CHALMERS UNIVERSITY OF TECHNOLOGY
SCHOOL OF ARCHITECTURE

November 1984

Dear contributer to

**THE FORSIUS SYMPOSIUM
ON COLOUR ORDER SYSTEMS
AND ENVIRONMENTAL COLOUR DESIGN,
the AIC Midterm Meeting at Kungälv, Sweden
1983**

At last, more than a year after closing of the Forsius Symposium, we are ready with the editing and printing of the second part of the documentation of the Symposium.

Part one called Colour Report F26 contained all papers given as preprints at the Symposium, none of which were read but all of them acted as valuable and inspiring backgrounds to the intense discussions during the different Sessions.

In this second part, Colour Report F28, you will find the Invited Lectures, the Moderators Reports and Glimpses from the discussions as much as we have succeded to interpret the various sounds on the recording tapes. All written comments sent in are also included together with the more official speaches.

During the edition of this report we have learnt a lot, found new angles of approaches and got inspiration for new research. We would be lucky if some will get the same experience when reading this documentation of so much clarifying and confusing discussions. At least it seems obvious that a lot of missunderstandings in communication between different categories of scientists and appliers are of semantic nature, the words we use mean different things for different persons.

With this report we thank you for taking an active part in the Forsius Symposium and hope you enjoyed it as much as we did.

Sincerely yours

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Färgrapport

Colour Report F28

THE FORSIUS SYMPOSIUM on COLOUR ORDER SYSTEMS AND ENVIRONMENTAL COLOUR DESIGN

Invited lectures, Glimpses from discussions and Moderators Reports

Edited by Anders Hård and Lars Sivik

CONTENT:

AIC

Association Internationale de la Couleur
International Colour Association
Internationale Vereinigung für die Farbe

MIDTERM MEETING 1983

Färginstitutet

SKANDINAVISKA FÄRGINSTITUTET AB • SCANDINAVIAN COLOUR INSTITUTE

Chalmers Tekniska Högskola
Arkitektur/Formlära
Chalmers University of Technology

THE FORSIUS SYMPOSIUM ON COLOUR ORDER SYSTEMS
AND
ENVIRONMENTAL COLOUR DESIGN

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INVITED LECTURES
DISCUSSIONS
MODERATORS' REPORTS

Editors Anders Hård & Lars Sivik

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Colour Order Systems and Environmental Colour Design,
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PREFACE

An AIC Midterm Meeting was held in August 1983. It was called the Forsius Symposium on Colour Order Systems and Environmental Colour Design and was arranged by the Swedish Colour Centre Foundation.

The name was chosen primarily because Forsius produced what was probably the first written documentation of principles for the ordering of colours. This was published in handwriting form in 1611. It appears also that he tried to indicate the use Man has of colours, a philosophy that of course was influenced by the kind of general scientific paradigm that was present in the late 16th century.

This approach was in line with the aims of the organizing committee of the Symposium in order to build a bridge between the scientists and practical users who try to clarify chemical, physical, physiological and psychological aspects of how colour perceptions are produced, and to those researchers and applicants who want to know how to use colour in all kinds of environmental design.

In order to be able to devote as much time as possible to discussions, all papers were documented in beforehand (Colour Report no 26) and circulated to all participants. The only oral presentations that were accepted were a number of invited lectures referring to certain subtopics notified in advance. The present Colour Report represents the second half of the documentation of the Forsius Symposium. It contains for each subtopic:

- the invited lectures
- glimpses of discussion
- written comments
- moderator´s report

Also included are

- the special lecture given by the Director General of the Swedish National Board of Physical Planning and Building, also Chairman of the Board of the Swedish Colour Centre Foundation,

- the welcome address by the General Secretary of the Meeting,

- the AIC President´s address and presentation of the Judd Award recipient,

- the Recipient´s lecture.

Regarding the "glimpses of discussion" we would like to make the following comments:

Each is a resumé of a two-hour both confusing and clarifying talk, transcribed from a tape-recording of extremely poor, and at times incomprehensible quality. Often it represents the reviewer's interpretation of what the speakers might have said more than a word by word account of what was actually said. (Those speakers who happened to have the best microphones and/or have the clearest pronunciation therefore will be better represented than others.) It has not been possible to check the transcription either before or afterwards with the speakers. As much of the Symposium was devoted to discussions and so many interesting aspects emerged, it is felt that it would be of some value to the readers to take part of some of the meanings and approaches that the very active partipants contributed to the Symposium. Therefore, we take the risk that some of the speakers may object to the reviewer's interpretations. The task of listening through the tapes was delegated to different persons and consequently the character of the reviews differ.

For some sessions the tapes have been lost completely and in those cases the only summaries are the moderators' reports.

Responsible for this Symposium and its documentaion have been Anders Hård, Lars Sivik, Gunnar Tonnquist, Berit Pernbeck, Åke Svedmyr, Jan Sisefsky and Åke Stenius.

The editors take full responsibility for any errors that may be found in the reports.

Finally we thank everybody who has contributed to the Symposium by attending it, by giving papers and lectures, by taking part in the discussions, and last but not least, having been good listeners.

Stockholm in August 1984

Anders Hård

OPENING AND WELCOME ADDRESS
Anders Hård

Ladies and Gentlemen! Workers in the scientific field of Colour in all its human and technological aspects, and a broad spectrum of AIC friends from the whole world, I welcome you to this AIC Midterm Meeting called the Forsium Symposium on Colour Order Systems and Environmental Colour Design. In the name of the Swedish Colour Centre Foundation and its collaborators, I especially welcome you to Sweden and to this little town of Kungälv, on the Swedish west coast.

The majority of people coming to Sweden for a meeting like this usually find themselves concentrated to the Stockholm region, but this time we wanted you to familiarize yourselves with quite another part of Sweden, the Swedish west coast with its capital, Göteborg, and one of its neighbouring towns, Kungälv. Göteborg with its unenglish spelling is sometimes called Little London reminding us of the good contact westwards and our sea connections.

When we were looking for somewhere to hold this AIC meeting, we came into contact with Nordiska Folkhögskolan, where we are now and we hope you will feel at home here during this symposium.

Some of you might be wondering why it has been called the Forsius Symposium. The reason is not only that it is four hundred and thirty three years (a prime number) since this Swedish/Finnish priest and scientist was born - but more the fact that already in 1611 he published a presentation of a three-dimensional model of what he said was the "true resemblance and order between colours" as they were seen or, what we today may call, perceived. He presented these ideas in a handwritten book called "PHYSICA" and they have much in common with today's phenomenological knowledge. An interesting fact about his idea of "true" colour order is that it is designed in opposition to a Colour Wheel previously used by, as he calls them, ancient people. In that "old colour wheel" the colours come in order: White-Yellow-Red-Brown-Black-Green-Blue-Grey and back to White.

Forsius not only had a descriptive approach to the order of colours but also aspects of what use man has of his capability to see colours, how they are related to other phases of the human mind and to man's behaviour, related, of course, to the state of knowledge at the end of the 16th century.

One of the intentions during this symposium is to focus on these latter aspects that Forsius contributed to the field of the colour senses.

With so many co-workers from different disciplines of colour science who have come together, we have tried to make this Symposium to a platform where we all have the chance and time to talk, not to but with each other, in order to get a better understanding of what and why we think the way we do. There is no doubt that there are many scientists and practitioners, especially represented within AIC and at this AIC Symposium, such as chemists, manufacturing engineers, physicists, physiologists and also psychologists, who have their main interest in all questions related to how colours are PRODUCED as material, as radiation, and as vision in man.

And so we have the other category of colour people who, unfortunately, are very under-represented within AIC, but who are most probably the dominating number within society e.g. all those who are less interested in the production problems but more in questions how colours can be USED. They are all those scientists and practitioners within art, design, architecture, psychology, sociology, not forgetting the ordinary man in the street, that is to say, all those who create and study colour design in the environment and its effect on man´s well-being and who want to know more about the importance and effect of colour in that context and how to create a better environment for man to live in. In addition, there are all those people who are interested in how the ordinary man uses colour information in order to understand the environment he lives in.

The aim of this Symposium is to get all these categories of people together for free discussions over the professional borders, in order to achieve a better understanding of the different scientific paradigms that might be relevant, and also to see what we might gain from each other´s knowlege in our particular fields.

This declaration may also explain the scientific organisation of this symposium. The Organizing Committee has formulated a number of sub-topics which are thought to be of importance for highlighting the different aspects on Colour Order Systems and their practical value, not only related to production problems but also on their usefulness in environmental colour design. We hope this will give an understanding, across the borders of different sciences, of why we have, and maybe must have, different colour order systems for different purposes and how important it is that we realize and formulate the different needs we want to cover when we design a colour order system.

Therefore, at this symposium, it is more the proposed topics that should be discussed and not so much the individual papers which are presented in the "Colour Report", mailed to all participants prior to this symposium. From the very beginning, we assumed that all the participants attending the Forsius Symposium were highly capable of reading so that the papers did not need to be presented (orally) once more but could serve as background documents and act a source of inspiration to the relevant topics.

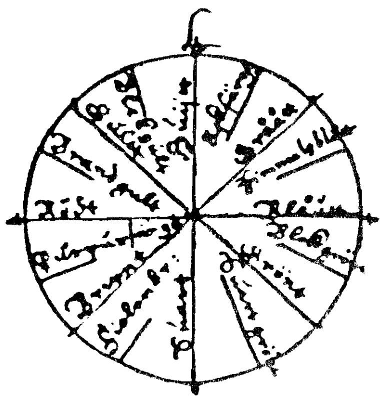
The formulation of the topics was included in both the first invitation and in the final program from which you have also found that we will go from the very philosophical one "Why colour order systems" to more and more pragmatic and practical application aspects.

For each of the sub-topics, we have asked a participant to give a main lecture in order to introduce the topic and give, as we hope, his broadminded but still very personal thoughts and views on it. We are pleased to be able to tell you that all of those we asked have accepted the challenge and all the work it involves to prepare these lectures. Thank you everybody. We are anxious to know how you have understood the topics and curious to hear your ideas. I wish to thank those of you who have accepted to act as moderators and see to it that the discussions run properly by, firstly, initiating the discussions after the main lecture, secondly, to steer the discussion in a meaningful direction and, thirdly, to supervise it so that none of us occupy all the discussion time for our own ideas, which of course is the most important - and, finally, afterwards to summerize what has been said or what the moderator thought was the meaning of what was said and eventually to draw conclusions. These summaries will hopefully, together with the main lectures, be published in a final Colour Report from this Forsium Symposium. Anyone who wants to secure a place in history for his/her speech during discussions must ensure that the symposium secretary gets a written copy for insertion in the Colour Report.

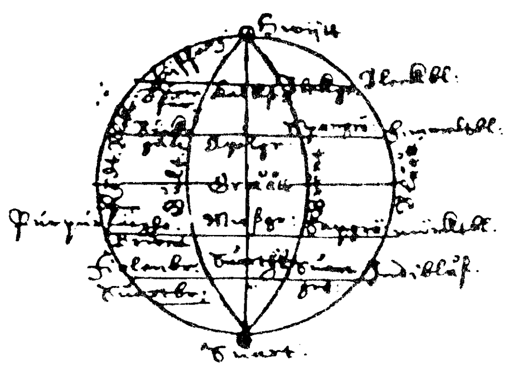
The Symposium will start here and now with the very philosophic topic Why color order systems and end on Monday with a more pragmatic approach Colour order systems and environmental color design. In addition to the written program, I can announce a lecture on Friday by the Chairman of the Board of the Swedish Colour Centre Foundation, Professor Lennart Holm, which he has called AESTETHICAL ATTITUDES TOWARDS SCIENCE. Professor Holm is Director General of the Swedish National Board of Physical Planning and Buildings.

Finally, I want to thank all of you who have come to this symposium to take an active part. In the form we have given it, I believe that you are the most essential components of the symposium because it depends on you whether the symposium is a success or a failure. And I feel absolutely confident that it will be a success, especially as we also have an agreement with the weather Gods! Deep in our hearts we hope that our formate ideas will work and that we will have lots of fruitful and friendly discussions and intellectual and social contacts. So once again,

WELCOME TO THE FORSIUM SYMPOSIUM, THE 1983 AIC MIDTERM MEETING ON COLOUR ORDER SYSTEMS AND ENVIRONMENTAL COLOUR DESIGN.



"Old colour wheel"



Forsius' colour model

AIC MIDTERM MEETING 1983 IN KUNGÄLV
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PESIDENT'S ADDRESS
R. W. G. Hunt

Thank you very much Anders Hård and thank you very much all of you on the Committee for arranging this Symposium. I am certainly delighted to be back in Sweden again and everybody looks very happy and very pleased to be here. You've certainly chosen a very lovely spot for us to meet in and so we are able to enjoy it to the full. I think that the Committee is to be congratulated on having got together a very representative cross-section of those interested in colour. There are 18 countries represented here amongst the 73 delegates and they come from as near as Norway and as far away as Australia, although I notice it is Western Australia; I think there must be some special significance in that. All right, I think that's very fine - Japan, Canada and the United States are, of course, also represented so that's a very fine result.

Now Sweden, of course, is a remarkable country. If, like me, you are interested in tennis you know immediately why it is remarkable, because it's only a Swede who has won Wimbledon five years in succession. He's given up now but never mind that was a pretty good effort wasn't it? But as far as colour is concerned, I think that for a country of this size, the record for Sweden is really very very remarkable. I think almost as remarkable as perhaps Borg at Wimbledon. First of all, we have to go back 433 years to this gentleman, Forsius, whom all of you are very familiar with I'm sure. I have never heard of him. 433 years is obviously very significant. It's not only a prime number but also it's very appropriate for colour. It starts with 4 and there are 4 basic hues. The set number is 3 and there are 3 different types of cones and the third number is 3 - there are 3 basic attributes of colour - hue, brightness and, well, the other one!

But not only Forsius - I was looking actually first this morning - I left it a bit late - at one of Addeny's (?) books. He was an English colour worker and he was writing in the period of 1890 when the railways in Gt Britain were suffering from the effects of one or two colour deficient engine drivers and he was saying that it wasn't until the Holmgren wool test was brought in as the method of testing engine drivers that this problem was really solved. So that was one of the first reliable tests for defective colour vision and Holmgren, of course, was a Swedish physicist. And then as we go on down the years other names come to mind. I made a list that I checked with Anders Hård, he added a few more. I checked this with those whom I was having dinner with and they said - no he wasn't a Swede, he wasn't a Swede, he wasn't a Swede, but I kept on going. Some of them lived here, some of them were born here and some of them were both born and lived here. But anyway, Granit, of course, was one of the pioneers in electrophysiology. He certainly worked here and his pupil Swaetichin also was still active, an outstanding worker. The psychologist Katz; Johansson who was an early advocate of the opponent theory.

And then, if we look at the record in recent years of colour meetings - international colour meetings - I think Sweden has certainly more than had its share. And what excellent meetings they have been. In 1951 there was the CIE meeting in Stockholm which I remember very vividly. It was the first time I had ever been abroad. We still had food rationing in England, believe it or not, and we came to Sweden and we could eat as much as we liked and that was quite an experience. And I remember particularly the banquet in the Golden Hall and that was an experience. I think that those of us who were there will never forget. I see one of you smiling as I mention it. Then in 1966 there was another international colour meeting organized by Anders Hård on the outskirts of Stockholm. He found again a place, a little bit like this, on an island, so we couldn´t escape there. I am referring to it as the NCS meeting because it was when the NCS system was beginning to be evolved and we had a very interesting discussion about this. Then in 1969, the AIC had its first official congress in Stockholm. Again this was a very important milestone for AIC and again the Swedes were in the forefront.

And so we come to 1983 where we have this Forsius Symposium, which is certainly a very very fine record for any country and for a country the size of Sweden. I think it is an outstanding record in colour affairs. Then if we think of some of those active in the field today - it is always dangerous to mention some, I shall leave out others but please excuse me but there are just five names that I very much want to mention, of five people who are here at the conference: Sven Hesselgren for his early work on colour attributes, Anders Hård, of course, whom I always regard as the main spring behind the NCS system, although others I know were involved, and Gunnar Tonnquist who has been active on many parts of colour. I think of him particularly in connection with the vocabulary work and we have had a very fruitful correspondence with him in time gone by. Åke Stenius, the King of Whiteness and other subjects as well, who is sitting at the back there, and Lars Sivik who has done so much on colour appearance. Well I think you will agree with me that Sweden is very outstanding really in colour work. I would like at this point to ask you to join with me in showing our appreciation for all that Sweden has done and is doing for the world of colour.

