Additive and subtractive color

Elizabeth Ann Maclean

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ADDITIVE AND SUBTRACTIVE COLOR

BY

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Candidate for the Master of Fine Arts in the College of Fine and Applied Arts of the Rochester Institute of Technology

August 12, 1972

Advisor: Roger R. Remington
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Ronald Mix
Louis Villalon

Sound and Script
Chris Cristof
John Linn
Ronald Testa
Sandra Butler

Modeling
Rebecca Rob
Sandra Butler

Other Advice and Assistance
Dr. Richard Zakia
Frank Argento
Thomas Forrester

Media Design Center - Rochester Institute of Technology

Thesis Committee
R. Roger Remington
Frank Argento
Hans Barschel
PURPOSE OF THE THESIS:

The purpose of the thesis is to design and produce for educational use, a synchronized slide sound presentation on the subject of color.
BEGINNING THOUGHTS:

As a student in undergraduate school, I received a more than average dose of color theory. However, once I had made the decision to create and produce a synchronized slide sound presentation about color, I realized how little specific knowledge I actually had in this field. As I began research, I discovered that I wasn't alone; that most of what we know about color is recent discovery.

I found scores of books with contradictory, incomplete or erroneous theories. Only by wide reading and comparison could I begin to piece together meaningful information. The field of color is very broad and there is no one book that even begins to touch on all aspects of the subject. There are so many different viewpoints (historical, psychological, scientific, utilitarian, etc.) that the research alone could continue indefinitely.

Once I had read enough material to achieve a unified understanding of color theory, the problem was to limit the scope of the presentation to very specific goals. Since time and resources were also limited, this was especially necessary. I felt that by working from a small but basic selection of all the possible information, the show would have a concentrated, instead of scattered, effect.

Other limitations also had to be set before starting production. It was to be aimed at beginning art students 2.
and students in related fields. I felt that technical information should be accurate but brief, since the nature of the show was to be primarily an entertaining visual experience.

In the show, many complex phenomena are described in a few words. In order to better understand the meaning behind these words, the first section of this paper presents a highly condensed description of additive and subtractive color. Other sections of the thesis describe the process of bringing the presentation into its final form. The conclusion discusses other aspects of color not covered in the slide presentation.
The Electromagnetic Spectrum

<table>
<thead>
<tr>
<th>x-rays</th>
<th>visible light</th>
<th>infrared</th>
<th>gamma rays</th>
<th>ultraviolet</th>
<th>radio waves</th>
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<tbody>
<tr>
<td>.00000001mm</td>
<td>.000001mm</td>
<td>.001mm</td>
<td>.001mm</td>
<td>10mm</td>
<td>1000mm</td>
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I. COLOR: ADDITIVE AND SUBTRACTIVE

Light

All that we see of the world is a reflection of light in our eyes. Color is not something "out there in reality" but a subjective experience. The process of seeing begins with light and continues in the eye and brain.¹

When electromagnetic activity occurs, as for example in the sun, waves of energy are sent out in all directions. Although there are many varieties of energy waves (radio waves, x-rays, heat, etc.) they are all basically the same except for their wavelength. In the middle of the electromagnetic spectrum is the small section of waves that stimulate nerve endings in the eye. We call them light.

Waves of light radiate outward like ripples on a pond, effecting and being affected by everything they touch. What we see as white light is the compound of an entire range of wavelengths. Each wavelength creates a separate color which can be seen individually when white light is broken up by a prism.²

Each time a beam of white light hits an object, part of the light is absorbed and part is reflected back to us. In that instant, color becomes visible. For example, if light


hits a leaf, all the wavelengths are absorbed except the wavelength for green. Green is reflected back to our eyes and we see the leaf as green. The chemical makeup of an object determines which wavelengths it absorbs and which it reflects. Some surfaces such as mirrors and metal, reflect almost all light. Others, such as glass, let it pass through.¹

Although there are hundreds of separable wavelengths (colors) within the spectrum of light, only three can be considered as primary. The three: red, green, and blue, can be mixed and blended together to produce all other colors; each adds its wavelength to the other, which creates a new wavelength (color). When red, green, and blue are added together in equal amounts, they total up to white light.²

What we perceive as color is actually a physical sensation created in the eyes by light. Since our eyes cannot possibly comprehend the number of vibrations in a light wave (between 350 and 700 billion per second), we experience them as color.³

