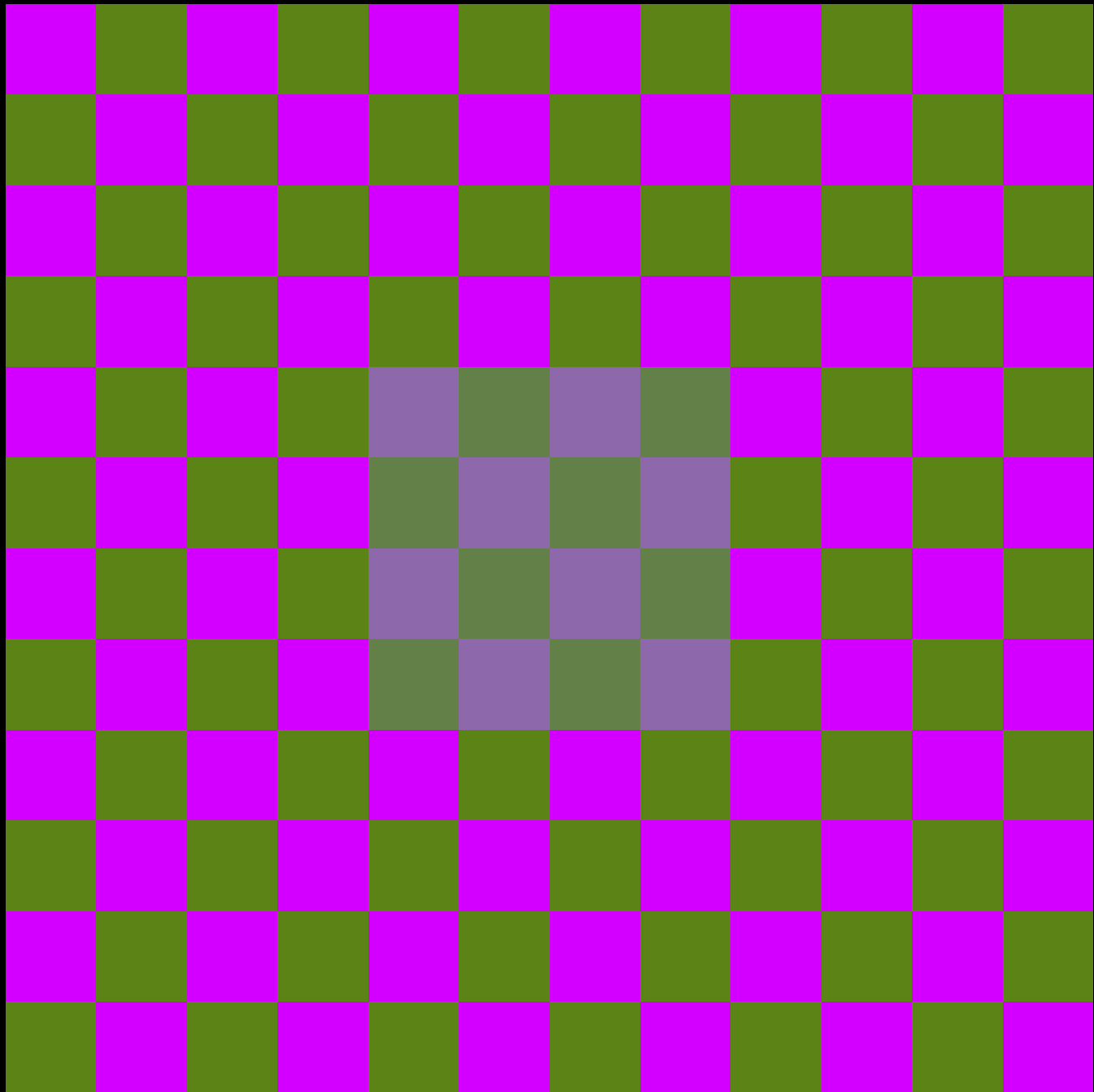
Based on Joseph Albers *Interaction of Color*

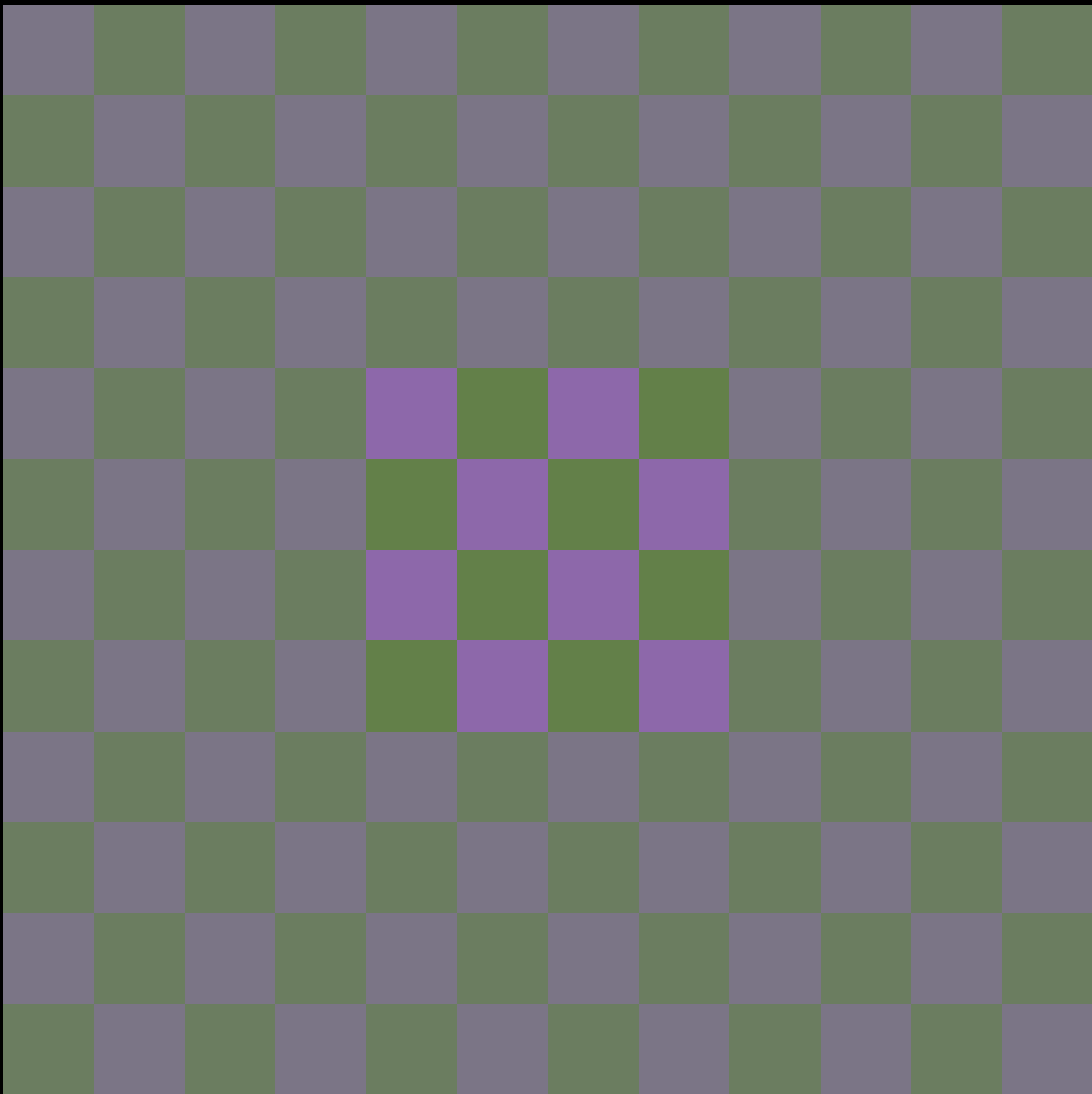
“A color has many faces, and 1 color can be made to appear as 2 different colors” Here, the left and right small squares are the same shape.

