

Color Space and Its Divisions

*Color Space and
Its Divisions*

*Color Order from
Antiquity to the Present*

Rolf G. Kuehni

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*To the memory of Dorothy Nickerson and David L. MacAdam, and to
Andreas Brockes for their encouragement to continue the pursuit of color
order and color difference*

*All that is alive tends toward color, individuality, specificity, effectiveness,
and opacity; all that is done with life inclines toward knowledge, abstraction,
generality, transfiguration, and transparency.*

Johann Wolfgang von Goethe

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Preface

Our color experiences are an important component of our visual experiences and as such form a significant aspect of our consciousness. Color experiences are the outcome of processing by the brain of information acquired as a result of interaction of light energy with the three types of retinal cone cells in the eyes. The three cone types filter the spectral complexity of our surroundings and from the three kinds of signals the brain constructs complex experiences that allow us to interact with our surroundings in a purposeful way. Luminance contours are important input for the generation of these experiences but much of the original complexity of the information arriving at the eye is in terms of spectral signatures translated by the brain into colors. It has been estimated that we can distinguish between color experiences that number in the millions.

Given the human predilection for ordering experiences and given the large number of different possible color experiences, it is not surprising that the question of how to bring order to this multiplicity is one that humans thought about since antiquity. Confusion created by the seemingly different result of mixing colored lights and colored materials has complicated the search for answers considerably. Only in the later eighteenth century have color experiences begun to be sorted into three-dimensional arrangements, and three attributes of color experiences have only been defined unambiguously in mid-nineteenth century. Ordering color into a uniform color space means the creation of a geometrical model that is considered to be isomorphic (one-to-one correspondence) with experiences. It is evident that this cannot be a simple effort. Alternately, it can mean ordering color stimuli in a regular way so that the most general psychological ordering principles are observed.

This text presents a history of the significant steps in development of thinking about color order in the Western world from ancient Greece to the present. Not surprisingly, given the complexity of the matter and the fact that it involves a sense, several fundamental questions continue to be unanswered. Among other things this has to do, despite hundreds of years of concentrated effort by many individuals, with the absence of a scientifically satisfactory experimental database of how humans perceive colors and color differences. The text is limited to issues of color space as viewed against a simple achromatic surround. It does not address issues of color appearance under widely varying surround conditions.

Every space is divisible and a given color space is inextricably linked with the definition of the divisions used. A dividing line is drawn between uniform color spaces where distances in all directions are isomorphic to perceived differences of equal magnitude and general color spaces that are ordered according to some other principles. The plural is used because it has become evident that there is no single uniform color space but each such space is related to a quite highly specific set of viewing and general experimental conditions. Uniform color spaces are of particular interest for color quality control purposes in industries manufacturing colorants or colored goods. A considerable variety of general regular spaces are in use, for example, in the graphics industry and in computer display technology.

Regular arrangements of colors fit into euclidean space and can have many different simple geometrical forms, depending on the definition of distance. It is not evident that a uniform color space can have euclidean form (there are no obvious reasons why it should).

The book begins with a general introduction to the subject in Chapter 1. Following the historical account of color order systems in Chapter 2, fundamentals of psychophysics, the branch of science concerned with the relationship between stimuli and experiences, are presented in Chapter 3. Chapter 4 describes the results of perceptual scaling of colors according to attributes. In Chapter 5 these scales are related to scales based on psychophysical modification of physical measurements (reflectance or spectral power distribution measurements). The history until the present of the development of mathematical color space and difference formulas is described in Chapter 6. Three of the color order systems presented in Chapter 2 have been selected for more detailed description of their development, their psychophysical structure, and the problems associated with them in Chapter 7. Chapter 8 contains an analysis of the agreements and discrepancies in psychophysical data describing color at levels of difference ranging from color matching error to large. Chapter 9, finally, draws conclusions and offers an experimental plan for the kind of reliable, replicated perceptual data needed to make progress in this field.

Aside from offering the first extended historical account of this fascinating field, the book contains new analytical results of perceptual and psychophysical color data and a synthesis of data developed for different purposes and

under different circumstances. I believe it to be not only of interest to experts and educators in industry and academe but also to neuroscientists and philosophers grappling with problems of awareness and consciousness, to designers, graphic artists, art historians, students of vision, psychology, design, and, last but not least, the general reader with interest in the subject matter.

This book represents the culmination of some forty years of interest in the subject. During these years I had many discussions with fellow devotees in industry, academe, the Inter-Society Color Council, and other organizations that helped shape my knowledge and views. I am grateful to all that helped me to see the issues clearer.

The text was read and commented on in its entirety by Dale Purves. Individual chapters have been read by Larry Hardin and Andreas Schwarz. I am grateful to all three, but any remaining errors are my own.

A note about certain conventions: An author's name with an associated year relates to a complete reference at the back of the book. Comments in angled parentheses are by the author, except in Chapter 2 where they usually contain Greek and Latin color names.