The back of the eye, the retina, is a light sensitive photo-receptor for the brain. It is made up of two kinds of cells: cones and rods. Rods are more numerous and are sensitive to light and darkness. The cones are sensitive

only to light of particular frequencies. On the evolutionary scale, the rods developed before the cones, which accounts for differences in vision between man and many other species.¹

The cones of the eye can be divided into three groups: the first is strongly acted upon by long waves, producing red; another set responds most powerfully to medium waves, producing green; the last set responds to short waves, producing blue. When light of the red wavelength is acting on the first set of receptors, it is also affecting the second and third to a lesser degree. Through the mixture of red, green, and blue, all the colors are experienced within us. If all three sets of nerves are stimulated to about the same extent, white is experienced.

Mixing Lights

If we understand how the three primary colors of light interact, we can create color mixtures for our own purposes. Red, blue, and green light added together in equal amounts produce white light. If the amount of each color is equal but the light itself is of a very low intensity, we experience grey, or if low enough, black. White, grey, and black can be considered as the point of equality or neutrality between the colors. When red, blue, and green lights are mixed in unequal and varying amounts, all other colors are created. The simplest but most significant mixtures are

1. Gregory, Eye and Brain, the Psychology of Seeing, pp. 34-59.
made from equal amounts of only two of the primary lights. They are:

Red and Blue light = Magenta
Red and Green light = Yellow
Green and Blue light = Cyan

Mixing Pigments — Subtractive Color

If we mix red, green, and blue lights, we create every other color plus degrees of neutrality. Yet if we mix red, green, and blue paint, we are limited to a few colors and various shades of mud. However, with yellow, magenta, and cyan pigments, we can produce all other colors including red, green, and blue. If we mix them in equal amounts, we have black instead of white. Although the systems seem contradictory, they are interrelated.

If white light falls on an apple, green and blue light are absorbed while red light is reflected. Green and blue light equal cyan. We call cyan the complement of red because it would have completed red to make white light. Instead it was subtracted, absorbed by the chemical makeup of the apple.

Cyan is the complement of red.
Magenta is the complement of green.
Yellow is the complement of blue.

The pigments: yellow, magenta, and cyan are called subtractive primaries because they have the capacity
to subtract wavelengths of light from white light. Note that we are talking about these colors as pigments, not as lights. Each absorbs its complement from white light and reflects the rest.

**Cyan paint** absorbs red light and reflects blue and green. (In the additive system, blue and green light equal cyan; thus our eyes see the paint as cyan color.)

**Magenta paint** absorbs green light and reflects red and blue. (In the additive system, red and blue light equal magenta; thus our eyes see the paint as magenta.)

**Yellow paint** absorbs blue light and reflects red and green. (In the additive system, red and green light equal yellow; thus our eyes see the paint as yellow.)

It is possible to demonstrate this phenomena with cyan, magenta, and yellow filters. Each filter will absorb some light and let the rest pass. If all three filters overlap, they will absorb all the light and we will experience black.

In the additive color system, we add lights together to make other colors and white. In the subtractive color system, we start with white light and use pigments to take color away from white so that the desired color is achieved.¹

II. OBJECTIVES

In order that I should start production with clear objectives in mind, I listed exactly what information would be covered. The slides and sound would try to demonstrate each of these points as clearly and creatively as possible.¹

1. All color is light and all light possesses color.
2. The primary colors of light are blue, green, and red. All other colors are mixed from these three.
3. Mixed in equal amounts, red, green, and blue light add up to white light.
4. If white light is reduced in intensity, we see grey. If completely subtracted, we experience blackness.
6. Yellow, cyan, and magenta are the primary pigments in the subtractive color process. These pigments absorb light. They can be mixed to produce all other colors of pigments.

<table>
<thead>
<tr>
<th>Opening sequence Music</th>
<th>Black and white kodalith slides.</th>
<th>From extreme closeups to more distant views.</th>
<th>Wide-angle landscape.</th>
<th>Color of sky appears. (Cartoon color on kodalith)</th>
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<tr>
<td>yellow</td>
<td>Figure in white leotard, wig, makeup.</td>
<td>Idea: Creative light sequence.</td>
<td>Colors mix over body.</td>
<td>Idea: T.V. is additive color.</td>
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Abstract patterns from T.V.