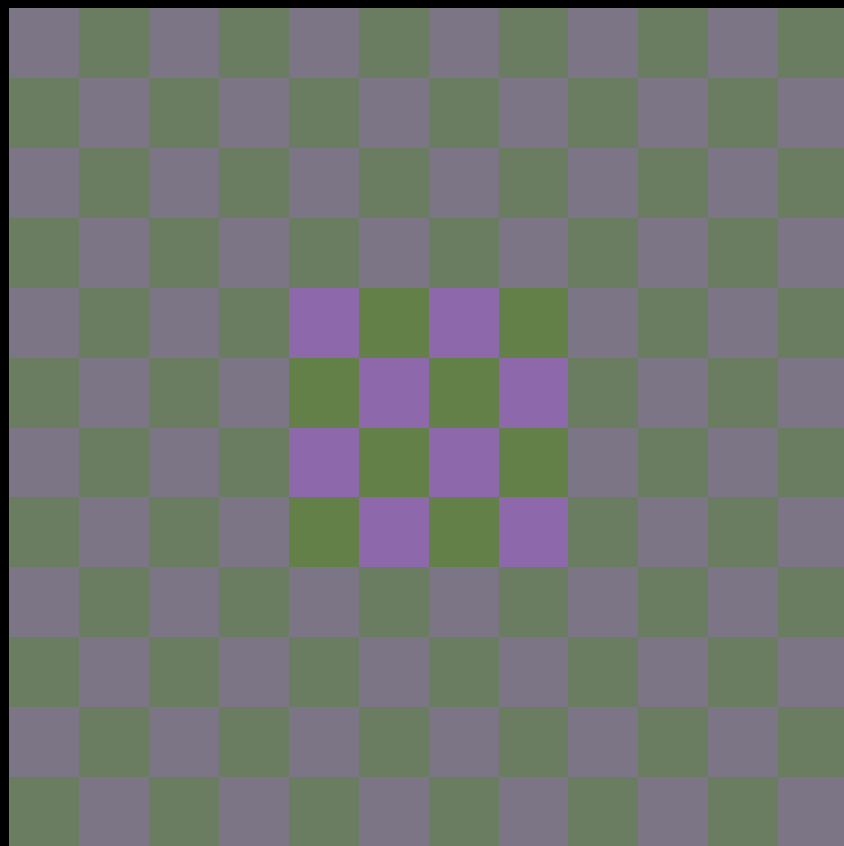
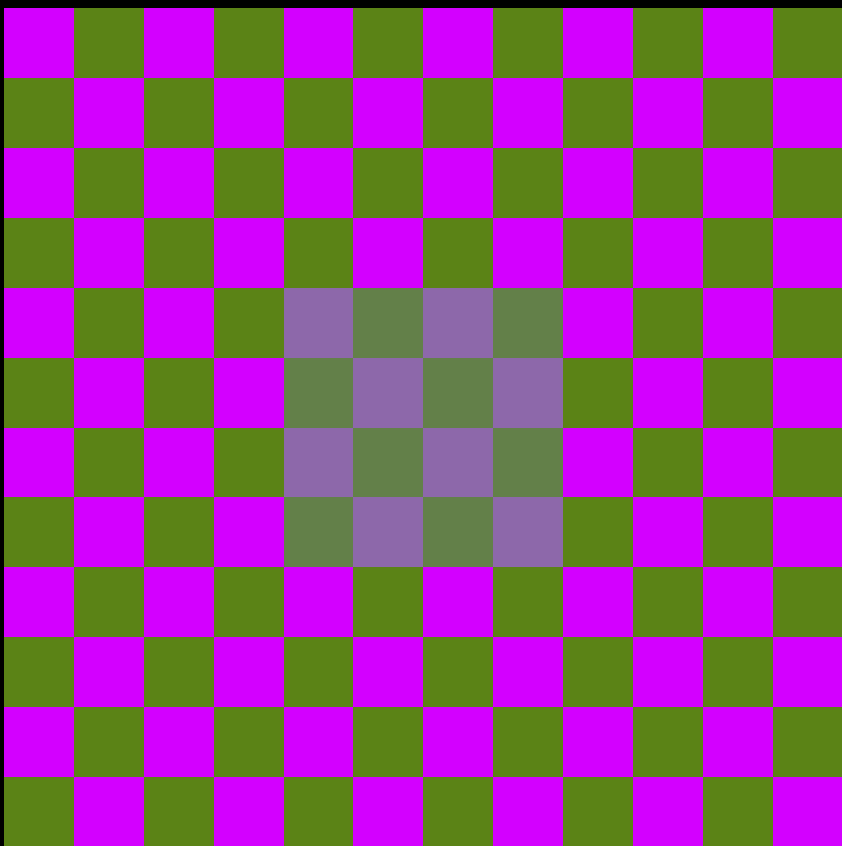
“...and no normal human eye is able to see both squares—alike.”