JUDD AIC REWARD TO DAVID LEWIS MACADAM
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PRESENTATION OF RECIPIENT
R. W. G. Hunt

Well, now we come to the second part of my duties this evening - very pleasant duties both of them and this second part, of course, is to present the Judd AIC Award for 1983, and as I am sure you all know it is to be given to David Lewis MacAdam. It was in 1945 that I went for my first interview at the Kodak Research Laboratories at Harrow and they were discussing what they wanted me to do. They said, well, what we want you to do is the sort of work that Dr MacAdam has been doing in Rochester, which I´m sure you are very familiar with. I tried to cover my confusion - I had never even heard of him at that point which was a great omission on my part. That was the first time I heard the name of MacAdam mentioned. I should have known about him because five years earlier in 1940, Dr MacAdam was presented at a meeting of the OSA Meeting at Rochester with the first Adolph Lomb medal. I took the trouble to turn up the citation for this medal. It was awarded, I presume still is awarded, to workers in optics who have not yet achieved the ripe old age of 30 and I read what Dr MacAdam had done by that age and I was absolutely flabbergasted - I don´t know how he did it, but anyway I thought it would be interesting just to recall some of his activities. In the citation, it reminds us that he was born in Philadelphia in 1910 and then attended schools in Upper Darby, Pennsylvania and Lehigh University, receiving the BSc degree from the latter in 1932. He then spent 4 years at the Massachusetts Institute of Technology where he received a PhD degree in 1936. He then became a member of the staff of the Physics Dept of the Research Laboratories at the Eastman-Kodak Company, Rochester, New York. By 1940 Dr MacAdam´s scientific contributions had been embodied in twenty-one published papers - 21 - at the age of 30. He had only been 4 years in the Kodak Laboratories. Amazing isn´t it? A survey of his contributions shows five studies of major importance.

(1) Dr MacAdam developed a theory of the maximum luminous factor of colour materials and, on the basis of the appropriate computation, prepared tables showing the maximum luminous factor as a function of excitation purity for twenty-four dominant wavelengths. He studied and examined the general type of spectrophotometric curve which yields a maximum value for the luminous factors for materials exhibiting a given chomaticity when illuminated with light of a specified quality, and presented a new proof of the validity and uniqueness of this type of curve.

(2) In a study of ´Photometric Relationships between Complementary Colors" he presented formulas and tables for the interconvertion of colorimetric and excitation purities, and reviewed the complementary relations between colors having maximum luminous factors.

(3) In a review of the "Photographic Aspects of the Theory of Three-Color Reproduction" he examined the significance of the concept of photographic spectral sensitivity and emphasized the desirability of emulsions having contrast independent of wavelengths. He also determined the limits within which it is possible or desirable to increase purity by an increase of contrast.

(4) In a report on "Subtractive Color Mixture and Color Reproduction" he showed how the analytical form of a simple rule for predicting the colors of mixtures of certain dyes can be incorporated into the theory of color reproduction, and derived formulas for use in printing a subtractive reproduction, and in the simultaneous introduction of partially negative spectral sensitivities.

(5) He investigated the "Noticeability of Color Difference in Daylight". He developed and carried out an extensive series of colour-match observations and examined in detail the probable errors to be expected and encountered in such color matching.

Well, that was a remarkable achievement at such an early age and then the President went on and presented Dr MacAdam with the Adolph Lomb medal. Dr MacAdam then replied in what, I think, must be the shortest speech he ever made and he said "I must not take the time that would be necessary to express adequately my appreciation of the award which you have just bestowed upon me. May I say simply that I feel greatly honored at being chosen to receive the first award of this symbol of encouragement for young men entering the field of optics. I thank you sincerely".

So, this was the young MacAdam. He´s still young at heart but it interested me greatly to see how the foundations of his later career were all laid in those early years. I suppose its perhaps usual in the experience of scientists for most of them that the proof comes later that one can see signs of so early. But I think that was quite outstanding.

Well,it was not until 1946 that I first met Dr. MacAdam. He came over to England. I was working in Professor Wright´s laboratory at South Kensington at the time. I was working on an instrument, I had made my own apparatus and in order to reduce the amount of stray light I painted it copiously with matt black paint. I promptly invited the great doctor when he came in to have a look down my apparatus. He pressed his face hard against the viewing tunnel and when he took it away he had a great black mark on his nose. That was my first meeting with Dr MacAdam. Characteristically of the man he took it in very good humour and even said that when he got back to the United States he would send me a bottle of black paint that didn´t come off on distinguished visitors´ noses! I never received the paint however.

In 1953 on my first visit to the United States, I met Dave MacAdam again and his family and I am delighted to have Muriel with us this evening. I think this would be a good time to give her a very warm welcome.

Well, at that time I had many useful and helpful discussions with Dave MacAdam and also many very happy social occasions. One picnic I particularly remember we went on was to Watkins Glen which some of you may know of. Memorable though for me, in that it seemed to me that the MacAdam family took most of the kitchen equipment on that occasion. I have a slide of it showing all this brightly coloured kitchen equipment out at the picnic site.

By this time in 1953, his work on his famous ellipses had been published, that was 1942, his work on local adaptation (1949) his extent of the ellipses to elipsoids (1949), the dye-mixture analysis using IBM punched cards and selected ordinates in 1949 and I think this is particularly worthy of mention. We are very very familiar nowadays with using computers for scientific work. Remember this is 1949 and I think must surely be one of the first applications of computers to scientific work. Certainly in the field of colour and then constant hue and brightness 1950 and 1951. These topics were continued by Dave MacAdam in his research down the years, especially of course his colour discrimination work and he played a very important part in the development of the Optical Society of America (OSA as it's usually called) Color Order System on which he published an important paper in 1974 and has been active indeed on that ever since and will be talking to us about it at this conference. But other topics were also pursued by him including his spectroradiometry and he contributed to the establishment of the CIE D65 being the most famous of course, and was co-author with Judd and Wyszecki in the 1964 paper which described that work. He was at the research laboratories at Rochester in 1936 until 1975 finishing as a senior research associate which is one of the highest ranks, almost the highest rank of a working scientist in that organisation. He was editor of the Journal of the Optical Society of America from 1964 to 1975, that's a period of 9 years and that was no formality either. As he used to have what was called the editor's page and in this editor's page were all sorts of words of wisdom, one of which is the use of the words "of" and "in" and he tells us there that we are using the word "in" too much. "variations in temperature" ought to be "variations of temperature". It can only be "in" something if it can literally be inside, so we have "variations in a color solid" but not "variations in temperature". It has to be "variations of temperature". That was 1968. By 1970, the editor's page had become the editor's last inch. I don't know whether somebody was squeezing him but it was a pretty good inch - it was two columns each about 4" long and here he talks about the over use of the word "which" and one of the authors that he was dealing with wrote back and said "well if the word 'which' is good enough for the Lords Prayer, it's good enough for me". And of course it was characteristic that he turned up an earlier version of the Lords Prayer in which the word "that" was used instead of "which". He wasn't done by that one either.

Well, he's now Professor at the Institute of Optics at the University of Rochester and he still lives in the City of Rochester. In addition to his many papers describing his original research, he has written or edited four books on colour, 1953 the Science of Color published by the Optical Society of America and Dave MacAdam played a major part in the production of that work which was written by many authors but, as I say, Dave really pulled the whole thing together. 1970 Sources of Color Science which he reviews the contribution down the years starting as early as Plato and going up to the 1940s. Back in 1979 Contributions to Color Science by D. B. Judd edited by MacAdam; very useful volume of Judd's work and in 1981 up until that year his own book of Color Measurement which has been published in Germany and is now widely sold right around the world. So it's no wonder that in Applied Optics in 1971 a gentleman called W J McConeghey, who I don't remember having met, wrote this under the title of geniuses: and some of this may be a little lost on those of you who are not familier with the opening verses of the Bible in English, King James' authorized version:

"In the beginning there was darkness and void

And God said "Let there be light, and there was light"

And God saw the light that it was good and God divided the light from the darkness

And God called the light and darkness Value

And on the sixth day God created Munsell

And these are the generations of Munsell

Munsell begat Adam and Adam begat MacAdam

And MacAdam begat Simon and Goodwin"

So Dave, if I may call you that, your research contributions to colour standardization through national and international organisations, your contributions to colour education particularly in the fields of the history and technical applications of the subject have earned you the admiration and gratitude of colleagues and associates throughout the international colour community. The Executive Committee of the Association Internationale de la Couleur is therefore pleased to honor Dr David Lewis MacAdam with the 1983 Deane B Judd-AIC Award.

RECIPIENT'S LECTURE
David L. MacAdam

"Thank you, Dr. Hunt, for your gracious words. Thanks also for your steadfast friendship during the 36 years since Dr. Wright introduced us at Imperial College, prior to the memorable 1947 Cambridge Conference on visual Problems of Colour. My gratitude to the AIC for the honor it has conferred is particularly heartfelt because the medal commemorates my dear friend, Deane Brewster Judd, and bears his likeness.

Thank you."

JUDD, HARDY: COLOR MEASUREMENT AND SYSTEMS

Our gathering, to commemorate Forsius and his thoughts about colors, reminds us of the long history of efforts to organize colors. Many artists and designers have found orderly arrangements of colors suggestive and helpful. Colors in systematic arrangements are fascinating to everyone who examines them attentively. One of the most useful and interesting features of color systems is their exhibition of equal contrasts; that is, equal differences between successive pairs in various series of colors. The evolution of color systems has been marked by increased success in making the steps perceived within each series more nearly equal, and in equating the magnitude of the steps in different series. Such series are called color scales.

To make the steps more nearly equal requires meticulous judgment about equality or inequality of pairs of perceived color differences. Such judgments are difficult, not very reproducible by even a single observer, and usually not very closely confirmed by two or more observers. Great effort is necessary to make such judgments and to obtain agreements or compromises on average or otherwise composite evaluations of magnitudes or ratios of judgments of color differences. After all that effort, the question arises: What were the colors that the judges examined? Unless the answer to that question is precise, and usable, so that the colors can be reproduced for re-examination, the results are sooner or later lost.

Three ways have been used to record the colors included in color systems. The first was by color names. The second was by color samples. The third is by color measurement.

Color names are notoriously unreliable and evanescent. Their meanings shift from time to time, and from place to place - with style, technology, and economics, as well as with language, culture, and even politics.

Thus, Newton said that there is a distinct color, which he called "indigo", in the spectrum violet and blue. This puzzles people who think that blue should be neither reddish nor greenish. No color in the spectrum between that blue and violet merits a separate name. I think that the explanation is that by "blue" Newton meant the somewhat greenish blue that is nowadays often called cyan. It is the color of a paint that, when mixed with yellow paint, produces a clear, bright green. In Newton´s time, and earlier, that was what most writers meant by blue. Even today, that is what many painters and printers mean by blue. I think that by "indigo" Newton referred to the blue that is neither greenish nor reddish. Thousands of other unrecorded and chaotic shifts of meanings and introductions and disappearances of color names render names quite unsuitable for recording colors in color systems.

Color samples, old as well as modern, change with time, especially if they are not protected from light and extremes of temperature, humidity and atmospheric pollutants. Sets of color samples prepared more than 100 years ago differ in unknown ways (often grossly) from their original appearances. Even modern colorants are unstable, to degrees that are unknown for the long future and for unpredictable conditions of storage. Color samples may also be lost: Herring grays: 1900: Cornell U. partial set 50 numbered from lightest to darkest.

Wilhelm Ostwald and Albert Munsell recognized the ephemeral characteristics of color names and color samples. They had confidence in the permanent reproducibility of physical measurements made in clearly defined ways. They were first to attempt to define in physical terms the colors they selected for their systems, and to measure them for permanent record.

But neither Ostwald nor Munsell had instruments adequate for the purpose. Ostwald said that his full colors completely reflect all wavelengths between complementary pairs and completely absorb all others, or the reverse in both respects. Materials with such properties never existed and never will. Erwin Schrödinger modelled his concept of optimal colors on Ostwald´s full colors. Siegfried Rösch used Schrödinger´s concept to determine the limits of the object-color solid. He showed those limits on a color triangle that Herbert Ives published in 1915.

Spectrophotometers adequate for measurements of color were not available at the turn of the last century when Ostwald and Munsell were active. After a König-Martens spectrophotometers was installed at the National Bureau of Standards in Washington, the Munsell Company sponsored a guest worker there - Deane B. Judd - to measure the colors of the Munsell system. His purpose was to make a permanent record of the Munsell colors and to study the uniformity of the Munsell color scales by examination of irregularities of spacing in the colorimetric representation. This was a very long and laborious task, because Judd´s spectrophotometer required a manually adjusted, visual, photometric match at each wavelength.

Colorimetric reduction of his results, by use of the color-matching data published by the Optical Society of America in 1922, required three multiplications, each of three factors, for each measurement. Dr. Judd devised methods to expedite those tasks. His methods were prototypes of data and procedures now recommended by the Commission Internationale de l´Eclairage (CIE).

When the color-matching data determined by Wright and Guild were being considered by the CIE in 1931, Dr. Judd pointed out that, because color matches were complete matches - for brightness well as chromaticity - the luminous efficiency function must be a linear combination of the color-matching functions. To economize on arithmetic and to facilitate interpretation of the results, Judd suggested that the luminous efficiency function be used as one of the color-matching functions. That feature was included in the 1931 CIE recommendations, which are still in effect.

To facilitate spectrophotometry, as soon as usable photoelectric cells became available between 1926 and 1932, Professor Hardy designed and supervised the construction of several automatic recording spectrophotometers. They drew continuous curves of reflectance (or transmittance) from 400 to 700 nm, in as little as three minutes per sample - compared to several hours of visual photometry with previous instruments. Professor Hardy also adapted a well-known, efficient method - and used it in a mechanical, digital, 3-channel integrator that was attached to his last spectrophotometer. That integrator, in 1937, was many years ahead of computers that now (by use of a different method of integration) yield complete colorimetric results at the same time that they record the spectrophotometric data. Today, those results can be obtained in a very few seconds for each sample.

At Dr. Hudd's suggestion, one of the first uses of Hardy's spectrophotometer was measurement of the Munsell colors. The data were reduced by manual application of the selected-ordinate method. To facilitate the task of reading reflectances from the curves produced by the spectrophotometer, I prepared glass plates, each of which had vertical lines that corresponded to the wavelengths of the selected ordinates for one of the CIE color-matching functions weighted by illuminant "C".

Students placed each plate in turn over each curve and manually entered the indicated reflectances into mechanical adding machines, to determine the tristimulus values.

When plotted, the chromaticity coordinates revealed many more-or-less serious irregularities of spacing of the colors. Those irregularities were confirmed by later measurements with a commercial version of Hardy's spectrophotometer by Kelly, Gibson and Nickerson at the U.S. National Bureau of Standards. The irregularities were studied by the subcommittee on Spacing the Munsell Colors, of the Committee on Colorimetry of the Optical Society of America. The conclusions of that subcommittee, published in 1943, have been used to improve the uniformity of the scales in the Munsell system.

While evaluating wavelengths for selected ordinates, for use in the Munsell project, for preparation of the <u>MIT Handbook on Colorimetry</u>, and for design of Hardy's automatic integrator, I rediscovered the principle of optimal colors. Calculation of the chomaticities of colors that had prescribed values of white-light reflectance was facilitated by tables that I prepared for calculation of wavelengths of selected ordinates.

I presented an oral report on the upper limits of white-light reflectance of object colors at a 1932 meeting of the Optical Society of America. A few minutes before I read that paper, Professor Hardy introduced me to Dr. Judd, who then gave me references to the prior publications of Ostwald, on full colors, of Schrödinger, on optimal colors, and of Rösch, on the color solid defined by optimal colors. Because my results were based on the CIE data, whereas Rösch, who published his results in 1928, could not have used the data that were adopted three years later in 1931 by the CIE, Judd encouraged me to present my paper and to publish my results. All subsequent publications of such results have been shown on the CIE basis, as I then presented them.

After that, I always sent drafts of proposed papers to Dr. Judd and revised them as he suggested. He and Professor Hardy served as the sub-committee for final review of the report of the 1932-1953 Committee on Colorimetry of the Optical Society of America. They approved, almost without changes, the sections I wrote about the Ostwald Munsell, and Ridgway color system, and also those of selected ordinates, optimal colors, and transformation of chromaticity diagrams.