Ideas: Transition from light to pigment.

Closeup of paint.

Dissolve to Van Gogh's "Sunflowers".

More Van Gogh Idea: The richness of paint.

The 3 primary pigments.

Cyan, yellow, and magenta mixed.

3 filters over white light.

Idea: The mixtures of each two.

3 together absorb all light (black).

3 primary lights.

Cyan filter absorbs red light.

Yellow filter absorbs blue light.

Magenta filter absorbs blue light.

Children's drawing - 3 primary pigments.

Color mix.

Montage of colors. Different patterns.

END CREDITS ACKNOWLEDGEMENTS
III. THE STORYBOARD

The storyboard as originally conceived, was a rather literal translation of the learning objectives into visual form. The beginning ideas are described in this section. Almost all underwent a great deal of revision during production.

The Opening Sequence

I first planned to make black and white kodalith slides of nature that would follow each other in a rough animation sequence. Slides would have cartoon color added to them, gradually becoming more colorful, and building to a dissolve into a full color landscape. This effect was to establish the importance of the subject and the relationship of nature, light, and color. The entire idea was discarded as being unrelated and unnecessary to the rest of the show. The technical problems involved far outweighed the importance of the concept.

Color and Light

Color is light and all light possesses color. This concept was to be illustrated by a sequence of various light sources. It would dissolve to shots demonstrating the breakup of light into its component colors, (rainbows, prisms, etc.). I felt this would prove to be too obvious
and unexciting. A better way of stating the idea had to be found.

Additive Light Mixing

I conceived this as a simple demonstration of colored lights and how they mix. On the storyboard I drew lights crossing each other, mixing, and forming abstract patterns. I did not at that time have any idea of how this would be produced.

White on White Figure

I visualized a figure totally in white: white leotard, wig, and makeup on a white ground. Colored lights would play on the form, creating all the possibilities as they merged and blended. This section would investigate the visual potential of pure colored light and act as a break from the more explanatory sections.

Transition from Light to Pigment

This was to begin with shots of a color television... to closeups of the screen... to dots of light that make up the image... to dots of paint... to a section of a painting... to an entire painting.

In effect the slides would be acting as a movie camera, zooming in, cutting and zooming back. The actual differences between colored lights and paint would be misleading if handled in this manner. It would have to be established that color television works on the principles of additive
light. For the purposes of the show, that explanation would be a digression.

**Subtractive Color**

The demonstration of subtractive color and how it relates to additive color would be the most difficult idea to put across. Because of the complexities, I wanted to present this in a simple form that would show the principles with a minimum of confusion. A technique for the demonstration had to be developed.

**Subtractive Color Montage**

This section would have to paralleled section IV. I wanted to suggest the unlimited creative possibilities of mixing pigments. This, I thought, could be accomplished by gathering a collection of posters, paintings, and other materials which would be shot and combined into a montage.

The storyboard gave my beginning ideas a visual form but also made clear how many problems had to be solved. The greatest difficulty seemed the lack of continuity and style; there was a real danger of making each section unrelated to the others. I had no idea of how to write a script, shoot slides, synchronize sound, or accomplish any of the technical

effects necessary. The next step was a search for information and advice from specialists.
PRODUCTION OF SLIDES

Light on White

In order to regain enthusiasm for the project, I began production of the potentially most interesting section: the white on white figure. However, it presented questions. How could colored lights be arranged to mix over a white figure?

I mounted Kodak Wratten filters (red, green, and blue separation filters) in glass slide mounts. These were placed in three projectors with 3" lens for wider covering area. The projectors acted as focal point light sources that could be arranged and controlled easily.

Photographing the model in white body paint rather than a leotard seemed a more effective idea. Because of the problems of coloring the hair, she wore a white wig which contrasted with the texture of her skin and caught light in interesting ways. Plans for the background were changed from white to grey since extraneous colors might detract from the figure. This created a black background that powerfully silhouetted her body and intensified the color.

At the time of the first shooting session, I was not competent enough as a photographer to shoot the sequence without help. Ronald Mix of Montage Visual Communications,

shot most of the slides while I acted as "art director". On viewing the results, we found many strange and unexpected effects: an illusion of posterization, more color on film than had been anticipated, an intensely black background and surrealistic feeling. Although I knew more work had to be done with this sequence, the challenge began by my setting the rest of the show in line with the effects already created.