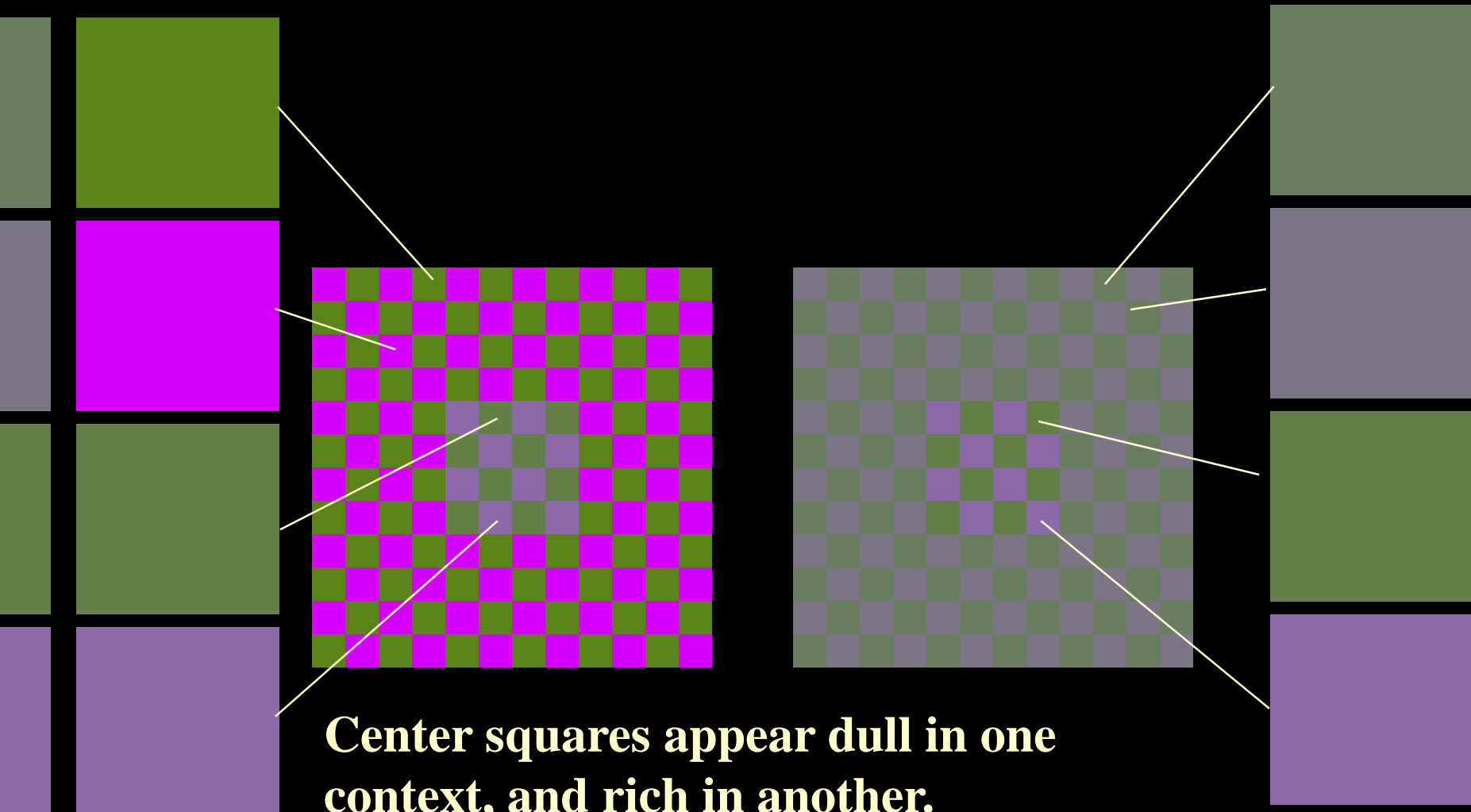










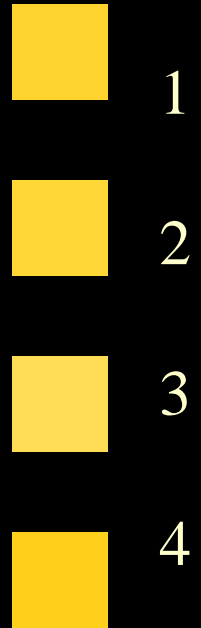
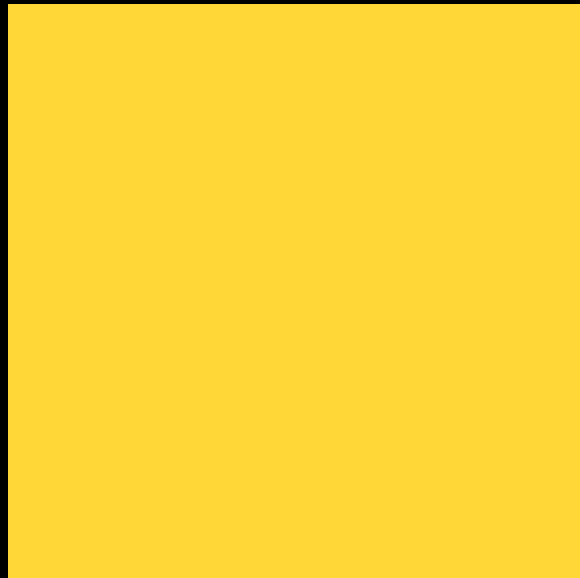


Center squares appear dull in one context, and rich in another.

Perception of Chroma is relative to context.

Color Size and Context

- There are many color perceptions that have no clear explanation, but are regularly used for effect by designers and artists.
- Large expanses of color appear brighter than small samples of the same color.



Color Size and Context

- There are many color perceptions that have no clear explanation, but are regularly used for effect by designers and artists.
- Large expanses of color appear brighter than small samples of the same color.



Color Size and Context

- There are many color perceptions that have no clear explanation, but are regularly used for effect by designers and artists.
- Large expanses of color appear brighter than small samples of the same color.