From 1947 until his death in 1972, Dr. Judd was chairman of the Committee on Uniform Color Scales of the Optial Society of America, which labored long and hard to devise the most complete and uniformly graded color system. The aim was to have the maximum possible number of color scales, in each of which all steps would consists of equal color differences, and in which the steps would be the same in all scales. Although Dr. Judd admired the Munsell system and usually thought in terms of it, he recognized that neither it nor any other color system organized on a polar-coordinate plan could satisfy the committee´s requirements.

Carl Foss, a member of the committee, showed that the requirements could be satisfied only by colors located at lattice points on a face-centered cubic crystal in a euclidean color space in which all equally different pairs of colors are separated by equal distances. Dr. Judd adopted that plan. The committee obtained extensive series of pair-comparison judgments by many observers who had normal color vision. Difficult decisions were necessitated by discovery that the results indicated that color space is noneuclidean. The committee finally agreed upon the best-possible euclidean compromise. Dr. Judd specified in that space the origin of coordinates (gray of 30% reflectance), the direction of the yellow axis, and a formula for "crispening". Crispening is the effect of a background, which enhances the perceptibilities of differences between colors that are not very different from the background.

I will show, in a poster session, 30 charts that exhibit most of the colors and scales of the resulting system of uniform color scales of the Optical Society of America. Shortly before Dr. Judd died, I used a computer-controlled method to prepare photographic approximations to the colors and scales for his examination. Dr. Judd spent several hours examining those scales and charts, which were similar to those in my poster paper. He said that he foresaw endless uses for those scales. Because their specifications in terms of CIE coordinates have been published, colors based on the committee´s work can be reproduced exactly at any future time. The scales can be extended to higher purities when suitable colorants become available. The steps between neighboring colors can be subdivided as desired, in any range of colors, by use of formulas published in terms of CIE coordinates.

During the past five years, I have obtained repeated judgments by 35 young observers, who reported their estimates of the ratios of more then 1000 pairs of colors that are adjacent in varous OSA color scales. Some of the observers repeated their own results surprisingly closely, in observations made days or even weeks apart, with no knowledge of their previous reports. However, the results of different observers are so different that for the average observer there are no indications of ratios significantly different from those that I computed from spectrophotometric-colorimetric measurements of colors. I therefore conclude that no departures from uniform spacing of the OSA colors have been revealed by my observers. Note that 1000 or so pair comparisons is an exceedingly small sample of the 4,793,910 possible pairs of adjacent colors. I cannot undertake to study many more pairs. I hope other investigators will extend the study and will report their results, for comparable numbers of observers who have normal color vision and who have no knowledge of their previous reports.

These features of permanence, equality of spacing, extensibility and subdivibility, which were foreseen and desired by Ostwald Munsell, and Judd results from the development and use of color-measurement apparatus and procedures. Such apparatus and procedure should be used to record the colors of every new color system,

WHY COLOUR ORDER SYSTEMS
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Session a

INVITED LECTURE

Sven Hesselgren

Leonardo da Vinci - the great ingenious forerunner of art and science - said that there are six primary colours. They are, he said, not only yellow, red, blue and green - something that to him apparently was self evident - but also white and black. He argued against those philosophers who said that white and black are not colours at all. How can they be non-colours? The reason why he became interested in finding some sort of structure in the realm of colour experience might have been pure curiosity, even if he perhaps hoped that this could throw some light on the structure of man´s mental "inside". He presented his ideas about the primary colours about 1500 in his Notebooks. (See McCurdy, E., Notebooks of Leonardo da Vinci, N.Y., 1955).

As far as I know, nothing further happened until 1611 when the Swedish Scholar, Forsius, published his attempt to describe the structure of the World of Colour by means of a three-dimensional diagram, as illustrated at the top of the letter about the Forsius Symposium which you have received. As you can see he had some difficulty in making the perspective drawing of the sphere. However, you can also see that he pointed out the six primary colours of Leonardo. Thus he could be regarded as the first person who drew a diagrammatic representation of the structure of the World of Colour.

In 1680 another Swedish Scholar appeared, Brenner, this time not with a diagrammatic representation but with a colour atlas. It contained 31 colour samples, grouped together in six groups: white, red, blue, green, yellow, and black. It is not known if Brenner knew about Leonardo da Vinci´s Notes. It might be that these three observant persons had independently found a hidden secret. This time we can find an answer as to "why": these samples were intended to be a means of making miniature-paintings.

It then took about one hundred years until Lambert published his colour solid in 1772. As Forsius already had found, it is not possible to make a two-dimensional diagram of the structure of the World of Colour, a three-dimensional one is needed. From now on in such a diagram, the grey colours between white and black have always been the axis in the diagram, with the chromatic colours around. But often the inventors had difficulty in finding a reasonable order of chromatic colours. The inventors apparently did not know about Leonardo da Vinci´s idea concerning the four chromatic primary colours, as you can see from Runge´s colour solid of 1810 as well as from Lambert´s. The same holds good even for Wundt, the famous German pioneer of perception psychology experimentation. He made two attempts to demonstrate the structure of the World of Colour. The first one, in 1874, was a sphere like the Forsius diagram, but in the second, in 1893, he went back to Lambert´s cone.

Why Colour Order Systems? One answer was given by Chevreul, a French chemist and textile manufacturer. He wanted to find a system according to which he could arrange his textile samples. It can be seen in the illustration, drawn by myself following his written description in 1889.

A different answer was given by the German perception psychologists, first of all Wundt. His answer was: perhaps it can elucidate the complete perception process. Ebbinghaus, another leading early perception psychologist, in 1902 in his colour solid showed that he had understood what Leonardo da Vinci said: but he combined this with an idea, later also put forward by the American Munsell, that chromatic colours can differ in lightness.

We can pass rapidly over Rood´s colour solid of 1910, over to Munsell´s colour sphere of 1905, and his colour atlas of 1915. Munsell based his colour systemization on the concept that colours could most easily be represented on a sphere where one pole is white, the other black and the axis occupied by greys of different lightness while the equator is a hue circle made up of colours with the highest "chroma". In attempting to construct this system with painted colour samples. he found however that he obtained, not a sphere but an irregular body. Munsell´s original idea was probably only to arrange the colours in accordance with the judgment of their attributes, but in carrying out this idea he adopted the expedient, as Ostwald did somewhat later, of determining colours with the same hues by means of colour discs and of basing the grey scale on the Weber-Fechner law. After Munsell´s death, and on the basis of the work subsequently carried out first by the Munsell Colour Company, and then by Munsell Colour Foundation, a special committee was established to work on the correction based on judgement of Munsell´s colour norms. This work continued for a number of years and the results were published in 1943.

To summarize; Munsell´s colour atlas in its present form is an attempt to present the colours which, according to subjective judgments generally valid, are the same "distance" apart from each others, i.e. that differ from each other in the same amount in regard to the three colour attributes of hue, lightness and saturation (this nomenclature was agreed upon at the I.C.I. session in 1948); or as Munsell puts it, hue, value, and chroma. But it does not reflect the structure of the World of Colours!

At the same time as Munsell arranged his colours in the USA, Ostwald made his attempt in Germany. He was a Nobel Prize Winner in Chemistry in 1909. He published his colour solid in 1917 in the form of a double cone. White was placed in the upper apex, black in the lower apex. Along a common base is a hue circle on which the different hues were represented by what Ostwald called "pure" colours. The nearer the colours are to the white apex, the more whitish they are (mit Weiss verhüllt), the nearer to the black apex they are, the more blackish (mit Schwarz verhüllt). Inside the colour solid are situated more or less greyish colours (mit Grau verhüllt). Nowhere, however, are the colours placed according to their directly observable qualities, since Ostwald based his scheme on the assumption that for every colour, a stimulus could be given that was simple to describe, and it is these stimuli that are arranged in his system. He also started with the assumption that colours with the same hues can be obtained by rotating white and chromatic sectors of a "Maxwell disc". He further assumed that colours with the same saturation and hue are obtained when a given colour is shaded. Finally, he assumed that a series of grey surfaces whose reflection factors formed a geometric series, is experienced as a scale with equal intervals (this is known as the Weber-Fechner law, which it has been shown does not accurately describe the actual conditions), and that what are known as completementary colours represent the largest contrasts in hue that were observed.

Closer investigation shows that all these assumptions are incorrect, and Ostwald´s colour solid does not provide a colour system of the directly observable attributes of colours. In its day, Ostwald´s system was regarded as epoch-making, but it is only of historical interest now.

Why Colour Order Systems? For Munsell as well as for Ostwald the reason why they made their attempts to make a colour order system was that they wanted to create a "language" by means of which one could communicate with one another about colours without using colour samples. They both numbered each colour according to their systems. To Oswald there was another idea behind his system as well. He thought that he would be able to base a "harmony system" on his colour order. He postulated that two colours would be in harmony with each other if they had one of the three by him defined attributes in common. He even started a "Colour Harmony International Association". His idea was that researchers all over the world should communicate with him (and with other members) about particularly "beautiful colour harmonies" as they might find when they applied his harmony system.

Why Colour Order Systems? I have an answer of my own to that question. In 1930 I was a young architectural student. I detected that I couldn´t handle colours. My intuition was too weak and knowledge I had none. So Ostwald´s books Die Farbenlehre and Die Harmonie der Farben fell in my hands. Ah, I thought, here is the Answer. After I passed my examination as an architect I tried to apply Ostwald´s ideas about colour harmony in making a colour scheme for a hospital. The result was terrifyingly frightening. I have never seen such an ugly thing! If the patients were not ill when they arrived, they certainly would become sick after their admission!

I understood that Ostwald was on the wrong path. So I went to Uppsala where I met a young physicist, Tryggve Johansson. I said "Ostwald says". He answered: "Oh no, Hering says". What exactly did Hering say? In 1878 he wrote the following:

"When it is a question of obtaining suitable and strictly defined concepts for the attributes of our sense perceptions the first requirement is that these concepts are derived exclusively from the perceptions themselves, that any confusion of the perceptions with their physical or physiological causes is strictly avoided, and that no principle for classification is based on data from the field of these causes. It is remarkable that this requirement, which is in reality self-evident, is still constantly disregarded, and consequently we often find that painters have a more correct understanding of sense perceptions than scientists, physicists and physiologists, and that even in everyday language there is, in many respects, greater clarity on the subject under consideration than in the literature of physiological optics".

My visit to Johansson changed his life definitively. He gave up his academic career and devoted his life to Colour Research. He made several attempts to reflect Hering´s ingenius analysis of colour sensations by means of colour solids. They were published in 1937 and 1939. Hering - who was one of the leading pioneers in perception psychology - had convincingly shown that Leonardo da Vinci´s ideas about the six primary colours were right. However, Hering never made psychological experiments, he analysed his own colour sensations by means of introspection - something that later on has been called phenomenological analysis. Johansson tried to tackle these problems with experimentation, but he made a mistake when he wanted to combine Hering´s ideas with Munsell´s.

I myself tried to materialize Johansson´s colour solid by a colour atlas which was published in 1953. As you can see from the slides at this lecture, it reflected first of all the six primary colours, yellow, red, blue, green, white and black, but it also reflected Munsell´s ideas of lightness and something that Johansson and myself called "saturation" (mättnad in Swedish). This was a big mistake. I will explain in what follows.

But first I want to tell you that it was not only in Germany and Sweden that people were eager to penetrate the structure of the World of Colour. In the USA some researchers tried to demonstrate this structure by means of three-dimensional diagrams. In 1949, Arthur Pope, an art theoretician, published his colour solid that he invented as early as 1924. Pope, as well as Johansson, had made the mistake, as you can see, to look upon hue, saturation (Pope called this "purity"), and lightness as the three main attributes of a colour sensation. However, there were two psychologists. Dimmick and Boring, who made a more adequate phenomenological analysis and published a colour solid in 1929. I do not know if they knew about Hering´s work, but their solid evidently reflected Hering´s findings as you can see. I might mention here that the Scholars of Radiant Energy in the USA were not capable of understanding that the World of Colour is a mental entity and they had no understanding whatever of the method of phenomenological analysis. They might hopefully have had better understanding now since Leo Hurvich & Dorothea Jameson in 1964 published an English translation of Hering´s Zur Lehre vom Lichtsinne, published originally in Wien in 1878.

Now back to Hering´s idea as they were experimentally tested in Sweden. In 1964, 23 November at 14.00 h, the Royal Swedish Academy of Engineering Science under the chairmanship of Sven Brohult established the Swedish Colour Centre Foundation. The initiative for this came from Gunnar Tonnquist, a scholar in the field of Physical Stimuli of Colour Sensations, who had cooperated with Johansson for many years. Anders Hård was engaged as the leaders of the Colour Centre. He cooperated with Lars Sivik about psychological experimentation and with Tonnquist about the relationship between physical radiation and colour sensations.

In 1978 the Swedish Colour Centre Foundation was completed by the Scandinavian Colour Institute.

The first aim of the Swedish Colour Centre Foundation was to create another and better edition of Hesselgren's Colour Atlas, but fairly soon it was found that something was wrong in the theory supporting the atlas. It appeared first of all that saturation is not a basic colour attribute. It is instead a relation between two of the basic colour attributes, namely whiteness and chromaticness. If this relationship is constant when the attribute blackness varies from 0 to 100%, the colours thus obtained are experienced as "equal in saturations. The same holds good for what is called hue. Hue is not a basic colour attribute. It is instead a relation between two basic colour attributes, for instance yellowness and redness. After some years of psychological experimention it was in fact found that yellowness, redness. blueness, greenness, whiteness and blackness are the six basic attributes of a colour sensation. Hering's phenomenological analysis appeared to be quite correct.

There is a problem of another kind in regard to the entity "lightness". Hård and Sivik have found that there is a perception of a distinct borderline between two colour fields. The less distinct this borderline is between a chromatic sample and a given grey sample, the more similar they are in "lightness". You can see this clearly if you study the NCS atlas that is available at this symposium.

Why Colour Order Systems? I think the clearest answer is given by Hård and Sivik. If we are able to reveal the structure of the World of Colour, we are also able to create a "language" (for instance with letters and figures or by means of other symbols) referring to this structure. This gives us the possibility not only to give accurate information to a painter when he is going to paint a wall, but also to describe the "connotations" to colour in different parts of the World of Colour. Sivik has started to establish this study.

But I want to return to the question of equality in the two relations mentioned, "equality in hue" and "equality in saturation". It has been found that we are astonishingly sensitive of this double relationship. I will give an example of this from my own experience.

Once upon a time I painted the walls in my bedroom in different grey colours, as shown in the illustration. It became absolutely impossible to see any difference in colour between the white and the light grey in the corner A. The difference perceived was definitely referred to a perceived shift in illumination. The same held good also for the corner B, but in the corners C and D, one saw a difference in colour between the walls. The difference was apparently too great here to be perceived as a difference in illumination.

Recently I painted my new bedroom in reddish blue colours as indicated in the illustration. (The colour "names" refer to NCS.) As can be seen, the colours were equal in hue and equal in chromaticness, they shifted, however, in blackness. Referring to my experience in the grey room I expected that I should not see any difference in lightness between the wall colours at the corners A, B and C, but that there should be a great shift at the corner D. Since the series of chromatic-equal colours were so close to the grey axis I expected also that this series should be so close to the saturation-series indicated in the nuance triangle that I should not be able to detect any difference in saturation between them. But listen to what happened: In the corner A, the colour to the left had "something in it" that was perceived as "stronger" than in the corner to the right. The same held good also for the corners B and C. What was "stronger" was the saturation, i.e. the chromaticness in relation to the whiteness. I also detected a slight shift in hue. (The painter had not been able to copy the atlas sample correctly).

But it is not only the case that we are astonishingly sensitive to these relationships. We also have a tendency to appreciate them aesthetically as "beautiful". This is what Hård and Sivik have found during strictly carried out scientific experiments on intersubjective formal aesthetic evaluations of colour combinations. They have found that a majority of people, laymen as well as colour experts, show a preference for series of colours equal in hue and equal in saturation within this hue. I hope that they will tell you themselves about this.

It is therefore a pity that the NCS atlas gives so few opportunities to find such series, as it is presented now. I wish that this might be overcome in some manner, perhaps in a special edition. But it is of course possible to achieve these series by means of interpolation between the colours in the present atlas. To be able to do this, it is necessary to understand fully the theory behind the NCS atlas. It is not sufficient to have a tool, it is necessary to know how to handle it.

