R.W.G. Hunt

THE REPRODUCTION OF COLOUR

Sixth Edition

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The Reproduction of Colour

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The Reproduction of Colour

When the rainbow appears in the clouds,
I will see it and remember the everlasting
covenant between Me and all living
beings on earth.

Genesis 9:16

Wiley–IS&T Series in Imaging Science and Technology

Series Editor:
Michael A. Kriss
Formerly of the Eastman Kodak Research Laboratories and the University of Rochester

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Reproduction of Colour (6th Edition)
R. W. G. Hunt

Colour Appearance Models (2nd Edition)
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Series Preface

John Wiley & Sons, Ltd is proud to present the first book of the new **Wiley-IS&T Series in Imaging Science and Technology: *The Reproduction of Colour* by Robert Hunt**. As Series Editor I am delighted to have the sixth edition of this classic text on colour and colour reproduction in the fields of photography, colour television, classical graphic arts, colour digital hardcopy and the rapidly growing field of digital photography as the first offering of a series that will span the technology spectrum, from conventional photographic imaging to the ever-expanding realm of digital electronic imaging.

I would like to take an editor's prerogative in making this introduction personal. When I joined the Eastman Kodak Research Laboratories in 1969, one of the first books I read was ***The Reproduction of Colour*** by Dr. R. W. G. Hunt. Prior to reading this classic text, my understanding of colour and colour vision was limited to an undergraduate physic's exposition of how the human visual system recorded colour. Dr. Hunt's book provided for me the basic foundation of the complexities of colour reproduction and how colour was reproduced in the then dominant colour image reproduction industries: Photography, Graphic Arts and Colour Television. This exposure to colour reproduction laid the foundation for all my future understanding of colour vision and research and development on colour imaging systems. I remember particularly one very cold winter day in 1969 when Bob Hunt, then at the Harrow, Kodak Research Laboratories, visited the Rochester, NY Kodak Research Laboratories to demonstrate a new analog method to improve the image quality of prints made from Kodachrome and Ecktachrome slides by creating an electronic version of un-sharp masks. This method employed a CRT scanner and printer to implement the un-sharp masking technique. This astonishing result directed my attention to understanding better how image quality depended on image structure and how to simulate and emulate such imaging systems using a digital computer. In short, Dr. Hunt's demonstration shaped the next 34 years of my scientific and academic career. Just as Bob Hunt's pioneering work shaped my career in 1969, his sixth edition of ***The Reproduction of Colour*** will greatly impact the careers of all those scientists, engineers and developers who learn from it. As a closing vignette on how Bob Hunt, his texts and courses on colour reproduction, still impact "real" colour problems consider the following. In June 2004 a small company using a digital CCD based video camera for surveillance system contacted me. The CCD camera used a cyan-magenta-yellow colour filter array, CFA, (much like the popular Bayer CFA but with the subtractive counterparts to red, green and blue filters). They were getting very poor colour reproduction. Using the basic tools I learned from Bob Hunt's classic text, I was quickly able to direct them to a solution and suggested that they send their young engineers to the upcoming 12th Color Imaging Conference where Bob Hunt will be giving a two-day short course on ***Basic Colour Science & Imaging***. Each year a new generation of electrical engineers, like those in the small company mentioned above, graduate from the university with little understanding of colour. For over four decades Bob Hunt has educated these young engineers, directly or indirectly, on colour, how it appears and how good colour reproduction is achieved. The sixth edition of ***The Reproduction of Colour*** will extend Bob Hunt's impact for several more decades as it educates future generations of engineers and scientists.

Future contributions to the ***Wiley-IS&T Series in Imaging Science and Technology*** will endeavor to provide concise, detailed, practical and current expositions on imaging in all its

many facets. The scope will range from texts suitable for undergraduate and graduate programs in imaging science and technology to in-depth studies of modern imaging systems like digital cameras, digital graphics arts systems, digital motion picture systems, medical imaging systems, forensic imaging systems, digital hardcopy and colour display devices. Conventional photographic systems and hybrid systems (film and digital image processing) will also be explored in future publications. Human society is an image-oriented culture and civilization. It is the goal of the ***Wiley-IS&T Series in Imaging Science and Technology*** to both codify what is known about imaging and lay the foundations for future research, discoveries and uses of advanced imaging systems.

MICHAEL A. KRISS
Formerly of the Eastman Kodak Research Laboratories
and the University of Rochester

Preface to the Sixth Edition

The reproduction of pictorial colour in the twenty-first century is involving many new and fascinating technologies. In particular, the increasing use of digital signals for transmitting data is having repercussions not only in television, but also in photography and printing. But the enormous number of bits required in pictures presents a severe challenge; the way that this challenge has been met by ingenious regimes of data compression is a most intriguing story. With bit rates at manageable levels, electronic cameras giving adequate resolution are practicable, and, when combined with the newer printing methods, such as electrophotography and ink jet, colour pictures of high quality can be made on quite inexpensive equipment, resulting in the success of desktop publishing.