1



2



3

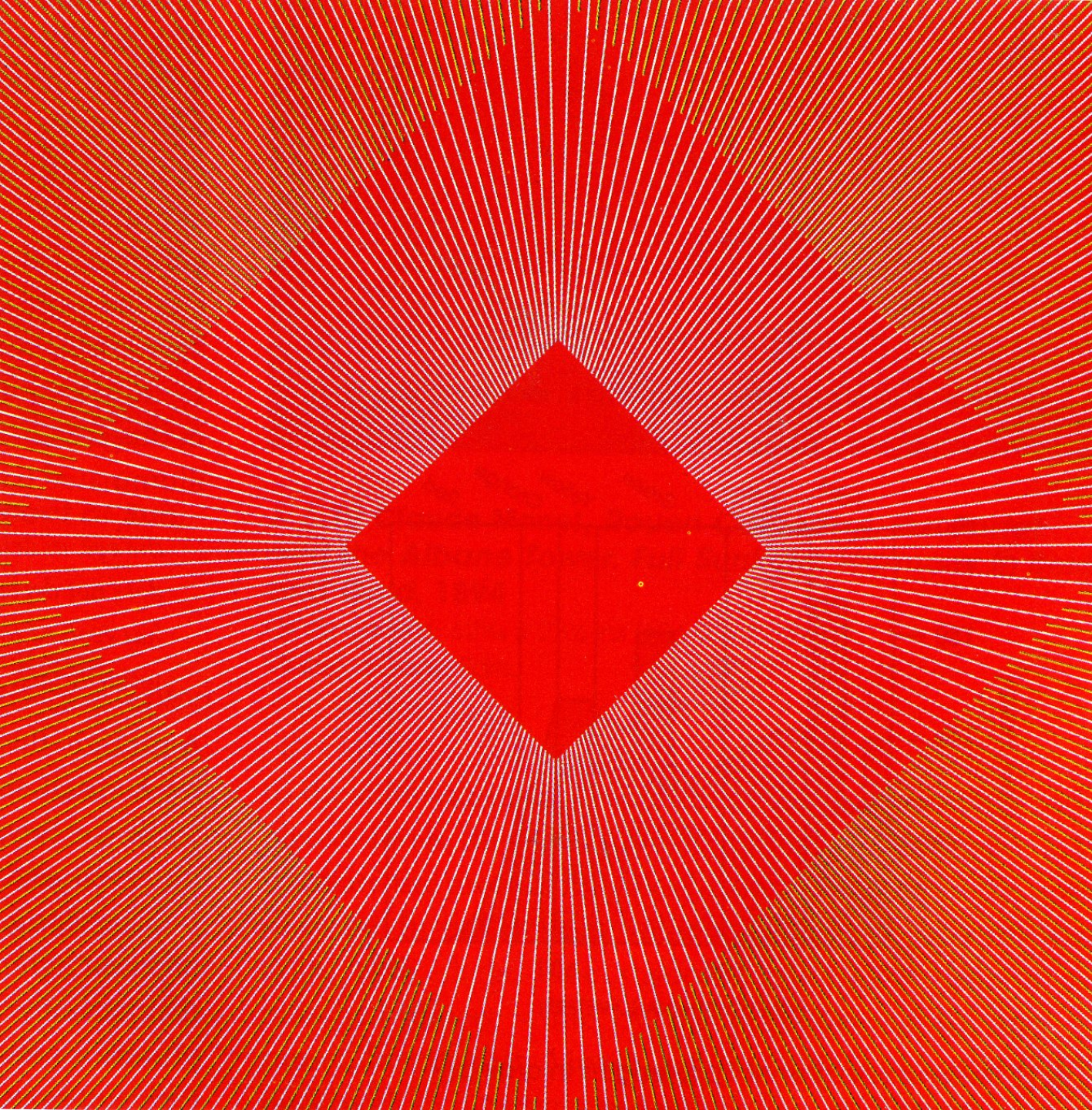


4

Color Size and Context

- There are many color perceptions that have no clear explanation, but are regularly used for effect by designers and artists.
- Large expanses of color appear brighter than small samples of the same color.





This projection of Op artist Richard Anuszkiewicz's *Splendor of Red* (1995) is only a vague approximation of the effect of fine lines of constant color (blue and green) painted on a constant field of red.

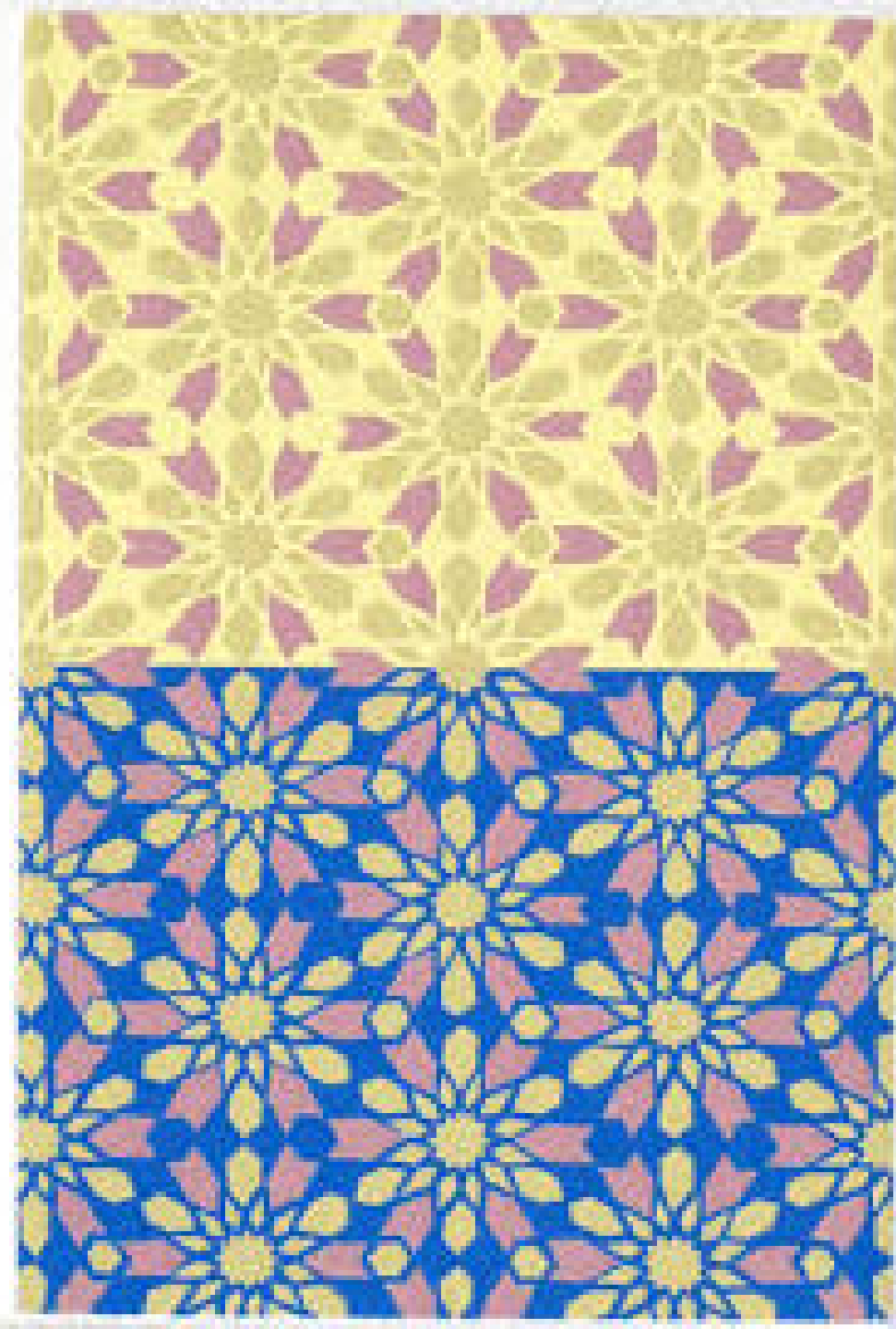
There's nothing else there but what you see. Which isn't there.

Bezold Effect

Wilhelm Von Bezold, A 19th century rug designer, discovered an OPTICAL INTERACTION effect, now called the BEZOLD EFFECT.

He noticed that he could change the entire appearance of his designs by substituting a different color from the color which occupied the most area.





Bezold Effect

Here only the background color is changed, yet the effect of the foreground color pattern changes dramatically.

Notice how the contrasts between the changed color, and specific foreground colors emphasizes new aspects of the pattern. The dark blue brings out tints, while the pale yellow allows the mid-tone pinks to build a prominent pattern.