Why Colour Order Systems? Let us once again go back to this question and look for an answer. During the last half century the architects all over the Western World have shown that they were not able to handle colour in architecture. This might be demonstrated by showing a slide of a modern grey building in Stockholm. It is easy to find it if you pay a visit to our capital. You just ask the taxi driver to take you to the ugliest building in the city, he knows immediately where to go.

But today the situation will shift. Colour in architecture, outdoor as well as indoor, has become an object of interest. We have become eager to preserve old buildings and to restore their original colours. I show at the exhibition here in Kungälv two posters, one from Stockholm, one from Gothenburg, demonstrating how this problem is handled. The Stockholm Town Architect in May this year received an award from EUROPA NOSTRA - The International Federation of Associations for the Protection of Europe´s Cultural and National Heritage - for colouring of Stockholm´s "malmar".

When you leave Kungälv you will pass through Gothenburg and, in doing so, you will have the opportunity to take a look at the buildings around Gustaf Adolf´s Square, where you can see an example of how old and modern buildings can "cooperate" in colour. The old Town Hall was enlarged in this century; the extension was designed by the famous architect, Gunnar Asplund. These two buildings are connected by their colouring almost to a unit. Their rather brilliant pale yellow strengthens their dominance over the other buildings around the square whose colours are a more humble greyish pale part of the same hue octant.

We human beings have unconsciously developed a terminology that describes the different characters of the six sub-triangles within the total nuance triangle (see the illustration). This *could be sufficient to describe* the character of the colours and the colour combinations at the buildings around Gustaf Adolf´s Sqaure, but if we want to describe more exactly a colour with reference to the structure of the world of colour, we will of course have to use exact colour names, for instance, those established by the NCS.

However, we have also to take care of the colouring of new buildings. I give an example from the interior of a brand new office building in Rissne, a suburb of Stockholm. We can - and ought to - use our intuition in such a case, but without knowledge about the influence upon us from colour sensations we cannot handle these problems in a conscious way. And in order to detect these consequences in form of emotional loadings and aesthetical evaluations we need knowledge of the structure of the World of Colour.

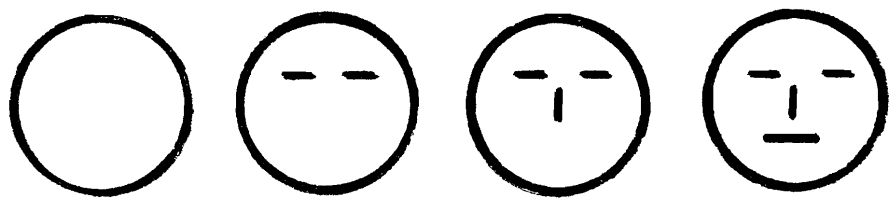
Why Colour Order Systems?

I will finish this review by relating, what to me has appeared to be, the most important result of the study of the World of Colour.

In 1947 I asked myself if Hering´s description of the method of phenomenological analysis could be applied not only to colour sensations but to the total perception of man-made environment - specifically Architecture and Townscape. After years of studies of the results of experimental perception of psychology - I might among the most important literature mention Edwin Boring´s Sensation and Perception in the History of Experimental Psychology, 1942 - I presented my thesis Arkitekturens Uttrycksmedel in 1954. During the following decades I have deepened my understanding of the total perception process, including semiotics, emotional loadings, and evaluations - aesthetical as well as social and practical - and have recently finished a manuscript to another book: On Architecture, An Architectural Theory based on Modern Psychological Research. I hope to have this published in a year or so. I will give a very brief review indeed of the main ideas referring to my "perception map".

When a given stimulus impinges on a sense organ, for instance when a certain kind of radiant energy touches our eye, we experience three types of sensation modalities, i.e., colour, light, and visual form. As I have explained, those sensations cannot be described by means of physical entities, they have to be described in their own terms. Thus, I have shown above that the modality of colour sensation is structured in a specific way. The same is true for the modality of light sensation as well as for the visual form sensation. The same is also true of auditory, tactile, haptic form, and kinesthetic sensations as well as for smell and taste. All of these sensation modalities are structured each one in its own mannaer. To Architectural Theory the most important modality is the visual form sensation. The structure of this cannot be derived from a geometric description of the stimulus. Phenomenological analysis, supported by psychological experiments. is the only method that can reveal this structure and it is thus for every sensation modality.

In everyday life, however. we always want to add meaning to a complex of sensations. We see for instance something that is red, round, seen in a certain light, can be touched by the fingertips, grasped by one hand, can be eaten when we feel taste and smell. And we exclaim: "A tomato!". Or to take another example: Look at these round figures:



It is almost impossible not to see a human face at the figure to the right.

We can say that we have put two different meanings - Tomato or Face - to a round form.

Meanings as well as the basic sensations are more or less emotionally loaded. Once again we can look at some round forms to demonstrate this:

Do you see that in the fourth figure the eyes are happy and glad, but in the fifth figure the identically same eyes are sad? The emotional expressions of the mouth is spread all over the face.

But the round form can have other meanings as well. In Architecture it may be a window. A window loaded with sadness if we are looking out through it from a jail, but loaded with happiness if we through that window can see a landscape into which we are invited. So let us look on our round window as a symbol of an entrance into a landscape of better knowledge, leading to a better world!

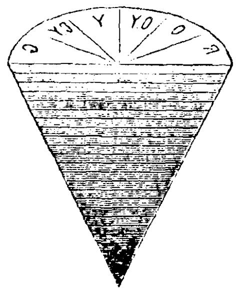


Fig. 3: 6. Lambert's colour solid (1772). (From Ogden N. Rood, Colour, London 1910.)

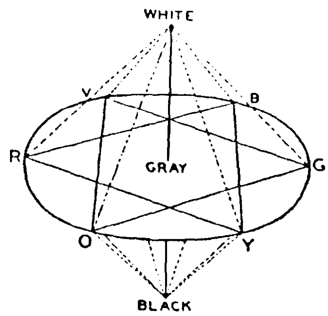


Fig. 3: 7. Runge's colour solid (1810). (From Edwin G. Boring, Sensation and Perception in the History of Experimental Psychology, New York 1942.)

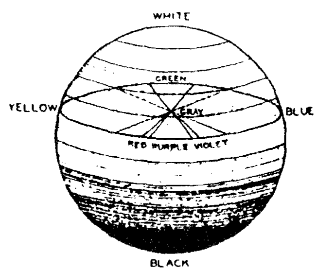


Fig. 3: 8. Wundt's colour sphere (1874). (From Boring, ibid.)

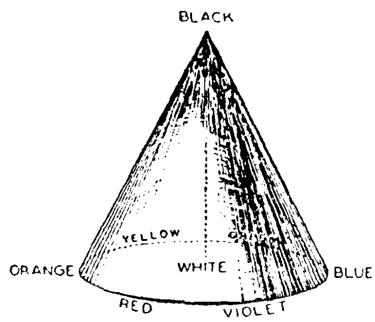


Fig. 3: 9. Wundt's colour cone (1893). (From Boring, ibid.)

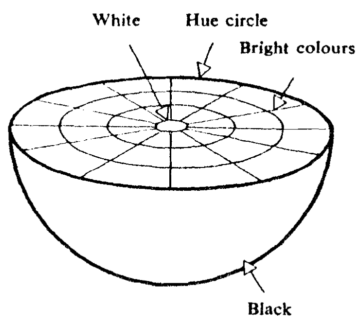


Fig. 3: 10. Chevreul's colour hemisphere (1889). (From a description in A. Rosenstiehl, Traité de la couleur au point de vue physique etc., Paris 1913.)

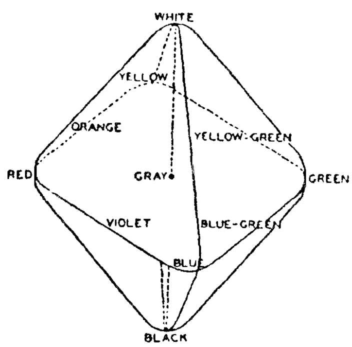


Fig. 3: 11. Ebbinghaus' colour solid (1902). (From Boring, ibid.)

From S. Hesselgren The Language of Architecture, Studentlitteratur, Lund, 1969.

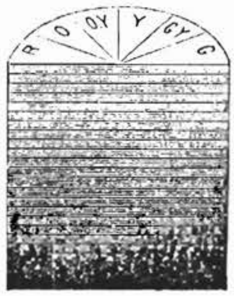


Fig. 3: 12. Rood's colour solid (1910). (From Rood, ibid.)

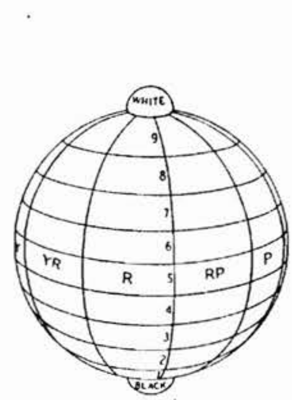


Fig. 3: 13. Munsell's colour sphere (1905). (From Maitland Graves, The art of color and design, New York and London 1941. See also A. H. Munsell, A color notation, Baltimore 1946).)

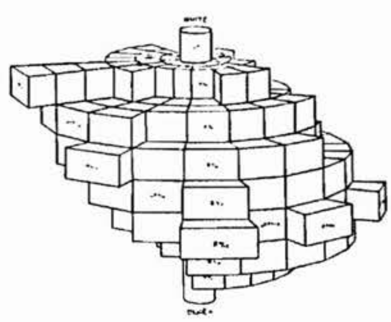


Fig. 3: 14. Munsell's colour solid, as it appears in his atlas (1915). (From L. Moholy-Nagy, Vision in motion, Chicago 1947.)

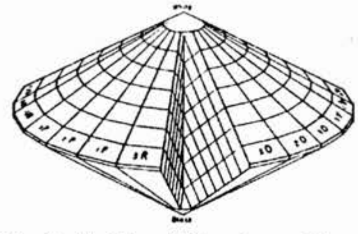


Fig. 3: 15. Ostwald's colour solid (1917). (From Moholy-Nagy, ibid. See also Wilhelm Ostwald, Die Farbenlehre, Leipzig 1922—30).)

From S. Hesselgren <u>The Language of Architecture</u>, Studentlitteratur, Lund, 1969.

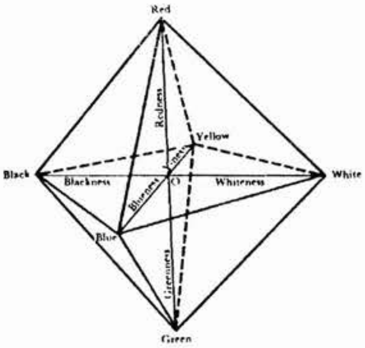


Fig. 3: 16. Dimmick-Boring's colour solid (1929 and 1951). (From Edwin G. Boring, A color solid in four dimensions, Année psychologique 1951. See also F. L. Dimmick, A reinterpretation of the colorpyramid, Psychological review 1929.)

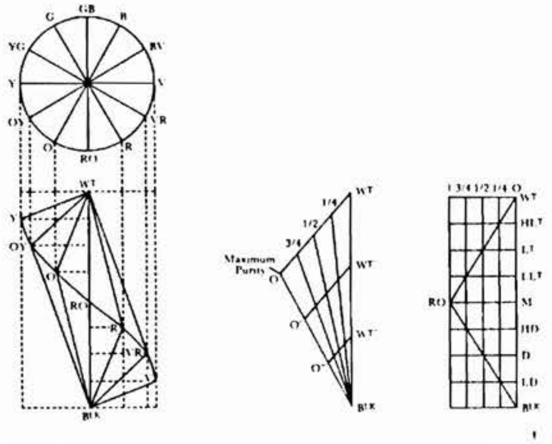


Fig. 3: 17. Pope's colour solid (1929). (From Arthur Pope, The language of drawing and painting, Harvard University Press 1949.) The most interesting detail in this representation is how the author diagrammatically points out the attributes in a given hue, shown to the right.

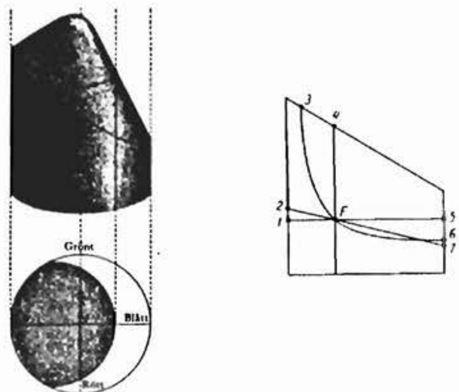


Fig. 3: 18. Johansson's colour solid (1937). (From Tryggve Johansson, Färg, Stockholm 1937. See also T. Johansson, Characteristic properties of colour and colour combinations, Revue d'optique 1949.)

Fig. 3: 19. The natural system of colours. In this colour solid, published by Johansson 1939 (see T. Johansson, Kartor över färgvärlden, Färg och fernissa 1953), the diagrammatic representation of the colour attributes in a given hue is exactly the same as in Pope's representation from 1929—the two phenomenologists have checked each other's work without knowing this. It forms the basis for Hesselgren's colour atlas.

From S. Hesselgren The Language of Architecture, Studentlitteratur, Lund, 1969.

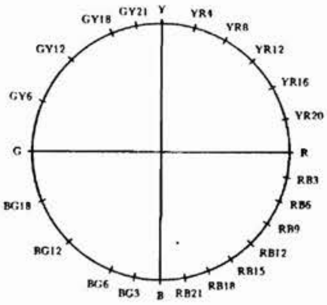


Fig. 3: 20. The hues in Hesselgren's colour atlas. Y, R, B, and G depict the primary or unique hues.

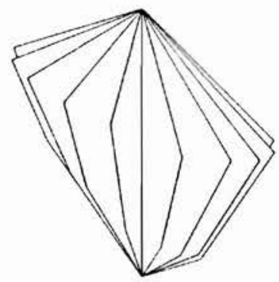


Fig. 3: 21. Equality of hue in the natural system of colours.

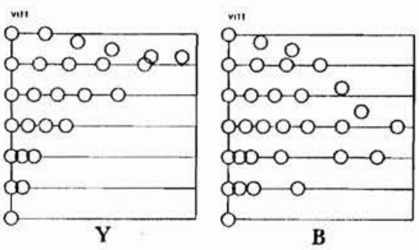


Fig. 3: 22. The scheme of the colours in the yellow and the blue hue. The lines connect colours of the same lightness. (From Hesselgren's colour atlas.)

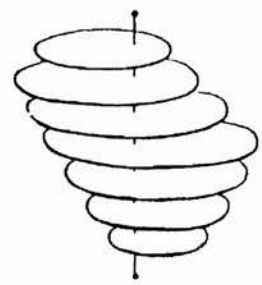


Fig. 3: 23. Equality of lightness in the natural system of colours.

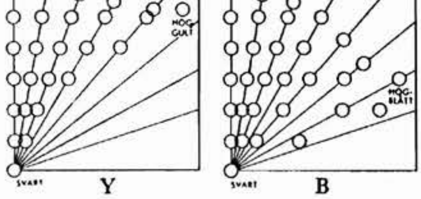


Fig. 3: 24. The scheme of the colours in the yellow and the blue hue. The lines connect colours with the same saturation (Pope's term is "purity"). (From Hesselgren's colour atlas.)

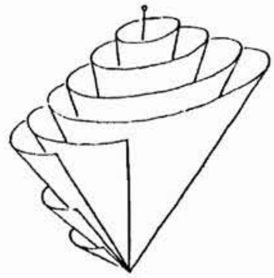


Fig. 3: 25. Equality of saturation in the natural system of colours.

From S. Hesselgren The Language of Architecture, Studentlitteratur, Lund, 1969.

WHY COLOR ORDER SYSTEMS
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Session a

GLIMPSES FROM
DISCUSSION

Hesselgren:
By means of phenomenological analysis, it has been made quite clear that there are six primary sensations in the world of colour sensations, and they are yellow, red, blue, green, white and black, and this is experimentally proved.

Fred Billmeyer:
I have taken the point of view that different manifestations of colour order systems are all sampling the same colour space and some of these colour order systems use three primaries only; others four, five, six, seven, eight and so on ... Does it really make any difference how many primaries are used? Is there anything truly fundamental that says that the only correct way to sample the space of all perceived colours is a way which uses four hue primaries and black and white?

Hesselgren:
From my point of view as an architect and environmental designer there is just this structure of the colour world. I may add that in USA, there has been very little understanding of this, in spite of the fact that psychologists have, rather convincingly, shown that you must take the phenomenological approach to the colour sensations.