However, although many new technologies have been developed, every system of colour reproduction depends on the fundamentals of human colour perception; and, although these fundamentals do not change, our understanding of them continues to grow as new research uncovers some of their previous mysteries.

An up-to-date treatment of the subject of colour reproduction therefore requires descriptions of both new technologies and new understandings of colour perception. This sixth edition, of what has become a standard work in the field, seeks to accomplish this dual purpose. New parts have been introduced to meet these particular requirements, and the whole work has been brought up to date as required. New pictorial reproductions have been included to illustrate many of the effects described in the text, and these help in the very important task of ensuring that theory and practice are properly linked together.

The increasing use of new technologies, however, has not prevented major importance still attaching to photography based on silver-halide, television depending on analogue signals, and printing by lithography; full descriptions of these technologies are therefore retained in this edition.

The object of the book is to describe the fundamental principles of colour reproduction, whether by photography, television, printing, or electronic imaging, so that those engaged in producing, selling, buying, improving, or just using colour images will be able to understand the nature of the phenomena that they encounter. Part One of the book lays the foundations that are common to all applications, and the next three Parts describe particular implementations: Part Two in photography, Part Three in television, and Part Four in printing; Part Five is on Digital Imaging, and Part Six on Evaluating Colour Appearance.

The subject of colour reproduction has quite a long history. As early as 1810, Seebeck and others knew that if a spectrum were allowed to fall on moist silver-chloride paper many of its colours would be recorded, although not with any degree of permanence. In 1835 Professor Robert Hunt published the third edition of his *Photography*, which contained a whole chapter 'on the possibility of producing colours in their natural colours'; and he described seeing a number of 'Heliochromes' which were, he wrote, 'perfectly coloured; . . . . but the colours soon faded'. By 1890, Gabriel Lippmann, of Paris, had not only perfected the technique of 'fixing'

these colours (by the same methods as are used in black-and-white photography) but had also much improved the process in other ways, and Lippmann colour photographs of very high quality were produced.

Seebeck and Lippmann, however, were not the forerunners of colour reproduction as we know it today. That honour belongs to the British physicist James Clerk Maxwell; for it was he who, in his famous Friday Evening Discourse at the Royal Institution in London on May 17th 1861, demonstrated for the first time *trichromatic* colour reproduction. By reducing the number of variables to *three*, Maxwell laid foundations upon which practically all modern reproduction rests. It was, therefore, a great honour for me when I was asked in 1981 to give a Friday Evening Discourse on colour reproduction in the very same lecture theatre at the Royal Institution that Maxwell had used over a century before.

In a field that is developing as rapidly as colour reproduction, it is salutary to remember that human colour vision apparently remains remarkably constant over the centuries. For William Benson (in his *Principles of the Science of Colour*, published by Chapman & Hall in 1868) translates Aristotle, in his *Meteorologica*, 3, 2, in the following words: 'The colours of the rainbow are those that, almost alone, printers cannot make. For they compound some colours; but scarlet, green, and violet are not produced by mixture, and these are the colours of the rainbow.' Colour reproduction in the fourth century before Christ apparently suffered from the same basic limitations as it does today!

The reproduction of colour is a fascinating subject; its understanding requires many different branches of science; artistic and aesthetic considerations are also part of its character; it involves a wide variety of industrial enterprises; it presents complexities to challenge the most astute; yet its climax is an event of the utmost commonplace: looking at pictures.

ACKNOWLEDGEMENTS

The reproduction of colour is such a wide ranging subject, covering so many disciplines of learning, and applications in industry, that no one person could give an adequate account without help from many quarters. My own indebtedness extends to a wide circle of colleagues and friends, and I am particularly grateful to the following for their assistance.

It was the late Professor W.D. Wright, who introduced me to the fascinating subject of colour science; his painstaking experimental work, his thorough grasp of the fundamentals, and above all his enthusiasm for the subject, have all been a source of real inspiration.

Then my thirty-six years in the Kodak Research Laboratories was a period of continual learning. The prominence of Kodak materials and processes in the photographic sections springs naturally from the fact that the information available to me concerning other manufacturers' products was much more limited; there is no intention to minimise in any way the contributions made by the rest of the photographic industry to the development and execution of colour photography as we know it today. Amongst my Kodak colleagues who were a great help, I am fortunate to be able to include, Ed J. Breneman, Ed J. Georgianni, Colin W. Hughes, Michael R. Pointer, Felix Pollak, and Daan M. Zwick, and, amongst those who sadly are no longer with us, C.J. (Jim) Bartleson, E. Roy Davies, David L. MacAdam, Ralph M. Evans, W.T. (Bunny) Hanson, Anthony Marriage, E.W.H. Selwyn, D.A. Spencer, and John A.C. Yule.

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Permission to reproduce Fig. 8.9 was given by the Physical Society, Fig. 19.5 by the Bell Telephone Laboratories, Fig. 29.1 by the Optical Society of America, and Fig. 33.9 by the Society for Information Display.

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