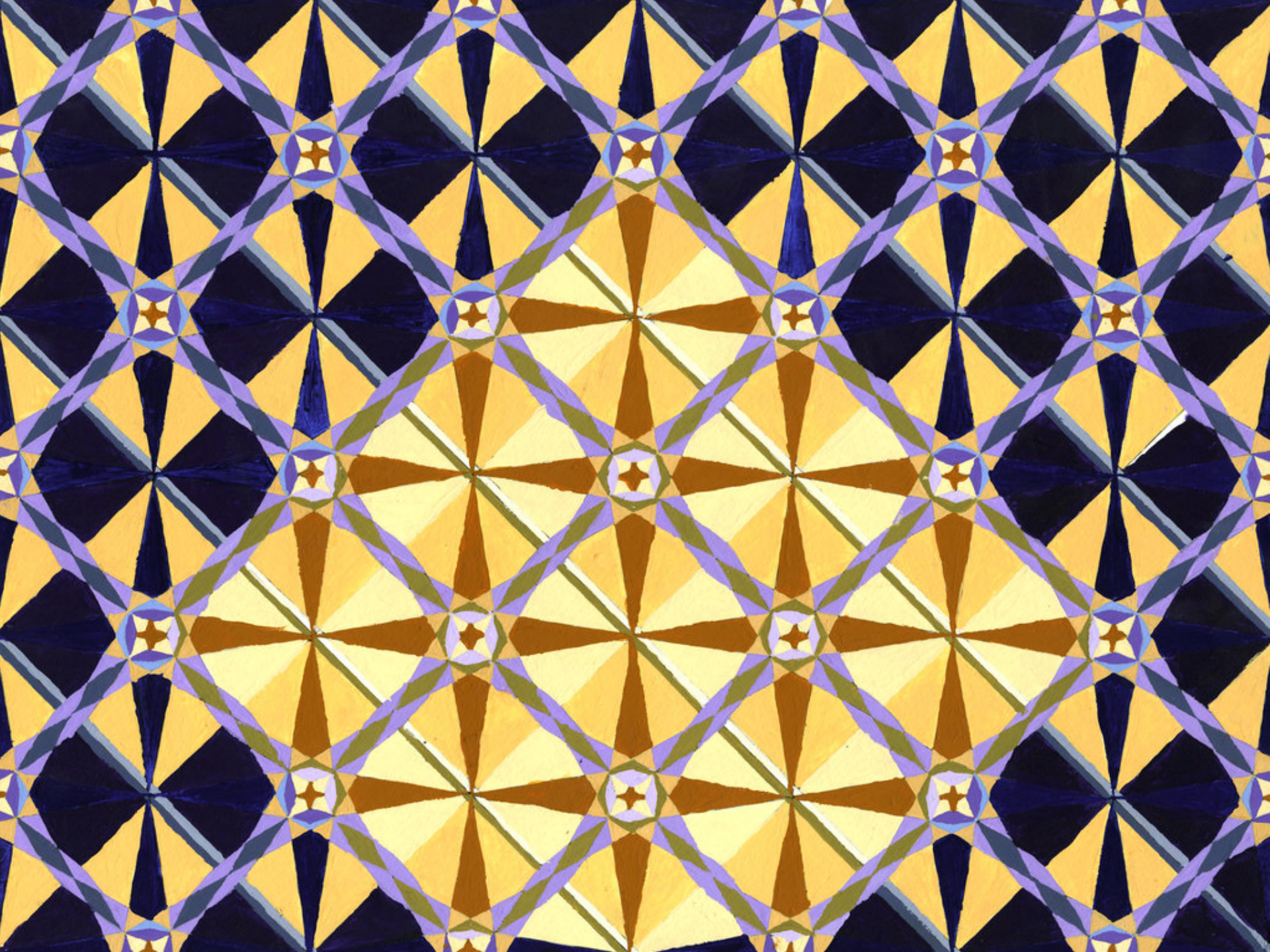
Bezold Effect

Here only the background color is changed, yet the effect of the foreground color pattern changes dramatically.

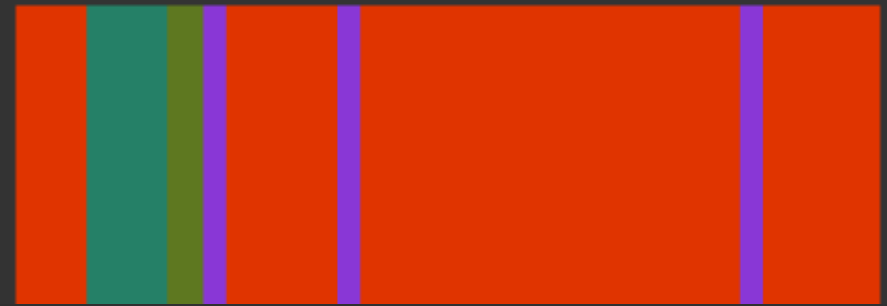
Again, the dark background allows light colors/shapes to play a bold role, While the light yellow background allows dark colors/shapes to be active.











Color Proportion Variations

Typically we think of a color scheme as a collection of colors selected for their collaborative effect.

However, a collection of colors is merely a “**Color Palette**” – a set of colors selected to work together.

A **Color Scheme** includes factors of proportion – which colors are dominant, and which are subordinate?

A scheme then, relies on the relative amounts of the colors present in a color palette.





Color Schemes varying color proportion

These simple designs each use the *same color palette* – the same colors are present in each design.

However, *the amounts of each color varies* – and so does the net *effect* of the colors present.