**Additive Light Sequence**

There had to be found a way of presenting the three primary colors of light to show the result of each color mixing with the other. I made three slides with a circular shape covered by a filter. Three slide projectors shot the slides onto a wall in a darkened room so that the patterns formed on the wall could be photographed. On film, the circles looked flat and disappointing; something more exciting had to be discovered.

Since this sequence was dealing with the mixture of primary light, the projectors themselves would be the light. This seemed like a better, more intrinsic use of the medium.

A filter was put in front of each projector and kodalith slides were made that masked the light into different shapes. The design for the first series of slides was a circle with interior variations. Since the three projectors were focused on one spot, they formed the image of continuous circle that
seemed to pulsate, at times dissolving into moiré patterns or three dimensional effects. The colors, forms, and registration became so complicated, however, that it was difficult to see what was happening in terms of mixing light. Also, the hard edge, mathematical style did not blend with the rest of the slides. Again one section was off on its own tangent.

This idea was discarded in favor of a warmer, less technical approach. I first applied rapid strokes of opaque solution to clear acetate using a dry brush technique. This produced interesting patterns and textures with a personal feeling. Then using kodalith film, I made contact prints from the acetate for a negative of the original brushwork. After the film was developed, I cut and mounted it into slide format. When the slides were projected with filters in front of the projectors, they created the effect of an abstract expressionist painting, animated by constantly changing color.

**Color is Light**

The opening section had to establish a relationship between color, light, and nature. I began to shoot slides of natural surfaces, such as leaves and rock, using a Micro-Nikkor lens. I wanted the form of the object to disappear, and the power of its color to dominate. For example, a slide of a tulip would appear to be a solid yellow or red with only the suggestion of a petal's edge to identify
it as a flower.

By this time I was doing all my own photography. There was no way I could communicate to another photographer, the feeling I wanted to capture on these slides. Framing was becoming very important since my own sense of composition and design was becoming a means of unifying the entire presentation. The slides were developing a "painterly" quality that could give the show its own style. For this reason I also reshot the nude sequence with the Micro-Nikkor lens. Meaningless distractions and awkward poses were eliminated. The slides became more abstract but also more related to the whole.

**Fingerpainting**

The last problem was to illustrate the relationship between additive and subtractive color. It called for a shift from one set of primary colors to another, and clear examples of how each affected the other. Also I wanted to keep the consistancy of the Micro-Nikkor lens and the painterly feeling.

I began by preparing solutions of the three primary pigments: cyan, magenta, and yellow. With a mixture of printing ink and silkscreen extender base, I produced an oil-based ink with a jelly-like consistancy. This could be used in the same manner as fingerpaint.

After spreading a quantity of ink onto wax paper, I
created a long series of tiny fingerpaintings, each an example of various pigments and their mixture. Since both the ink and the wax paper were basically transparent, they could be backlighted with a simple light box system. Light shone through the paper and ink, intensifying the color.

To demonstrate how the subtractive colors absorb light from the additive, I placed a filter between the light source and the paintings as illustrated in the diagram.

With differing techniques and consistancies, all kinds of varied effects could be created with these pigments. It seemed logical to use this method for the closing sequence, a montage of purely abstract color.

(Refer to LIGHT BOX DIAGRAM - Next Page)

The slides now broke down into four distinct but related sections: nature closeups, kodaliths, nudes, and fingerpaintings. Together they seemed all that was necessary for illustration of the beginning objectives. The original storyboard had been greatly altered; simplified in some respects while intensified in others. It seemed a better visual experience than that which I had first planned. In the process I, myself, had learned more about color and photography than the presentation could hope to show.

The final step was coordinating the visuals with syncronized sound.
V. SCRIPT AND SOUND

(Opening music)

(over music)

Announcer. It's really very simple. All that we see of the world is the affect of light on our eyes.

(pause)

All color is light. All light possesses color. You find this out when you play around a bit.

(pause)

Take 3 lights --- red, green, and blue. Call them the primary lights because that's what they are. Mixed together you get white light. Take them all away and you get black.

2nd Voice. Hey, who turned the lights off? What's going on here anyway?

(music)

Announcer. Take two lights at a time --- blue and red, you get magenta.

(pause)

Blue and green add up to cyan.