It is absolutely necessary to understand that you cannot describe anything concerning any kind of sensation by means of physics, and you cannot describe anything in physics by means of terms in perception. You do so - yes, you call the radiation from radiation sources light. It is not light. Light is the sensation that appears in your mental inside. It is awakened by means of the radiant energy, but that is something quite different from the sensational perception. The same stands for colour, of course.

Billmeyer:
Most of us here would agree completley with you, that what we are talking about here is strictly in the realm of perception, but I am not sure that this really is pertinent to the question I was asking, which is: Given the world of perceptual colours, what is it which says that the only correct way to describe these colours is a way which uses four chromatic primaries plus black and white?

Tonnquist:
I think that Prof. Billmeyer is quite right when he says that we have one and the same world of perceptual colours which can be structured in many different ways. But what Prof. Hesselgren says is that from his point of view, for the purpose of using colours, he has found that one system works much better than any other system. We who work with the Natural Colour System do not say that this is the only system. For printers, photographers,

etc., it would be nonsense to force them to use an opponent hue system in their practical technical work. We have various applications of colours that require various structures of the colour world. There are many applications which have not found earlier systems suitable, but which have found their solution in NCS. It is easy to learn and easy to use. It is easy to explain to other people what your intentions are with a colour scheme, when you can express it in terms of a purely perceptual system as NCS.

Sivik:
Shall we try to stick to the theme of this session and that is: Why colour order systems? I would like to ask some of the people here, who have created colour order systems. Why have they made them in the way they did? We have the CIE system., the UCS, the NCS, the Hungarian one and a couple more. Will the inventors please explain why they created these systems?

Hård:
When we formulated this topic, we had in mind at least one reason why colour order systems are born: simply out of human curiosity. In the same way as if you give a child a number of stones, he will soon start to arrange them in a certain order just for fun. To my mind, Forsius was a typical example of somebody who was curious about how these phenomena were related to each other, and for no other reason. On the other hand, we can say that for the type of colour order system represented by the CIE system, there is a very technical reason why it was born. Just to specify certain stimuli and to discriminate between them. If we do not put the question to ourselves, ´why do we do this kind of work with our respective colour order systems´, there will continue to be confusion at our meetings, because all of us will talk about THE colour system - believing that this is exactly what all the others do too, without realizing that we are talking about different things, and different reasons why these systems have been born.

In answer to the question why NCS was born, I would like to say that the reason was mentioned by Prof. Hesselgren, namely because of Tryggve Johansson. During his student time in Uppsala, he took interest in this question: Is it possible to find a basis for what, in 1946, he called "a colour harmony theory of the same value as we find within the tonal music" And in that case, he said, we cannot rely on physical properties of colour stimuli but have to turn to the perceptual properties of the colours and in his research, he more or less stumbled over the works of Hering. He searched for "colour harmony" not only just for the sake of art, but also to design the environment in which we live ...

Ralph Stanziola:
May I put the question 'if you were the only man on earth, would you need a colour order system'?

Hård:
No! - Yes! - If I had the colour order system in my mind!

Stanziola:
So, is not the reason for colour order systems to communicate about colours with other people?

Hård:
That is one reason. But I also want to be capable of communicating about these things with myself.

Frederick Simon:
I have come up with a new system, and the obvious question is: "Why another system?" - My problem is to teach colour from the viewpoint of colour mixing. I wanted a representation, which would demonstrate the procedure: Given a set of colourants, how to reach a certain other colour? I have found that artists and other creative people, are not capable of doing that at the outset. In consequence I have created what is called the YCM-system. I am here to get criticism on that system. (The YCM system is a colorant mixing system where the "ideal" primary colourants are defined by a tripartition of the visible spectrum. See colour report F 26 p. 39:1.)

Lorenzo Plaza:
I think that the question of Why Colour Order Systems is very simple. People need them. They pay a lot of money for them.

Billmeyer.
As was pointed out earlier: The NCS system is free! The atlas is not. I think the NCS system and possibly also the DIN system were developed to produce systems, where colours were equally spaced from a global point of view; in a hue circle, the quadrant between yellow and red is subdivided in equal steps or some such thing. The Munsell system was developed in order to provide a collection in which the differences between adjacent colours were perceptually equal, and that´s an entirely different thing.

Parra:
A unique solution to the problem of making a colour order system which will meet all needs seems impossible to me. It seems to me that there are two kinds of answers. In practice it is necessary to refer to a system of classification, in order to unify language and normalisation. In the subjective world it is necessary to make a sort of language with objective words to study a lot of perceptive effects. Philosophically, it seems, this will be another system of colours ...

The physiological and psychological properties are the basis of the creation of order systems - as Mr Vanel said, there are more than three dimensions for a world of colour.

WHY COLOR ORDER SYSTEMS
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Session a

WRITTEN COMMENT
Richard D. Ingalls

Color order systems can be compared to maps. There are different kinds so of maps to help solve different problems. One needs a topographical map if there is a need to find ones way through the mountains and valleys of an area. This can be compared to the Munsell color order system. The NCS color order system could be likened to a highway map that may simplify travel. Other systems can be seen as different kinds of maps.

If you do not want to be lost, you need a map when you are going through an unfamiliar area. You may need a special map or color order system to find your way to a color answer or destination. We need different color order systems in order to know where we are and recognize where we need to be.

WHY COLOR ORDER SYSTEMS
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Session a

WRITTEN COMMENT
Jan Sisefsky

I think it was a pity that Mr Billmeyer´s first question, although better fitting in the next session, was not further discussed. It seems to elucidate much of the confusion which arises when different colour order systems are confronted.

It has been shown, however, beyond all doubt that nearly all people (even "colour blinds") when looking at samples covering the whole hue circle, pick four, and just four unique fundamental or elementary hues: a red, which is neither yellowish, nor bluish; a blue which is neither reddish nor greenish and in a corresponding way, a unique green and a unique yellow. A unique purple, for example, is never picked because purple is always perceived and described as a bluish red: thus with <u>two</u> chromatic properties.

Further: even if mixing an orange and a purple colorant can give a red colour, this colour is never perceived as purplish orange.

The popularity of colour order systems which advocate three primary hues, depends, I think, on the belief that a colour system can, at the same time, be a perceptual one and a colorant mxing system. This is a mistake, which could have been considered a natural one during Goethe´s time, but today we know that the primaries of a colorant mixing system cannot display elementary colors in the NCS sense, if they are supposed to give the largest colour gamut possible. Neither the "red", "green" and bluish violet of an additive mixing system (as in colour TV) nor the "yellow" cyan and magenta of a subtractive one (like Mr Simon´s YMC) correspond to the elementary yellow, red, blue and agree with NCS. (additive "red" and "green" are both yellowish and subtractive "yellow" is slightly greenish). Contrary to common belief, the elementary colours can thus actually be mixed by colorants with non-unique hues.

The reason for this distinction between colorant mixing and colour perception, seems to be found in the very construction of the eye, which has shown to be more complicated than was assumed by both Young - Hemholz and Hering respectively. The colours of the color mixing primaries correspond in some way or other to the spectral sensitivities of the cones in the retina, whereas the unique hues are in some way "created" in a "deeper" layer of the retina, probably the horizontal cells, possibly in connection with the process where the colour perception is "adjusted" to compensate for differences in the illumination (ref: Walraven, perhaps also Land).

Even Mr Simon´s YMC system would, as I think, have deserved a further discussion. In Colour Report F 26 p 39:4, Mr Simon plots the colours achieved by his mixing system into a Munsell hue-chroma circle and also in two variants of the CIE system. In the same manner, these colours could have been fitted into an NCS hue-chromaticity circle, thus proposing the first happy marriage between a truly perceptional colour order system and a pure colorant mixing one.

WHY COLOUR ORDER SYSTEMS
************************ Session a

MODERATOR'S REPORT

Francois Parra

In a forty minute paper, Prof. Sven Hesselgren gave an interesting and difficult view of the problem. Interesting because it is the answer to a research in the world of colour. Difficult because the World of Colour is closely connected to the human life and to his expressions in the objective space.

The paper gives a large "Tour d´Horizon" on both levels at the same time; scientific and historical The answer to the question Why Colour Order System seems to have been given first by Leonardo da Vinci "an order system throws some light in Man´s mental structure "inside"".

Since this ancient point of view, many personalities of the scientific world (within physiology psychology and physics) have suggested answers. Some of them have created color spaces and the answer to the question above came naturally to their minds.

First Forsius and then Brenner gave a first answer why: "To make miniature paintings."

Then Chevreul in France made one in order to arrange his textiles (1889).

Then Wundt: Color order systems can elucidate facts of perception.

Then Munsell and Ostwald in order to have a language without samples.

Then Tonnquist, Hesselgren and Hård and Sivik who think that "If we are able to reveal the structure of the world of colour, we are also able to create a language."

It seems that there is nobody who can give an easy answer to the question, and this is a good starting point for an interesting discussion.

Can we verbally express the combinations of "interior" colours?

Somebody pointed out that a system like Munsell does not represent the number of perceived colours and this started a discussion about the number of parameters needed to give an image of the colour world.

Not only the idea concerning parameters: for instance four chromatic colours and two achromatic ones, comes to the commentaries, but also the logic deduction of that idea. That is to say, the existence of different systems is necessary.

Color order systems are necessary in industry and they help to solve problems in commercial competition.

The complexity of the Coloured World and the lack of answers in some aspects of perception determine a lot of confusions in the question "Why a color order system?". The fact that Man has created some systems is, in my opinion, a kind of answer that corresponds to the necessity of keeping an equilibrium in the complexity of this world and more simply to answer to many current problems of human life:

necessity of creation
commerce
industry
culture, harmony, and so on

As long as the deep answer to the question: "What is the reality of the colour world" is not known, it will be difficult to give an answer to the question "Why colour order systems".

Man is a living being before a philosophical one.

BASIC CONCEPTS AND BASIC ATTRIBUTES Sessions b and c
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INVITED LECTURE

W. D. Wright

THE BASIC CONCEPTS AND ATTRIBUTES OF COLOUR ORDER SYSTEMS

(Note: In this survey of the papers on the above topic being presented at this Forsius Symposium. I have referred to the individual papers by the authors' names and by their numbers as given in the Colour Report circulated in advance of the Symposium.)

Introduction

Colour order systems are our primary means of defining colour appearance since, as I understand them, they consist of a collection of colour samples arranged systematically in terms of the subjective variables of colour appearance. Colour appearance is important because it is the end-point of most, if not all, the uses we make of colour, and since I have over the years been particularly associated with trichromatic colorimetry and the CIE system, I would want to emphasize that to me the overriding value of colour order systems is that they deal with colour as we see it and not as we measure it. If the chips in a colour atlas have been calibrated in terms of their CIE co-ordinates, then they can, of course, be used indirectly for colour comparison and colour measurement, but this is not, I believe, the primary motive behind the production of a colour atlas.

Neither, I believe, does the knowledge we have about the spectral response of the retina play any significant part in the construction of a colour atlas, although our theories of colour perception may influence our choice of the co-ordinates we use for the atlas. Certainly, Forsius himself would have known nothing abut the colour receptors in the retina nor about the coding of the signals generated in the receptors and transmitted from the retina to the visual cortex. Yet having arranged the samples in an atlas purely on the basis of their subjective appearance, the structure of the colour solid that emerges does provide data which can be used to test different theoretical models of the colour vision process, as Hunt and Pointer (13) have shown.

My main responsibility in preparing this paper has been to read as carefully as I can all the papers presented at this Symposium which deal with the basic concepts and attributes of colour order systems. I think I have made some reference in the text to all the papers which have been given a (b) or (c) identification (and to one or two others as well) but inevitably there are four or five key papers which have claimed more of my attention than the rest. I can only apologise to the authors of these papers to which I have only been able to make a passing reference.

The variables used to define or describe a colour order system must be derived from the subjective or perceptual attributes of colour appearance, and we must take note of the very clear distinction made by McCamy (16) between colour order system conceived in terms of abstract colour appearance co-ordinates and the material or concrete representation of such systems by means of actual colour charts and colour atlases. This distinction has also be emphasized by our Swedish colleagues in their description of the Natural Colour System. (Hård and Sivik 35, Svedmyr 36, Tonnquist 38).

The Abstract Variables of Colour Appearance

As McCamy has explained, the first stage in establishing a colour order system is to identify the variables of colour appearance on which the system is to be based. These variables are abstract in the sense that they can be conceived independently of actual material colour samples and, on the assumption that colour appearance can be described in terms of three attributes, they can serve as the three dimensions of psychological colour space.

What, then, are these three attributes? As we know only too well, there is no agreed answer to this question and it seems unlikely that we shall reach agreement at this Symposium on a single set of variables, much as Tonnquist (28) would like to see such agreement and in spite of the attempt by Green-Armytage(9) to produce a marriage between the two main contenders for international recognition. Tonnquist has listed the variables and concepts of several different colour order systems and they fall into two main groups with, of course, some variations in each group.

The choice of terms to identify the variables in each group presents some difficulty, but the following should serve to distinguish the two groups:

Group A attributes: Lightness, hue and saturation.
Group B attributes: Whiteness, blackness and chromaticness.

Examples of Group A-type colour order systems are the Munsell system with its variables of Value, Hue and Chroma, and the German DIN System, with Darkness Degree replacing Lightness. The outstanding example of a Group B system is, of course, the Swedish Natural Colour System, in which chromaticness is expressed in terms of the proportions of the subjective perceptions of redness, yellowness, greenness and blueness. The Oswald system can also be considered as a Group B-type system, with its variables of white content, black content, and colour content, even though in the Ostwald atlas these are material variables rather than abstract colour appearance variables.

We can now ask ourselves a number of questions. First, are the A and B variables equally valid alternatives, or is one right and the other wrong? Or is one or other to be preferred, depending on the use to which the colour order system is to be put? Lightness (or darkness) is the most suspect of the Group A variables, as Green-Armytage (8) has pointed out. We certainly refer to colours as being light or as being dark, which would seem to support lightness and darkness as legitimate variables. Yet there can be confusion between the use of the adjective "lighter" or "whiter" to distinguish one pale colour from another, and in other cases in the use of "darker" or "greyer", Green-Armytage is in no doubt that the use of "lightness" should be abandoned.

For what it is worth, my own view is that the Group A variables suffer from the exclusion of whiteness and blackness, since I regard them as subjective attributes or components of a colour perception which are clearly identifiable.

Then I think we have to ask ourselves how abstract really are the A and B variable, in which I would want to include the colour names white, black, red, yellow, green and blue, since these are the names which form an essential part of the NCS group of abstract variables. McCamy claims that the Munsell system was conceived by A.H. Munsell in abstract form before a series of charts showing visual scales of hue, value and chromas was published in 1915 as "The Atlas of the Munsell Color System". We are now so familiar with the Munsell charts that it is almost impossible to envisage the problem of creating the system in abstract form before the atlas had been published. McCamy himself implies that it is not easy for non-specialists to recognize the Munsell variables without first having access to the charts themselves when he writes: "Chromas is a slightly more abstruse concept, but is readily recognized once it is understood. It takes very little training to be able to compare two different colors and describe the qualitative difference in terms of differences in hue, value and chroma". This perhaps suggests that the distinction between colour in the abstract and the perceived colour of a material sample is not quite as clear-cut as we are led to believe.

The same, I think, applies also to the NCS variables. In his description of the Natural Colour system, Svedmyr (36) writes: "This means that a person trained in NCS can, without comparing any colour samples, notate which colour he observes on an object in an arbitrary situation. The estimation is made by judging the degree of resemblance to the six elementary colours, pure white (W), pure black (S), pure yellow (Y), pure red (R), pure blue (B), and pure green (G), which are built into the human mind." But how are they built into the human mind? McCamy again: When a child is first taught the meaning of such words as "red" and "green", the only way the terms can be defined is by showing examples. The definitions of the psychological attributes ultimately depend on such definitions." What would imply that our so-called abstract perceptions have initially been acquired from viewing material samples and that the terms we use to describe them owe a great deal to the way we were taught about colour.

I would not, though, want to deny our ability to identify the elementary or unique hues red, yellow, green and blue, each of the four being free of contamination of the other three. The more difficult attribute of the NCS elementary hues to define must be their saturation. The observer who is asked to assess a colour in terms of the NCS variables presumably has to have some concept of the colour appearance of the elementary hues in their state of maximum saturation, that is, with zero contamination with whiteness. How does he acquire this concept unless he first carries out some adaptation experiments to demonstrate how a spectral green, for example, can appear more saturated when seen by an eye that has been pre-adapted to red light?