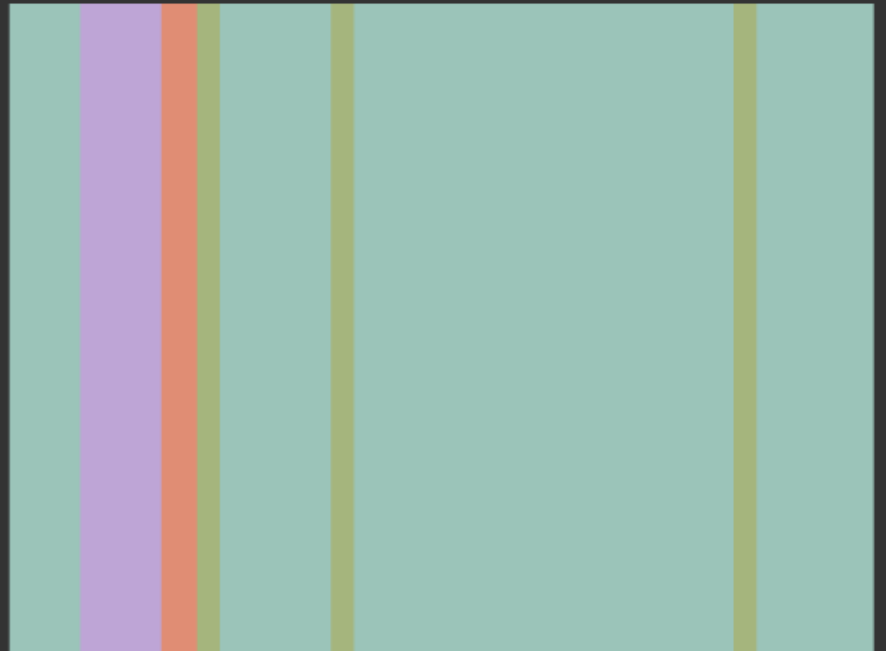
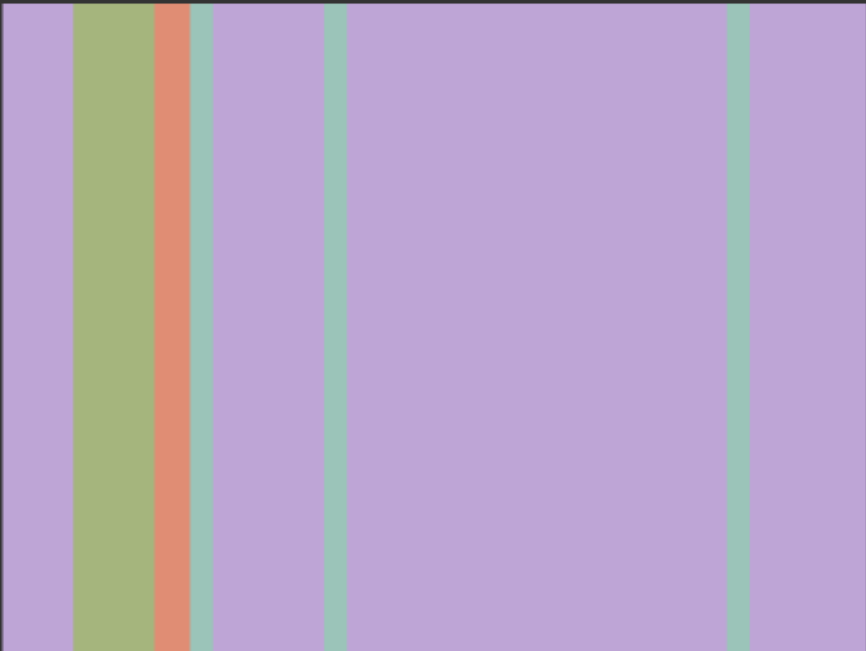
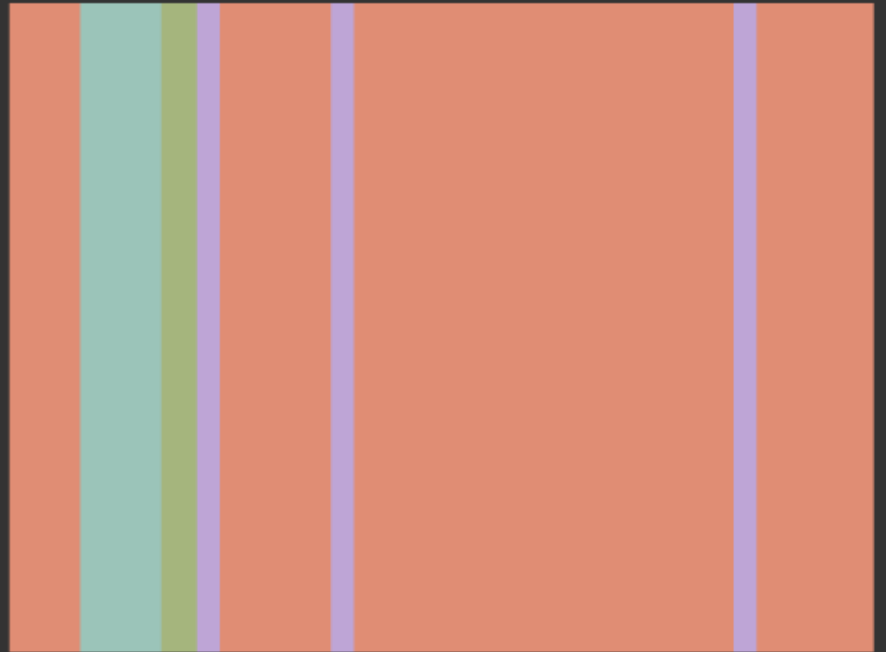
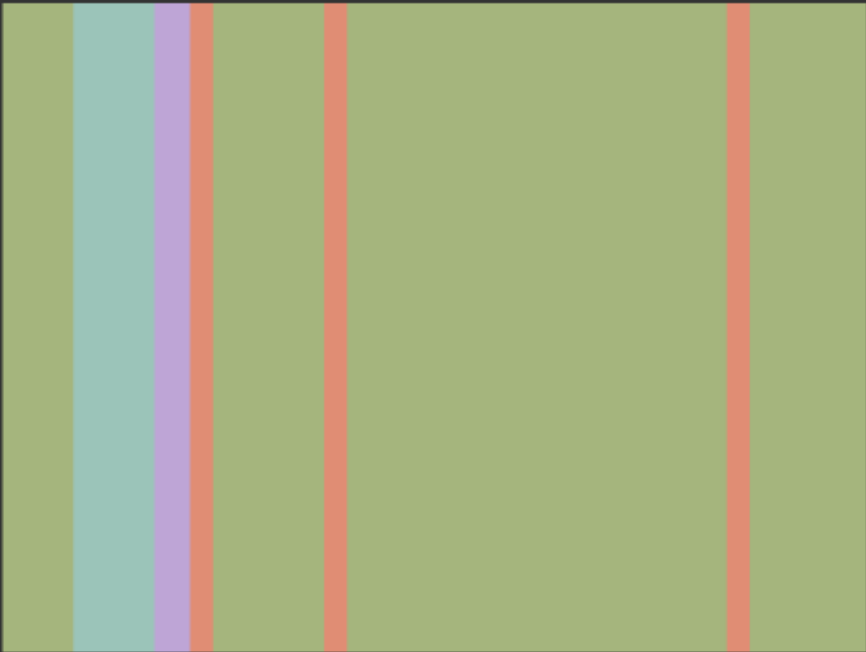
Notice how dominances and subordinates change the effect of a color design.