2nd Voice. Rhymes with Diane.

Announcer. And red and green lights add up to yellow.

2nd Voice. That's a surprise.

(music intensifies slightly)
(pause)

Announcer.. With the three primary lights, you can add up to every color of the rainbow. That's why it's called the Additive Color System.

Second Voice......... Far out.

Announcer.. Now let's paint something with light.

(music)

(long pause)

Second Voice......... Well, that's nice but I don't spend much time mixing lights. What about paints?

Announcer.. Red, green, and blue do fine as primary lights---but primary pigments, they're not. Surprisingly enough, the three primary pigments turn out to be cyan, magenta, and yellow. With just these three pigments we can make any other color.

Second Voice .......... But how is this different from mixing light?

Announcer.. The three primary pigments actually subtract light. When all three are mixed together, then all the light is subtracted and you know what that means.

Second Voice .......... The lights go off again.

20.
Announcer. Let's look at what's happening more carefully.
Cyan absorbs red light --- Yellow absorbs blue light --- and Magenta absorbs green light. So altogether they have subtracted all the light. And that's the difference between Additive and Subtractive Color.

Second Voice ....... Now let's paint!
Play it again, Sam.
(music up and out)
Exploded View of Light Box Photography System
Since I had no idea of how to write a script that would tie all the objectives and visuals together, I sought the advice of Chris Cristof, a freelance copywriter with television experience. She produced a rough draft using the idea of two voices that would discuss color: one a straight soft-toned announcer and the other, a rather flip character. After revision and simplication, the preceding script resulted.

I began taping male voices but soon realized that the tone was too heavy and dogmatic to be compatible with the sensuous quality of the slides. A woman's voice, softer in intonation, was substituted for the narrator's part while a male voice was kept for the second character. Guitar music of varying tempos seemed to have the tonal quality most in character with the slides.
VI. BREAKDOWN OF PRODUCTION COSTS

<table>
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<td><strong>TOTAL COST</strong></td>
<td><strong>$180.16</strong></td>
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</table>
VII. CONCLUSION

The purpose of the slide show is to demonstrate the most basic mixtures of additive and subtractive colors; it does not begin to touch upon color's subjective effects. Equal portions of cyan and magenta may produce blue, but the effect of blue is a phenomenon, not as easily measured. (If a female mouse is bred in a box with a transparent blue window, she will deliver a greater proportion of female babies; if the window is red, the greater proportion will be male.)¹

That color has a definite biological and psychological effect on living things is a theory scientists are only beginning to investigate. It effects the growth of plants, the sex life of birds and the general activity level of many mammals. Even insects and reptiles have color preferences. If we remember that man has evolved and endured under the balanced power of sunlight, it is easy to understand that each wavelength (color) fulfills a need in the system of living organisms. We must understand also, that color is a subjective experience with all the variety and emotional power that subjectivity implies.

The Uses of Color

Mixing color is easy; deciding how, where, and why to

use it is not. The choice of combinations is so unlimited that the colorist may find himself immobilized with indecision. From the experience of working on this thesis, I have come to the following conclusions on the use of color:

1. Of all the elements of visual language, color has the most potential for expressive power. (Studies prove we recognize color before form, shape or line.)

2. There are no rules or guidelines for the use of color; no good or bad color relationships. (We are fortunate that artists since the time of Van Gogh have broken every set idea of "acceptable" color schemes.) In making his choices, the colorist need only consider his purpose and the affect he wants to create in the viewer.

3. Artists usually provide more insight into the use of color than scientists. (Such artists as Albers and Vasarely have devised ways of manipulating the optic nerves. Others use color as a means of communicating a state of being, thereby giving us a visible manifestation of their psyches. The most original and unexpected color relationships can result from this process.)

4. The variables within even one color are unlimited. Besides factors of hue, value, and chroma\(^1\) we must consider qualities such as transparency, opacity, lustre, texture, and sparkle. (Black fur is totally different than black enamel although the value and chroma may be the same. The success of a color relationship usually depends on the small differences.)

5. Through the study and use of color, it is possible to develop greater sensitivity towards the endless variety of the visible world.

---

1. **Hue:** the direction of a color away from white. **Value:** the amount of black or white in a color. **Chroma:** the intensity or brilliance of a color.
VIII. BIBLIOGRAPHY

Books


**Pamphlets and Articles**