There is one last point I would want to make on the validity of a colour order system based on the identification of the abstract subjective variables of colour appearance. How far does this depend on the long-term stability of our colour perception process and also on the reliability of our colour memory? So far as I can recall, the colours of familiar objects still look much the same to me now as they did 60 or more years ago. If this is also the experience of other elderly people, this is a remarkable tribute to the stability of the visual process and no cause for concern for our NCS colleagues.

The Structure of Material Colour-Order Systems

A material colour order system consists of the organisation of arrangement of actual colour samples in 3-dimensional colour space according to the particular subjective variables of colour appearance on which the system is based. One system differs from another primarily in the arrangement of the samples in colour space and not in the samples themselves. No system can in principle claim to include more exotic colours than others!

Fortunately, the different systems that have been developed do have certain common features. Thus most systems locate the neutral grey samples on the central vertical axis of the colour solid, ranging from near-black at the bottom to near-white at the top. Then the vertical planes radiating out from this central axis each contain samples that are nominally of the same hue, with the sequence in which the hue planes are arranged around the axis almost universally following the same sequence of hues as they appear in the visible spectrum. The non-spectral hues - the purples - complete the hue circle by linking the spectral red with the spectral violet.

It is in the spacing of the neutral samples along the vertical axis, the spacing of the different hue planes around the hue circle, and the location of the samples in each hue place, that distinguish one colour order system from another. In some systems, notably in the Munsell Atlas (McCamy, 16) and in the O.S.A. Uniform Color Scales (MacAdam, 15), much importance is attached to the spacing of the samples at equal perceptual intervals. See also McLaren (17). In the Munsell solid the vertical axis has been divided into 10 equal steps of Value (the lightness variable), five principal hues are identified and are equally spaced round the hue circle, together with five intermediate hues and ten secondary intermediate hues, while in a given hue plane samples of increasing chromas (the saturation variable) are located at increasing distances from the central axis, again being spaced at equal perceptual intervals of chromas.

So far so good, but examination of a chromas series, for example of Hue R and Value 4, suggests that the more saturated samples, say R 4/12 or R 4/14, are brighter or lighter or more luminous than the desaturated samples, say R 4/1 or R 4/2. In other words, samples of equal value may not look equally light. This is not a problem peculiar to the Munsell system as it has been plaguing photometry for a long time. It is an example of the fact that the subjective attribute of lightness is not an exact correlate of luminance factor; that if you compare a neutral grey with a saturated colour of the same luminance factor as the grey, the saturated colour will look the brighter or lighter. We have therefore to conclude that the Munsell attribute of Value is not a true subjective variable.

The difficulty I have had in finding the correct term to describe the brighter appearance of the saturated red sample - whether to say that it is lighter or brighter or more luminous or whatever, illustrates the ambiguity in what we mean by lightness. I think the more meaningful way to describe the R 4 chromas series is in terms of the increasing proportion of redness to blackness as we pass from the R 4/1 to the R 4/14 samples. But blackness, unfortunately, is not one of the Munsell variables.

Another difficulty associated with colour order systems in which the samples are intended to be spaced at equal subjective intervals, is that the equality of the intervals is a function of their size. This was demonstrated many years ago by Nickerson and Newhall (J. Opt. Soc. Am., v. 43, pp. 419-422, 1943) in a paper on "A Psychological Color Solid". They illustrated two models of the colour solid, one based on intervals equated at a supraliminal level of colour difference and the other for intervals equated at the liminal level. In the latter, the vertical dimension had to be increased by a factor of 4 to take account of the relatively greater sensitivity to lightness difference at the limen. This is a particular illustration of the fact that colour differences are not additive.

A number of papers in the Symposium (Green-Armytage 9, Hanisch 11, McLaren 17) illustrate colour solids on three-dimensional co-ordinate systems in which horizontal planes of constant lightness are located at different levels through the colour solid. Assuming that we accept lightness as a legitimate subjective variable, an orthogonal co-ordinate system of this type does contribute to the ease of understanding the system, a matter of no little importance as McCamy (16) emphasizes.

The main alternative arrangement uses a triangular format for the hue planes, the samples being arranged in rows which converge on to the colour of maximum purity. In the Natural Colour System this point of convergence is the subjectively perceived pure hue, whereas in the Ostwald system the apex of the triangle is the material sample of maximum obtainable purity. I do not myself think that the NCS triangular format is particuarly difficult to comprehend, since it is easy to visualise any given colour sample within the triangle as the subjective mixture of the pure white, pure black and pure hue located at the three corners of the triangle. On the other hand, the triangular system of co-ordinates is unfamiliar and almost certainly more difficult to use in practice than rectangular co-ordinates.

What does impress me when I examine the actual NCS hue charts is the smooth gradation of the samples across the charts and the apparent equality of interval between one chip and the next. Whether this is fortuitous or a natural consequence of the method of assessing the relative whiteness, blackness and chromaticness of the NCS samples, I do not know, but it must be counted as a bonus for the system. I would suggest that this is worth the attention of our colour-vision theoreticians.

The same bonus does not, however, hold for the NCS hue circle. The steps are far from equal round the hue circle and as an example, the hue step between samples R60B and R70B is much bigger than that between samples B60G and B70G. We have, of course, to recognize the equality of spacing is not one of the attributes claimed for the NCS charts, yet if it could be achieved at least approximately without too much change in the structure of the NCS colour solid, it would surely be worth having. The main change that would be called for, as I see it, would be to bring the green and blue elementary hue planes closer together. I can appreciate that the location of the red, yellow, green and blue elementary hues at 90 degrees apart round the hue circle, provides a nice symmetrical structure to the colour solid, but if this arrangement is based on the fact that red and green, and yellow and blue, are the opponent pairs of colours of the Hering theory, then I think this is a misuse of the theory. The only perceptual justification for the four unique hues being spaces 90 degrees apart round the hue circle would be if it could be shown that the perceptual difference between red and yellow was equal to the difference between yellow and green, and between green and blue, and between blue and red. But perhaps there is something more subtle about the NCS solid that I do not fully understand.

Colour Naming as a Form of Colour Order System

I think it is not too far-fetched to consider colour-naming as a valid form of colour order system. Here we can refer to the paper by Styne (27) as our discussion document, since he has reminded us of the extensive study of colour naming carried out by Kelly and Judd. In his paper Styne summarizes the Kelly-Judd study so that there is no occasion for me to do the same here, but I would commend the main publication, NBS Special Publication 440, to which Styne gives the full reference, as a massive assembly of information and a very clear account of the division of the colour solid into increasingly fine levels of precision with colour terms of increasing discrimination to correspond to the finer divisions of the colour solid. Kelly and Judd defined the blocks of colour into which the colour solid was divided, by their Munsell co-ordinates of Hue, Value and Chromas, but the colour names attached to each block,with their qualifying adjectives and adverbs, are independent of the Munsell or any other colour space. In principle, the Kelly-Judd blocks could, no doubt, be transformed from their Munsell co-ordinates to those of any other colour space and McLaren (17) has urged that they should be transformed to CIELAB co-ordinates. He recognizes the great value of the Kelly-Judd study but believes that the data expressed in CIELAB terms would greatly facilitate their use in industry.

The paper by Sivik and Hård (32) is also very relevant to this topic, especially their experiments to determine the spread in colour space (which they would have liked to illustrate as "bubbles" in a three-dimensional colour space) for which a given colour name, for example brown, might be used. They also stress that certain groups of people living under unusual conditions may be concerned with quite small differences in colour, so that their scale of colour-naming could be greatly expanded. They mention the names of sand colours used by Arabs living in the desert and the names of snow and ice colours used by Eskimoes. This also applies to certain industries, for example horticulturalists with their description of the colours of soils and, I believe, in the paper industry where a near-white paper may be described as blue or yellow.

Another very relevant paper is that of Green-Armytage (8) in which he reports some fascinating results on the ordering of a set of colour chips in respect of a given attribute, as carried out by a number of subjects. We should not be surprised by the first two of his conclusions, namely that different people can mean different things by the same term and that some people can mean the same thing by different terms. As he says, the terms of everyday language, with the possible exception of whiteness and blackness, are understood in too many different ways. Even black was sometimes given some unexpected qualitites, coming near to the top in scales of "purity", "intensity", "saturation", and "brightness".

Results such as these must clearly throw some doubt on the validity of using colour naming as the basis of a colour order system. To take a couple of names at random from the Kelly-Judd diagrams - "grayish greenish yellow" and "moderate greenish yellow" - I wonder what agreement there would be among us at this meeting if we tried to identify samples in an atlas by these descriptions. My guess is that the Sivik-Hård "bubbles" in three-dimensional colour space would be quite large!

The adjectives used in the Kelly-Judd report are, however, quite instructive in revealing the range of subjective variables which could be used as co-ordinates in a colour order system. "Vivid", "brilliant", "strong", "deep", certainly suggest that vividness, brilliance, strength and depth are meaningful alternatives to the more orthodox variables being used and could have some advantages. White and black content are mainly indicated by the gray content of colours with terms such as "light bluish gray" and "dark bluish gray" and then only for colour chips of low chroma. Styne´s Fig. 3 illustrated the qualifying adjectives used in each hue chart and it is significant that "light" and "dark" are not applied to the samples of high saturation, confirming Green-Armytage´s doubts about lightness as a meaningful subjective variable. To take the Munsell sample R 4/14 to which we referred earlier as an example, this is described in the Kelly-Judd study as "vivid red". Similarly, a high chroma yellow, Y 8/12, is described as "vivid yellow". Evidently no need was felt, in deciding on this classification system, to use any additional qualification to indicate that the yellow chip has a much higher light reflectance than the red. We should be grateful to Styne for reminding us of the Kelly-Judd work which clearly calls for detailed examination and discussion.

Other Attributes of Colour Order Systems

A number of new approaches to colour order systems are suggested in papers to the Symposium, most notable in papers by Hård and Sivik (14) and by Sivik and Hård (23). In the former they describe distinctness of border as a concept for establishing a uniform colour space. They recognize that this is not what we would normally understand by a colour appearance attribute, but is more directly related to contrast which, as they rightly say, is of tremendous importance for our visual perception of the environment. I would link this with the remark made by Albert-Vanel (1) in the introduction to his paper in which he reminded us that colours are never seen on their own but always in relation to other colours in the scene. What is particularly interesting is that Hård and Sivik found that observers were able to identify the distinctness of border with high accuracy on a scale from zero where no border was visible to a maximum of 10 for the most distinct border the observer could imagine.

In the other Sivik-Hård paper, four different structure were studied using 10 colours of the same hue, each structure being based on a different subjective concept. The most novel concept was that described by the authors of semantic space, in which differential judgement of the ten colours was made in terms of three principal components, namely Evaluation (beautiful-ugly); Excitement (exciting-soothing); and Forcefulness (energetic-lazy). I would not dare to assess the significance of the results, but I would commend it as an adventurous challenge to new thinking!

In another paper Nemscisc (19) discusses "aesthetically even colour space" as a further attribute that we should consider. There is no doubt that certain complexes of colours are more aesthetically pleasing than others and Nemcsics raises the question whether there is any relationship that can be established which would show why one composition is pleasing and another is unpleasant. The paper by Adam (33) is devoted to the same theme and I would suspect that some of the cleavage planes through the OSA/UCS space model described by MacAdam (15) would quality as aesthetically very pleasing compositions. Undoubtedly, aesthetic considerations in colour design and in the general use of colour are central to many of the uses made of colour order systems and colour atlases, and a number of Symposium papers bear witness to this: Smedal (24), Spillman (25), T. Hard (37), O'Connor, Whitfield and Wiltshire (38). I would also want to link the contribution by Ingalls (34) to aesthetic aspects of colour, especially his reference to very small differences of colour which, in the limit, merge into a continuous gradation of colour. Our aesthetic appreciation of surface texture, for example, depends, I believe, on the gradation of colour over the surface, a gradation which may be of lightness, hue, saturation or some combined effect of all three. The colour difference series described by Ingalls could help in our study of surface texture.

Since trichromatic colorimetry is concerned with colour matching and not with colour appearance, it does not rank as having the attributes of a colour order system in the terms in which I defined such systems in the opening sentence of this paper. However, the CIE specification of stimuli can serve to identify samples on which colour appearance judgements are being carried out, and in the saturation experiments described by K. Uchikawa, H. Uchikawa and Kaiser (29), the loci of constant saturation have been plotted in the CIE x, y,and u′, v′, chromaticity charts. When used in this way, the chomaticity chart can be used to record colour appearance information.

In the same way, the YCM system described by Simon (39) is not strictly a colour appearance system and is allied rather to the principles of subtractive colour photography and to the Tintometer subtractive colorimeter. As Simon says, his system could be the basis of a general approach to another and unique form of colorimetry. From the point of view of this Symposium, we would want to know whether it could also be used to describe colour appearance. If so, the fact that the YCM system is based on colorant mixtures should mean that the system could be linked quite closely with the production of the samples in a colour atlas designed to meet specific appearance criteria.

Discussion

My aim in presenting this paper is to promote discussion on the more controversial ideas that we find in those Symposium papers which are concerned in particular with the basic concepts and attributes of colour order systems. There should be no shortage of questions to be answered and arguments to be settled, and as a contribution to the discussion I have prepared a supplement to this paper listing the questions which I would like to ask. Other contributors will have their own set of questions so we should be in for a lively time!

SUPPLEMENT

Suggested topics for discussion

The first stage in establishing a colour order system is to identify the variables of colour appearance on which the system is to be based. The variables that have been used in different colour order systems may be roughly divided into two broad groups:

Group A: Lightness, hue and saturation.
Group B: Whiteness, blackness and chromaticness.

Ignoring the minor variations within the two groups, the following questions arise:

> Are the A and B variables equally valid alternatives, or is one group right and the other wrong?
>
> Or is one group or the other to be preferred, depending on the use to which the colour order system is to be put?
>
> Is agreement on a single set of variables either possible or desirable?
>
> Is lightness such an ambiguous attribute that its use should be abandoned, as Green-Armytage suggests?
>
> Is chromaticness as used in the Natural Color System an identifiable of colour appearance? Is it the same as colourfulness?

Note that at one time the CIE defined chromaticness as the subjective correlate of chromaticity but I understand this has been changed in the revised vocabulary.

In his paper McCamy stresses that the variables of colour appearance are abstract in the sense that they can be conceived independently of actual material samples. In the same way Svedmyr in his paper claims that the identification of the six NCS elementary colours are built into the human mind. This leads to the following questions:

How abstract really are these perceptual variables?

How did we first learn our colours so that they became built into our minds?

How stable is our long-term colour perception process?

How good is our colour memory?

Styne has reminded us of the very valuable report by Kelly and Judd on "Color: Universal Language and Dictionary of names". This leads to the following questions:

Can we think of colour naming as a valid colour order system?

Bearing in mind the results reported, for example, by Greene-Armytage (8) and Sivik and Hård(33), could colour naming ever be precise enough to provide a practically useful colour order system?

Should the divisions of colour space of the Kelly-Judd report be transformed from Munsell co-ordinates to CIELAB co-ordinates, as recommended by McLaren?

How instructive are the adjectives used in the Kelly-Judd report to describe the different blocks of colour space, in suggesting alternative and useful variables of colour appearance?

Examination of the Munsell Atlas can lead to the following questions:

There is now general agreement that lightness does not correlate closely with luminance factor, in the sense that a saturated colour sample appears to reflect more light than a grey of the same luminance factor. Does this mean that Munsell Value is not a true subjective variable?

Would a Chromas series such as Hue R, Value 4, be better described as varying in proportion of redness to blackness, or redness to greyness, than to describe the series as being of constant Value, which presumably should imply constant lightness, and increasing Chromas?

Does the fact that the relative size of Hue, Value and Chromas steps depend on whether the steps are liminal or supraliminal, adversely affect the merits of the Munsell or any other system claiming equality of interval between the samples in an atlas?

Examination of the NCS charts can lead to the following questions:

Can an observer really be able to visualize what a pure elementary surface colour (that is, a pure red, yellow, green or blue free from any white contamination) actually looks like?

Is the triangular format of the hue planes a significant disadvantage compared to the orthogonal format, to which considerable importance is attached, of the Munsell system?

Is the apparent uniformity of spacing of the NCS chips in the hue planes fortuitous or has it some more fundamental basis?

Although uniformity of spacing is not one of the criteria of the Natural Colour System, the spacing of the Hue planes round the vertical axis could be made more uniform if, for example. the pure Green and pure Blue planes were brought closer together.