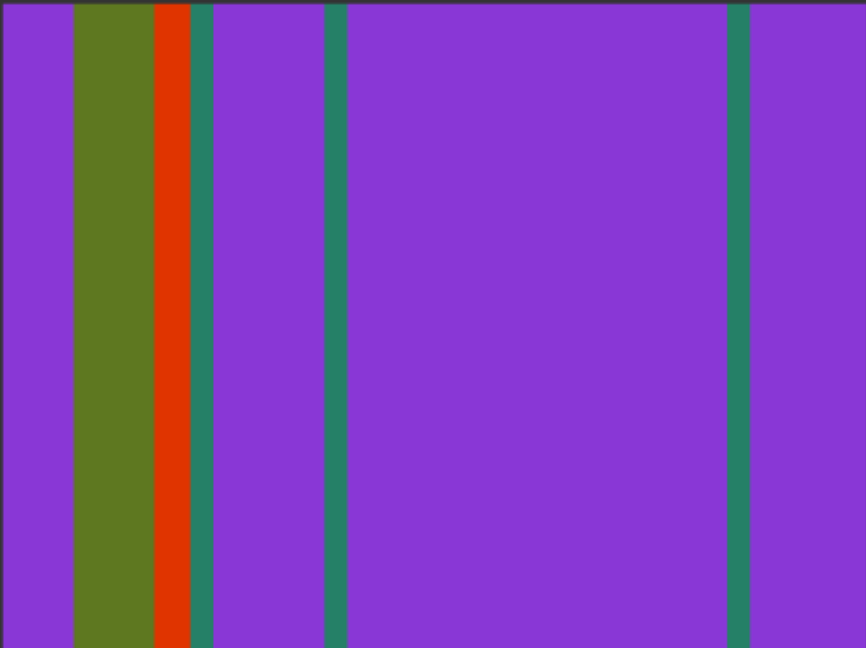
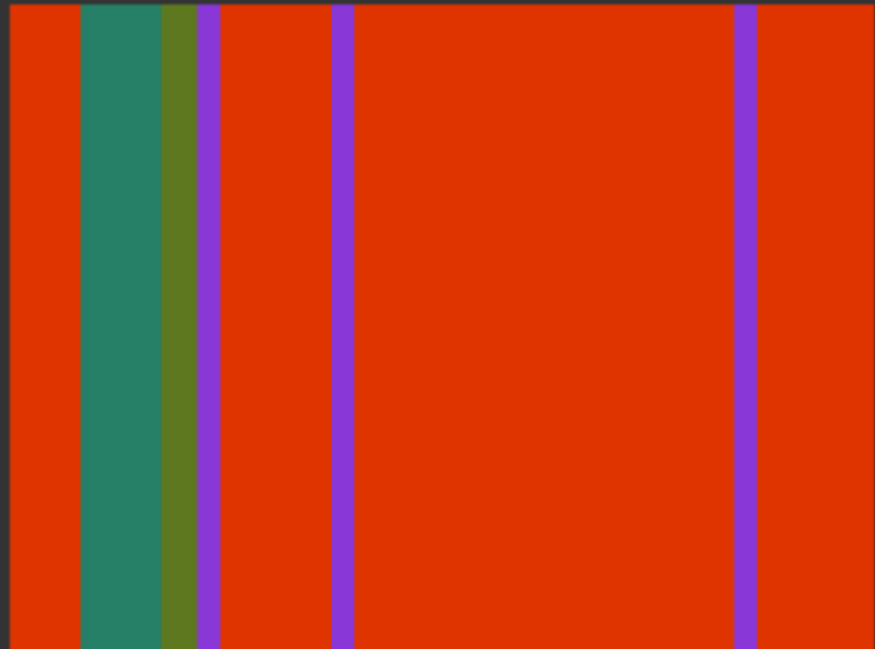


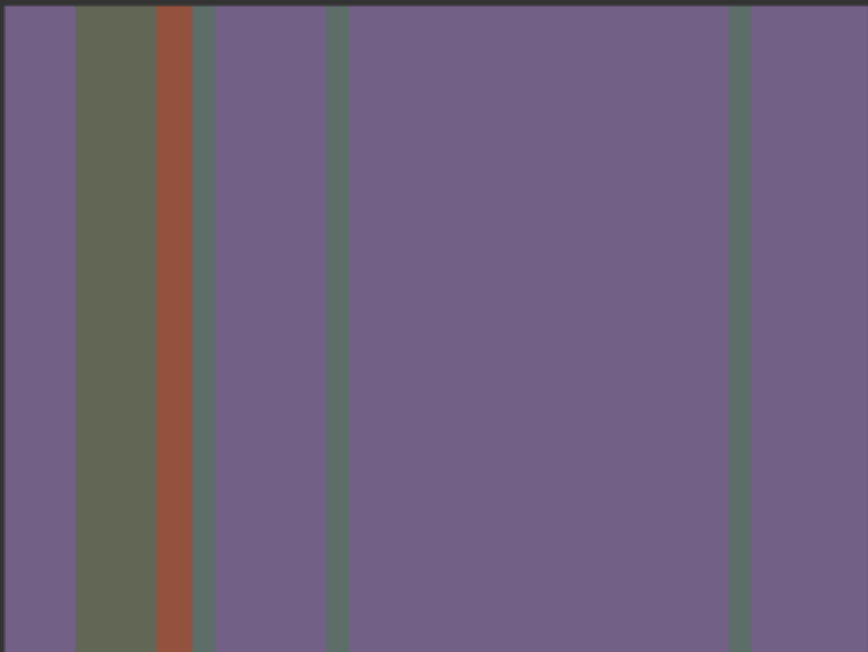
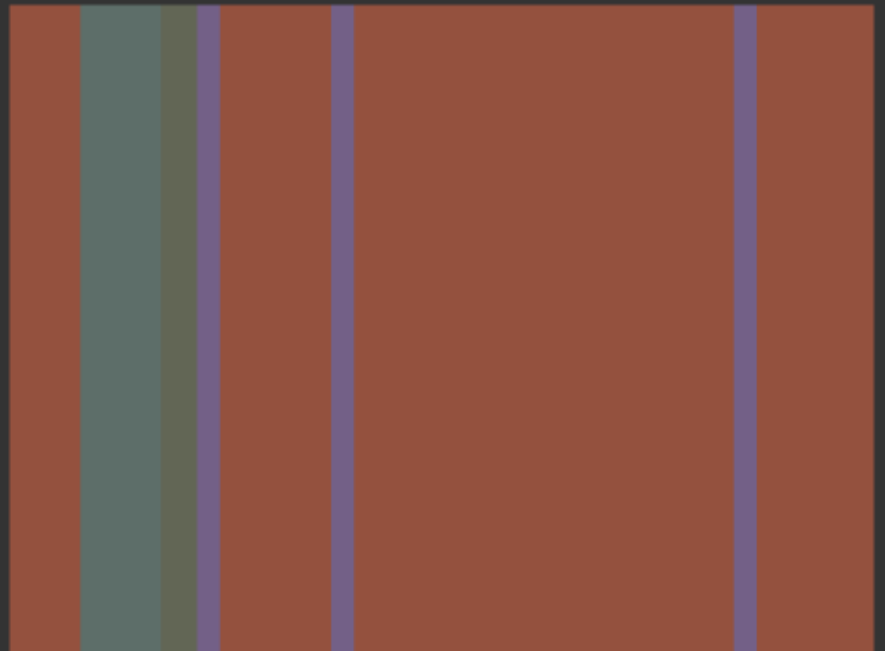
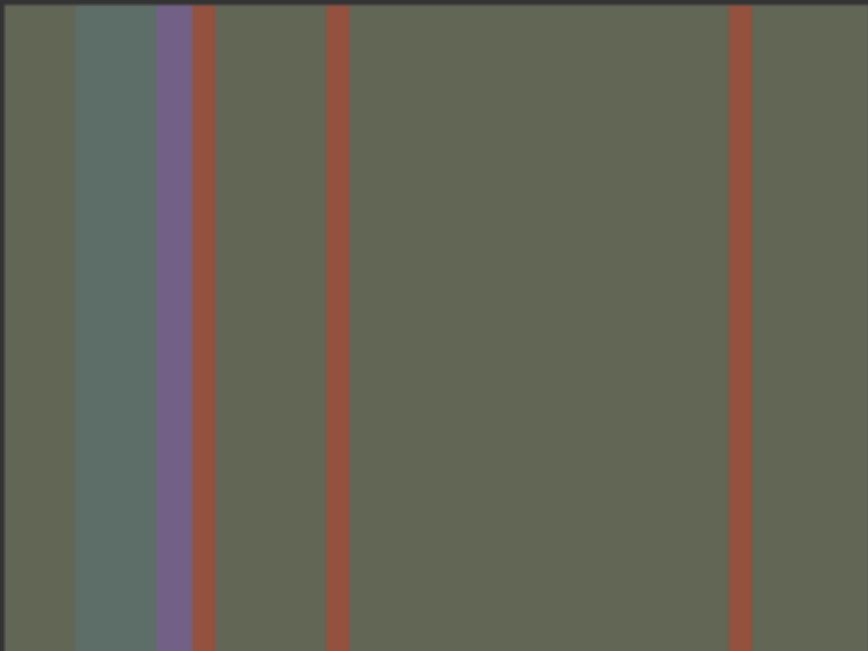


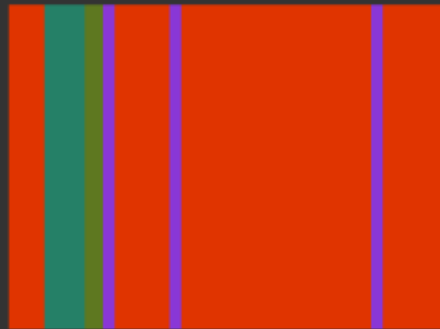
Color Schemes varying color proportion

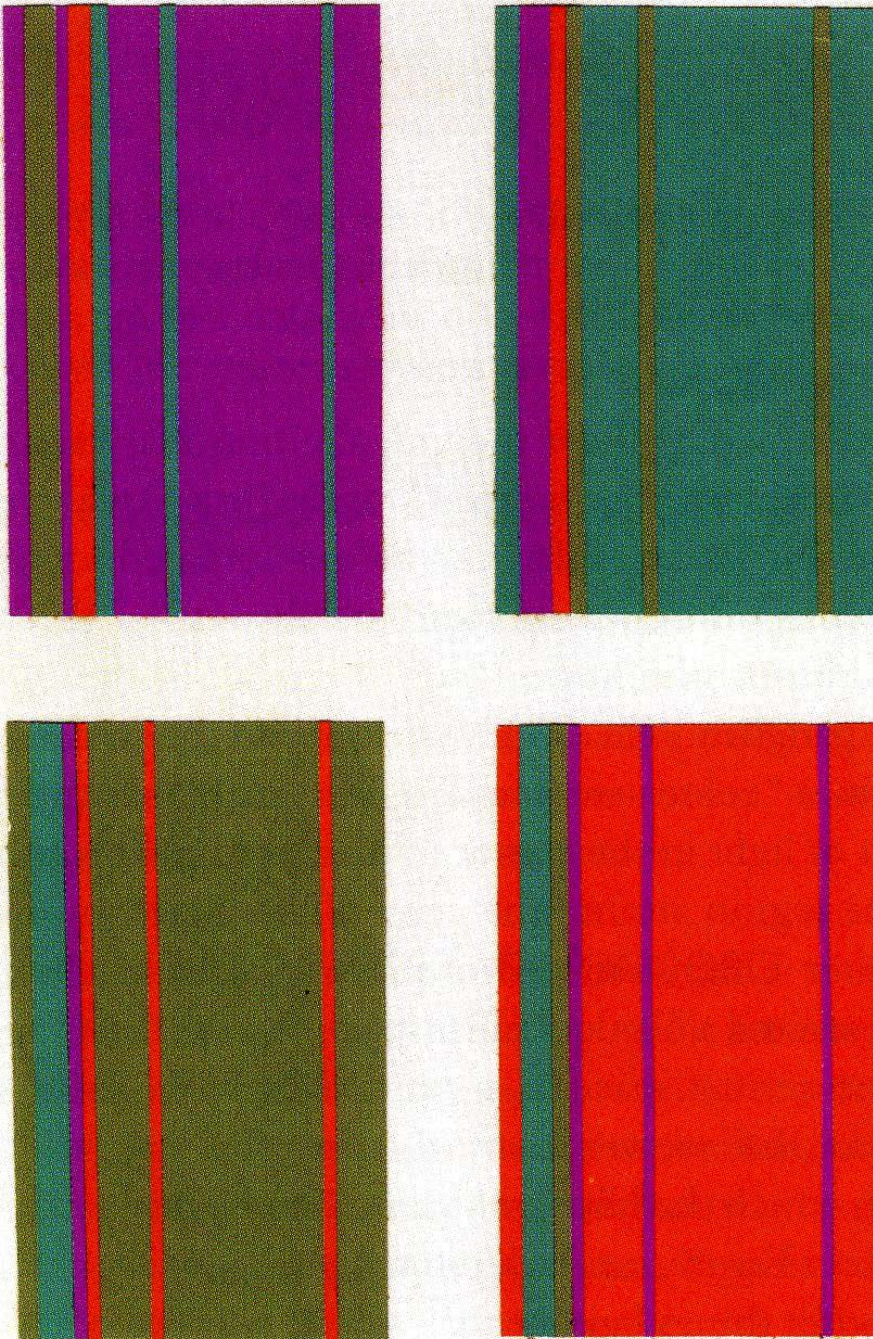
Color proportion,
not merely the
colors selected in
a palette, drives
color design.











- Varied Proportion studies of a single color palette.
- Note that as color *proportions* change, and as color *juxtapositions* change...
- The colors themselves shift.
- ..and the impact of the palette changes dramatically.

Fig. 3.11 Color/6th ed.

Color Perception - summary

- Cones in the retina sense colored light.
- Rods sense value in low light.
- Cones and rods can temporarily exhaust, enabling color after images.
- 3-hues are combined (cones — trichromatic theory) to generate information on presence of complementary hues (ganglion cells—opposition theory) and value.
- Fovea/Macula offers a small region of heightened color vision.
- Optic Nerve conveys impulses to the brain.
- Aren' t sure of much else...except it demands a lot of brainpower..

Color Perception - summary

- Color vision varies among species of animals, as it does human color-blindness and tetrachromat women.
- Color constancy provides a sort of automatic white balance for our vision, but it can be consciously overridden.
- Simultaneous contrast influences virtually all color perceptual experiences — colors look different in combination than when they are isolated. Context alters color; juxtaposition in design matters.