Is the location of the four elementary colours, red, yellow, green and blue, in the four quadrants at 90 degrees apart, sacrosant to the system or could they be displaced to give more equal spacing of the hues?

A number of miscellaneous points raised in various papers lead to the following questions:

Do we regard the aesthetic appearance of the charts in a colour atlas an important attribute to a colour order system?

Hård and Sivik have introduced "Distinctness of Border" as a new concept for a uniform colour space, a concept related to contrast perception and therefore of great important to our perception of the environment. Should we encourage Hård and Sivik to develop a new colour space based on this concept?

Bearing in mind the experiments described by K. and H. Uchikawa and Kaiser, under what conditions are we justified in using the CIE chromaticity chart (either the x, y, or the u′, v′ charts) to describe colour appearance?

BASIC CONCEPTS AND BASIC ATTRIBUTES Sessions b and c
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GLIMPSES FROM
DISCUSSION

Witt:
With reference to the CIE definitions of the terms: saturation, chromaticness, chroma, what is the difference in concept and what is the relation between them?

McLaren:
The simplest way of understanding this is the appearance of a shadow serie. If a shadow falls on a Munsell "chroma" colour, the perception is that the shadowed part is darker, has a lower perceived chroma but the saturation becomes constant.

Hunt:
In the new CIE terminology, chroma is defined as colourfulness or chromaticness judged in proportion to the brightness of a similarly illustrated white. Munsell defines chroma as the difference from the grey scale. But a fundamental definition of an attribute ought to say what it is and not define it as a difference from something else. I am a bit concerned about the use of chromaticness in the NCS system. Contrary to the CIE vocabulary it is used there as a measure of absolute chroma. This is to say that the chromaticness of a given sample varies with illumination but in the NCS system the chip carries its c-value with itself so that if the illumination of the page carrying that chip varies, the c-value is the same.

Hesselgren:
To try to define a sensation like saturation in terms of some properties of the stimulus of the sensation is not a correct way. In the NCS saturation, it has been defined as the proportion between the two perceptual attributes chromaticness and whiteness, in their turn defined as the degree of resemblance to the imagination of a pure chromatic and a pure white.

Tonnquist:
When we translated the Swedish terms we used in the NCS system into other languages, we tried to be logical. In a series from the achromatic white to the chromatic pure red, the chromatic attribute was called redness. And as a general term, independent of hue, we found it logical to use the term chromaticness as chromatic was the counterpart to achromatic. And we were also afraid of colourfulness as that indicated that white, grey and black were not colours. But if it can give rise to misunderstanding we are certainly prepared to change the translation to a better word but with the definition of the sensational attribute we are aiming at. Another thing is that the notations on the chips are not true for the NCS system unless certain viewing conditions are fulfilled. As to the question by Prof. Wright about the different attributes, I/we are very anxious to set a project up in order to find a synthesis between existing colour order systems including the advantages of each for different applications. An example of this ambition is the nomographs on

the NCS atlas pages giving the locus of constant lightness/value or which word we should give to the phenomenon by Hård/Sivik defined as colours showing minimally distinct border to one and the same grey colour with a practically approximate constant luminous reflectance factor. However, although we don´t see lightness as an elementary characterising attribute of a colour perception, we don´t see any reason why a colour order system could not contain several variables apart from the three parameters designing the space model, even if they are not independent. And the same could be said with regard to the spacing of the hues. In the NCS, as we see it today, we have used Hering´s model with the elementary hues in right angles. But if there are practical needs, the four characteristic hue scales can be more or less condensed. Hesselgren did that in his atlas, and was criticized for it.

Billmeyer:
As a group we are all guilty of making loose statements. We are not precise enough and if we want to make precise definitions of a number of terms which have been used far too loosely, we must specify the conditions more closely. For example, the equality of the steps in the Munsell grey scale has been discussed, but this equality will hold only under very specific conditions, illuminating light source must be daylight (C), the illuminants must be on a certain level, the background to the samples must be Munsell N.5, and if the conditions are not fulfilled exactly, the properties of the scaling will not hold.

Brill:
Last night we discussed "why should we have a colour order system" and now I would ask "what is a colour order system and what are the ingredients"? We must have that as a framework to handle the kind of precision talked about. We have to catalogize a number of reflectances - the appearances of which are specified. So firstly, every system must have a catalogue over these curves so we can change illuminants and still give meaningful statements. Secondly, we must know which order and spacing is determined for the illuminant. Thirdly, we need an operational framework for determining the spacing, as just noticeable differences - minimally distinct border - distinctness of border - colour naming - degree of resemblance to some imaginery references - or whatever. First, by having specified these ingredients can one find a connection between the colours one wants to use and the system that represents them.

Hawkyard:
As the word chroma is the Greek word for colour, it is contradictory to talk about achromatic colours. So to call white, grey and black colours must be wrong - they are noncolours. To me, colours are objects that show selective absorption of white light of one wavelength as opposed to another wavelength.

Billmeyer:
Equal reflectance is only one way of producing something that will appear white, grey or black. And if one wants to keep constancy in different illuminations, it needs much more complicated reflectance curves.

Green-Armytage:
If white, grey and black are "not colours" what are they? Are they visual nothings? And if one refers to the reflectances of a surface, everybody knows that an object that appears grey - not being reddish or blueish or yellowish or anything elseish - in one visual context may appear chromatic in another illumination or surrounding it will acquire chromaticness. So in that case, it would be a colour in one context and a noncolour in another. We have to remember that language changes and so the meaning of the words. So should we come up with new words for defining the visual attributes, maybe Latin words as it is a dead language that will not change any more.

Hesselgren:
Leonardo da Vinci already claimed that white and black were colours. What Billmeyer pointed out has to be stressed still more: there is not one relevant correlation for all situations between properties of a colour stimulus of an object and the perceived colour of it.

McLaren:
I think that we all accept that white, black and grey are colours devoid of hue - (voice: doesn´t "hue" originally mean only "colour") - and to coin new words would be completely unworkable. They will never be part of the practical colour workers´ vocabulary.

Simon:
Changing the subject, I want to know how colorant mixing comes into the Frieling system in which it is claimed that in its geometrical form it will have all its mixing points opposite to one another. I cannot understand this.

Witt:
Frieling has declared that it is based on rotating discs - a kind of additive mixing. Analyzed, however, it shows nonlinearity, the five basic colours are not in a plane in the three stimulus space and the mixing lines do not meet in a point, a problem Frieling was not aware of.

Hawkyard:
In Wright´s comparison of the NCS and the Munsell systems, he thought that white was missing in the Munsell and that it did not incorporate variant amounts of black but he did not say that one should have variant amounts of white. In textile dyeing and printing, I use coloured dyes and I use black but obviously I don´t use white as it is the background. So I wonder if we should not have a system which uses transparent colours on a white background but which incorporates a variable black.

Wright:
When referring to blackness in the NCS, I was implicitly incorporating whiteness, as both describe some deviation from the appearance of a "pure chromatic" which is not the case in the Munsell.

Green-Armytage:
Kuppers describes a mixture system which involves black mixtures on a white background for process printing.

Hesselgren:
The NCS system refers only to such object colours that are perceived as being of the mode of appearance that David Katz in his book "The World of Colours" called **surface** colours, i.e. colours that appear to belong to the outer surface of an object. Contrary to those, **volume colours**, colours that appear to belong to the inner of a transparent object, do not include the perception of white. In the future we hope that it will be possible to give a structure not only to the surface colours but also include all aspects of the phenomenon of colour appearance.

Hård:
This discussion is a good example of the need for defining different basic concepts for colour order systems. For example, everyone is talking about "basic attributes" from fundamentally various conceptual backgrounds, the phenomenologist, the dyer, the paint manufacturer, the physicist, the instrumentalist, the designer, etc. And, of course, the communication will be frustrating. Already in the realm of interest Sivik and I deal with, the appearance of perception of colour environment - we believe it is most probable that we are dealing with two conceptually different phenomena stemming from the same stimulus situation. One is the perception of the characteristics of each colour and how they are related, and the other is the perception of the difference as such (the interval or contrast). Maybe we should talk about primary - or as we prefer to say, elementary - attributes for the characteristic relations and primary variables for discriminative specification. Hering already indicated this in his polemics with Helmholt´s use of the term ´lightness´. It is a fact that one says that one grey is lighter than other - a quantitative statement. From a quality point of view, one grey can be described as resembling white and black to an intrinsic degree - we can judge its whiteness and blackness which have their natural reference and zero points as they are polar attributes. So in a colour descriptive system, it might be so that the characterization of elementary colour attributes are: whiteness, blackness, yellowness, etc., and in a system for specifying differences it might be more relevant to talk about the variables: hue, lightness and saturation. These variables can be derived from the elementary attributes.

Robertson:
In the series of samples shown on the table with increasing redness, I neither see a decrease in whiteness nor in blackness but in greyness. Has anybody considered greyness as an identifiable and useful attribute in a colour order system?

Hård:
As an immediate comment I have the hypothesis that greyness as a visual phenomenon is the simultaneous perception of resemblance to white and black. And there are several such secondary attributes like brownness, pinkness, orangeness, etc., which we have not yet investigated.

Seim: I have a comment on the NCS system relating to the fact that the attributes have been normalized to add up to 100. Do you consider this as a limitation. If you have a vision of something transient, you only have chromaticness and no blackness or whiteness and why this normalization.

Hård:
What we have tried to do is to identify and quantify the attributes of the totality which we call a colour and so we have given the totality the number of 100. Can a totality be more than 100% of itself? And should this be called a normalization?

Wyszecki:
The statement that there should be different concepts does not seem to be very useful to describe what the difference is. To say that an attribute does not imply a difference is not true. The very word yellowness means a difference to a yellow and means a difference. The same is true for other attributes including chromaticness - there are all degrees from certain anchor points so you are assessing differences. And I cannot envisage any measurement where there are no differences involved - that is the very word of measurement or assessment. So I register here my complaints for the conceptual issue.

Simon:
What surprises me is that the noble name of Ralph Evans has not been mentioned here. In his "last words" THE PERCEPTION OF COLOR he realizes that there are not only three, but at least seven different attributes that have to be considered - greyness is one of them, fluorescence which was another word he coined himself to describe a phenomenon, etc. And it is quite clear what he tried to define in terms of perception and he has influenced a number of people who have concerned themselves about the appearance of colour. So I think we are very corruptive if we try to reduce the phenomenon of colour attribute down to three simple ones. We must think in larger terms and accept these other phenomena that we deal with improperly or have words with special definitions that could be useful.

Tonnquist:
Reverting to one of Wright´s questions: Can an observer visualize or imagine what a pure chromatic elementary surface colour would look like? Based on the empirics from our investigations, the answer is YES. Completely naive observers who had never seen the colour of a spectral colour stimulus had no problem understanding the meaning of "pure chromatic colour" as it was so obvious that one could also trace very small resemblances to white and black - now called amounts of whiteness and blackness in colours of the surface mode. From what we have understood from the experiments, the observers really had in mind what a pure chromatic colour would look like.

McLaren:
Any system which is based on physical colourants is bound to be limited because it ignores the existance of the fluorescent

colourants. When Hård says that you cannot have anything more colourful than a 100% of the colour, it means a 100% of the selected colourant, and that is wrong. It should mean 100% of the colour is the spectral colour which virtually nobody has ever seen and then he would be right. Do the physical examples of the NCS atlas include the maximum colourants of the maximum chroma, and are they given the value of 100? If the spectral colour is given the value of 100, we have to realize that no physical colourant reaches to the spectrum locus.

Hård:
Several times we have tried to make it clear that our research was based on the judgements of what the observers really saw in relation to their imaginations of the pure elementary colour sensations and that the order and scaling of the NCS colours had nothing to do with the colourants used. This is the reason why in the atlas in some hues we have not reached as near to the theoretical boundary as in others.

McLaren:
I can imagine a green that is more chromatic than a spectral green.

Hård:
But the appearance of a spectral green is not perceived as a surface colour.

McLaren:
It can be arranged by letting a monochromatic beam shine on a white surface and then we see what Evans called a fluorescent colour.

Hård:
Exactly, and he describes fluroescent colours as having negative greyness and to my mind such a colour perception has passed the border from the surface mode to the illuminant mode of appearance.

Döring:
What happens with the fluorescent colours? Are they inside or outside the NCS colour triangle?

Sivik:
As has been pointed out, the NCS is, for the moment, limited to denote colours as perceptions and in the surface mode of appearance. It is the apparent colour as a kind of abstraction that is notated and not the stimulus. And in our phenomenological experiences a fluorescent stimulus is not perceived as a colour of the surface mode.

Döring:
One can perceive a fluorescent colour. In the yellow region in the NCS you are very near the maximum chromatic colour C. But yellow fluorescent colours have a luminous reflectance factor of 130.

Hård:
A luminous reflectance factor is not a perceptual attribute. It has never been said that the NCS colour order system includes all imaginable attributes of colour perception but only of so-called surface colours, which in this context does not mean colorants. Normally fluorescent stimulus results in what Evans called fluorent colour perceptions and that phenomenon is not described in NCS, neither is the phenomenon of volume colours - and do we know which are the basic attributes of those?

Sivik:
A comment on the difference between differences and attributes from the phenomenological point of view. Of course the concept of attributes will also mean characterization of different colours by their different resemblance to the imaginary elementary colours - contrary to the situation when you compare juxtapose colours or even a judgement of the interval between the colours as such. And spaces or space models will be different for these two cases.

Wyszecki:
But it is not a conceptual difference. It is just different measurements with different anchor points and these anchor points might be more convenient for certain applications - in one case using so-called "built in" anchor points and in other cases they may be generated by artificial means for some other convenience. So it is not a question of conception but of methodology.

Brill:
Regarding the difference between additive and partitive mixture. A spinning wheel is a partitive mixture and produces a stimulus that lies between the components in the thristimulus space. An additive mixture completes the parallellogram which is generated by the components. And one gets more light than what you get in any of the components in the mixture.

A second comment with respect to the statement is that the maximum saturation should be maximized by the spectral colours and the notion as to what we can imagine as being more saturated. The supersaturated colours attainable by accessive chromatic adaptation of the colour mechanism means that we have a hierachy that constitutes the limits of maximum saturation.

Stenius:
From our experiments with judgements of whiteness, I can report that first we tried to use a physical specimen as anchors for the psychometric measurements. When we heard about the successful attempts by Hård to use only the words as anchor points for judgements of blackness, blueness, etc., we did the same for the special judgements of whiteness for near white colours. This

simple instruction, which should be the reference for whiteness, gave much better consistency both for a single observer and between observers in the psychometric measurements which we interpreted as the method in this case which gave more correct results.

Nemscics:
There are problems when comparing different colour order systems with, for example, CIE or any other, based on colour stimulus if they are based on colour sensations. In the Coloroid we wanted to make make this connection withCIE and colour sensations, and it can be used directly for colour projecting. It is based on aesthetically uniformed steps and their coordinates are related to the CIE. In comparison with the Munsell, we have found a relation which in some cases is a square root and in others a cubic root function.

Stanziola:
As a direct question regarding NCS. When producing the samples to the NCS Colour Atlas, which mechanism did you use to achieve the red that was imaginable and how did you decide that this decision was correct in relation to what was producible in colorants.

Hård:
We did not make any decisions except from the results of our experiments. Our observers were instructed to judge, for each single sample presented to them, the resemblance to their own imagination of, for example, a pure red, a pure white and a pure black. If that sample happened to be the best red we could produce, we got the NCS notations for the appearance of that stimulus and by a sort of extrapolation we afterwards also decided on what stimulus in CIE terms a pure red should be in the viewing situation in question. The statistical accuracy in this kind of psychometric measurement was found to be rather good and can be expressed by the confidence interval on 95% level which was less than 5% as an average.

Plaza:
I cannot understand that it should be possible to judge a colour in relation to something you call an imagination and to get the results you have got. I don´t believe that anybody can imagine a colour he has not seen - so it is what he has seen that is the reference. And as an example, in my experience, there are many stimulus that people call white and will give the same number to all of them, so that if you present a stimulus to an observer without any reference you cannot get the results you get.

"Unidentified":
There seems to me to be some fundamental questions to consider. If it is theoretically possible to order all the colours in a perceptually uniformed space in all directions according to a psychological point of view, we should obtain one system only. And if it is possible, which is then the best experimental psychophysical procedure to use? On the other hand, it is theoretically impossible to reach such a goal. What are the reasons for this impossibility?

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WRITTEN COMMENT
Anders Hård

Referring to Prof. Wright's questions regarding the difference between two groups of perceptive variables that he called A) and B), I would like to make the following remarks:

In the NCS context we see HUE as a derived variable from the chromatic attributes of colour qualities named: yellowness, redness, blueness and greenness defined as a certain proportion between two of them. CHROMATICNESS (approx. = Munsell Chroma) derived and defined as the sum of two of them. SATURATION (mättnad in NCS; approx. DIN Sättigung) is derived and defined as constant proportion between chromaticness and whiteness and could be said to represent the perception of a shadow series. BLACKNESS seems to have a lot in common with DIN Dunkelstuffe and also the inversion of what I phenomenologically understand is behind the English/American term 'brightness' (for colour objects in a constant illumination).

For achromatic colours, brightness and lightness (and WHITENESS which on the achromatic level, and only there, is the inversion of BLACKNESS) could be different words for the same phenomenon. However, in the NCS content LIGHTNESS for simultaneously seen stimulus is treated as a contrast variable and not as a characterising attribute.

The whiteness-blackness scale serves as a reference scale for lightness determination. For chromatic colours, constant lightness is defined as having a Minimally Distinct Border (Boynton-Kaiser) to one and the same sample of the reference scale.

I am aware of the fact that other systems do not usually use phenomenological analyses as a basis for their definitions, contrary to the NCS definitions. This will obviously result in differences in the physical representation of the variables. In spite of that, my comparisons are an attempt to get "under the skin" of the "system inventors" to try to find out what perceptual phenomenon they might have had in mind for their definitions - very often they seem to have been physical ones.

Finally, I wish to focus on a question that has concerned me for a long time. Is it so that the NCS attributes (Group B) represent quantified colour quality attributes that man uses to describe and identify a single colour in an arbitrary colour content, and that Group A variables are more relevant to man in describing the difference between two simultaneously observed colours. We also have to add as a fourth variable (when the two colours have one border in common) the visual phenomon called Distinctness of Border. Could it be that these two approaches could have something to do with the two halves of the brain so that discrimination is dealt with in the rational half (left) and characterization in the emotional half (right).

BASIC CONCEPTS AND BASIC ATTRIBUTES Sessions b and c
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WRITTEN COMMENT
Sven Hesselgren

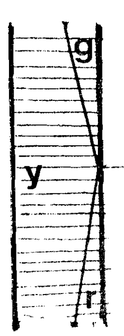
ABOUT THE STRUCTURE OF THE WORLD OF COLOUR SENSATION

We communicate in many ways. One way is by using spoken or written language - words. It is, for instance, used in the physical science. In colorimetry we say that we can measure the stimulus of colour sensations by measuring the wavelengths of the radiant energy that impinges on our eyes. But what "are" these "waves" that we measure? We will come to a point where it appears to be impossible to use ordinary words. We have to explain what we have found by using mathematical symbols. This is even more evident when we follow Albert Einstein into the macrocosmos or Niels Bohr into the microcosmos. I think it would not be necessary to demonstrate this to a researcher in the Physical Universe, a researcher such as a colorimetrist.

How can this be so? Our words from the very beginning are symbols of our mental experiences, and they are not applicable to the entities within the realm of the Physical Universe. To take an example: "Light" is originally the name of a particular sensation. We see that it is light (or dark). This sensation is "awakened" when a particular type of radiant energy touches our eye. The radiant energy can be described as quantas of physical energy, the co-called "photons". But we don´t see photons, we see light. So it is in fact rather misleading to call the physical entity radiant energy "light".

The same holds good also for colour sensations and their stimuli, which are the same as those for the sensation of light.

However, in the realm of sensation and perception it is finally not sufficient to use words to describe these mental entities. We soon arrive at a point when we do understand that experiences must be experienced. If we restrict ourselves to descriptions we will never be able to understand what, for instance, a "colour" is. And in spite of this statement I will now describe a phenomenon that you can experience if you follow my description.



Greenish yellow

Decreasing greenness = increasing yellowness

Only yellowish

Decreasing redness = increasing yellowness

Reddish yellow

You arrange a close series of strong chromatic colours as indicated in Fig. 1. You will find that there is a yellow colour that is neither greenish nor reddish. You can do the same across red, blue and green as well. You will find that there is a red that is neither yellowish nor blueish. a blue that is neither reddish nor greenish, a green that is neither blueish nor yellowish. What you have done so far is to apply the method of phenomenological analysis. But this method can lead you to further experiences.

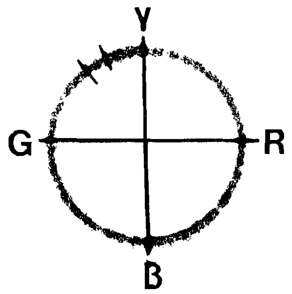


Fig. 2

Arrange a close series of highly chromatic colours in a hue circle like that in Fig. 2. You ought to have them so close to each other that they differ less than a hue threshold. You will need at least 100 colour samples. Take now a pair of two colours that are more than a threshold apart, as indicated in Fig. 2. Look at this pair and "look at your own sensation". You will find that the two colours "belong" to each other in a certain way. They are both yellowish and greenish. Now select another colour pair clockwise further on along the circle. The new pair gives you the same impression of "belonging". Then select further pairs until one individual in the pair passes Y (yellow). Now something suddenly happens. The two colours still "belong" to each other since they are still yellowish, but at the same time they "do not belong" to each other since one is greenish, one reddish. Continue to select colour pairs clockwise along the circle. When the second individual passes Y something concerning "belongingness" happens once again. Now the two colours again "belong" to each other, but in another way than they did when they were greenish. Now they are (yellowish and) reddish. What you have experienced can be described in saying that Y act as as a point of changing character. But remember: This was a description of an experience.

If you want to "know" what I have talked about, you have to repeat the experiment. If you do so, you will experience the experience. If you want to know if other persons have the same experience, you have to use them as observers. Probably their Y:s will not fall upon exactly the same point as yours. You may then use statistical methods to find out what "ordinary people's" mean is.

You can repeat all this across R, B and G. And you will find that Y, R, B and G are the four changing points of character as far as hue is concerned.

If we take into account two opponent nuance triangles, like G and R, we can make the same experiment by passing Wh (white). Also here we can find a similar shift in character, but when we pass over R from what I have here called "bright" to "deep" red, the shift is less and of quite different character.

What I have said so far might allow me to say that the Natural Colour system (NCS) reflects the structure of the World of Colour Sensatiohn.

This statement is supported by a phenomenon that I will show in the following.

Fig 4

Can you see that the eyes in the face to the left are happy, whilst the same eyes to the right are sad? The two figures are <u>emotionally loaded</u> in two opposite ways. It might be observed that it is the <u>meaning of a face</u> that is loaded in this way.

Fig. 5

But also a "pure" form (a meaningless form) is - or can be - emotionally loaded as I have tried to show in Fig. 5. It is, however, difficult to describe these emotional loadings. The nearest we can come might perhaps be using the concepts of "yin" and "yang".

There is a specific pair of emotional loadings related to colours, which cannot be experienced without experiencing colour sensations. They are therefore called <u>sensorial emotions</u>. They are opposite to each other and most often verbally expressed as <u>warm</u> contra <u>cold</u>. This has nothing to do with temperature, it is an autonomous emotion, specific to colour sensation. Everyone who is dealing with colours - artists, designers, architects - knows from her/his own experience that Y is "warm", R also "warm", but B and G "cold". When we use a colour within the quadrant Y-R, the emotional loadings of Y and R "cooperate", almost to "hotness". But when we take a colour between R and B, this is both "warm" and "cold". If you look upon a slightly reddish blue colour, as indicated in Fig. 6, we see that "to be a cold blue it is astonishingly warm". And if we look at a slightly blueish red colour "to be a warm red colour it is astonishingly cold".

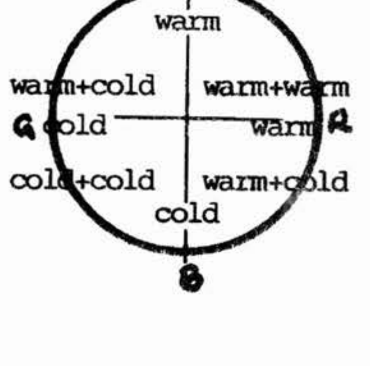


Fig.6

Not all the nuances of the four primary hues are equally loaded. The loading varies with the nuances, as indicated in Fig. 7, showing the result of an experimental investigation carried out by Lars Sivik. We also see that white and black are to some extent emotionally loaded, as relatively "cold".

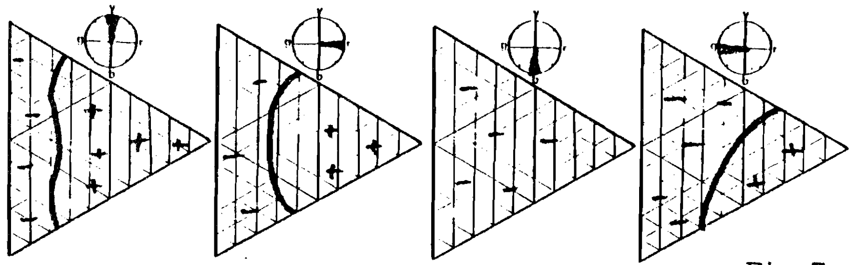


Fig.7

All I have said so far points to the same conclusion: NCS - as Anders Hård has developed it - reflects the true structure of the World of Colour Sensations.

Now back again to the point where I started. For thousands of years man thought that (s)he could obtain true knowledge only by philosophical speculations. These speculations were based on the belief that our perceptions reflected the "true" physical universe. But after "some" time s(he) understood that (s)he also had to look for facts. There are two men whose intuitive thoughts may be looked upon as the shifting point. The first man was Galilei. He published his book Sidereus Nuncius in 1610. There he says "Let us go to demonstrations, observations and experiments". The other one was Newton who published his Philosphia Naturalis Principia Mathematica in 1687. After that physicists began to make experiments. Modern physical "science" was born. And - as I have explained - after several hundred years they found, to their own astonishment, that sensations and perceptions are not at all reflections or "photos" of the external Physical Universe.

Something similar has happened to the study of man´s mental "inside". In about 1850, man began to be interested in facts also here. Modern "psychological science" was born. (I am using the word "science" in a somewhat different manner than the English-speaking world.)

The study of Psychology is a large realm, larger perhaps than the realm of Physics and to Man more important. One subrealm of Psychology is the study of Perceptions. Men like Wundt, Mach, Ebbinghaus, Bühler and many others started to look for facts by experimentation. In regard to Colour Sensations, two names should be emphasized: David Katz and Ewald Hering. Katz developed "phenomenological analysis" in all sensation modalities; as far as colour was concerned he was most interested in Colour Appearance. Hering, on the other hand, deepened his phenomenological analysis into the sub-realm Surface Colours and gave the introduction into what now is known as the Natural Colour System (NCS).

Facts concerning sensations and perceptions can - must - be obtained by experiments, carried out in order to test previous experiences. As I have said in presentations in this periodical, this combination can and must be applied also to the Sensation of the Visual Form World as well as to all other modalities.

Now our civilization has come to a crucial point. Technology based on Physical Science can perhaps lead us to make a better world from the physiological point of view (it might also lead us to destroy ourselves). But to survive physiologically is not sufficient. When we have achieved this goal, we want to fulfil our psychological needs, like perceiving other human beings, other animals than man, other life than animals (vegetation), the inert natur, and - at the very end - our artifacts, objects created by ourselves to meet our own needs as human beings.

It is essential that we handle the environmental artifacts in a more conscious way than we have done so far. Therefore, it is necessary that we - laymen as well as architects - take our conscious knowledge from the realm of Perception Psychology Research.

BASIC CONCEPTS AND BASIC ATTRIBUTES Sessions b and c
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MODERATOR´S REPORT
Peter Kaiser

The session devoted to Basic Concepts and Attributes of Colour order systems was introduced by a lucid, interesting and informative lecture by Dr. W. D. Wright (reproduced herein).- Wright noted that colour order systems are our means of defining color appearance. He specifically noted that "the overriding value of colour order systems is that they deal with colour as we see it and not as we measure it".

In his presentation he neatly tied in all of the papers that were printed in the proceedings that related to the topics of basic concepts and attributes. These included written papers W1, W8. W11, W14 - W17, W19, W23 - W25, W27 - W29, W33, W34, W36, W38, W39 as well as posters P9, P32, P35, P37. The written papers and the poster are reproduced in the Syposium´s proceedings. Therefore, they will not be elaborated on here.

During the discussion period, which was stimulated by Dr. Wright´s lecture, the topics included basic nomenclature, e.g. lightness, hue, saturation, whiteness, blackness and chromaticness, comparison between the Munsell system and that of the NCS. Extensive consideration was given to whether the term lightness should be eliminated. Various opinions were expressed about the number of color names that are required to adequately describe color space.

In summary, the enthusiasm of the participants for the general topic of the symposium, colour order systems, was evident by the general lively and friendly debates that characterized the discussion portion of this session on Basic Concepts and Attributes of Colour Order Systems.

COLOR SPACES AND MODELS
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Session d

INVITED LECTURE

A.R. Robertson

Abstract

The principles on which colour-order systems are based are reviewed briefly. The major examples of colour-order systems based on colour appearance are listed and their scales are compared and contrasted. Major aspects and controversies are discussed with particular emphasis on issues raised in the contributed papers at this Symposium.

1. Introduction

The organizers of this Symposium have asked me to introduce the sub-topic "colour spaces and models" which they characterize as including mathematical, graphical, semantic, and spacing principles. Other aspects, such as philosophies, paradigms, dimensions, variables, quantities, and units have been included in other sub-topics. The border-lines are not very distinct so my contribution may overlap some of the other introductory talks to some extent.

I will review very briefly the principles by which colour-order systems are organized but will then restrict myself to a discussion only of those systems based on colour appearance. Judging from the contributed papers, systems based on colorant or colour mixture seems to be of less interest. I will try to compare and contrast the scales of the major systems using graphs and, in some cases, mathematical formulae. Finally, I will review those aspects of the sub-topic that have been emphasized in the contributed papers assigned to this session.

2. Types of Colour-Order Systems

Three types of colour-order systems have been distinguished./1/ These are: (1) Systems based on the additive mixture of colour stimuli. In these, colours produced by systematic variations of the settings of a Maxwell disk or tristimulus colorimeter are duplicated by material samples. (2) Systems based on the regular adjustment of a limited number of dyes or pigments. The main purpose of these systems is to illustrate the gamut and other properties of a particular set of colorants. (3) Systems based on the perception of colours by an observer with normal colour vision. The scales of these systems are chosen to represent various attributes of perceived colours. However, there are many differences between the attributes of the various systems. The spacing of colours along the scales also varies from one system to another, even when the scales represent the same attribute. In some cases the scales and spacing are based on aesthetic considerations. This is important in environmental design and art which are subjects included in another sub-topic of this Symposium. For this reason, and because of lack of expertise, I will not discuss them here.

3. Types of Scale

3.1 Psychometric Scales/1,2/

Psychometric scales provide a way of assigning numbers to physcal stimuli according to the psychological attributes that the simuli evoke. Of the many types of psychometric scale, four are particularly relevant to colour-order systems:

(1) Nominal scales merely determine whether or not things are equal. Numbers are assigned to the stimuli in such a way that any two stimuli with the same numbers will be equal in the particular attribute being scaled. The catalogues of many paint manufacturers contain examples of nominal scales.

(2) Ordinal scales have all the properties of nominal scales and in addition assign numbers in such a way that the order of the numbers corresponds to the order of the magnitudes of the attribute being scaled. If one stimulus has a higher scale value than another, then it will be perceived as having more of the attribute. All colour-order systems are composed of ordinal scales.

(3) Interval scales have all the properties of ordinal scales and in addition have the property that differences (intervals) between numbers characterize the sizes of the corresponding perceived differences of the attribute. Most colour-order systems consist of interval scales.

(4) Ratio scales are interval scales with the additional property that they have a natural origin; that is, the zero point of the scale corresponds to a stimulus for which the attribute being considered has zero magnitude. This additional property means that the numbers on the scale are proportional to the perceived magnitudes of the attribute being scaled. Many colour-order systems have scales with this property.

3.2 Colour Scales

The perceived colour of an object, viewed in fixed conditions of observation, can always be described in terms of three independent component attributes. Thus colour-order systems always have three, and only three, independent scales. The choice of the three attributes to be scaled varies significantly from one system to another, but three classes of attribute are particularly common:

(1) Lightness is the attribute according to which a sample appears to reflect a greater or smaller fraction of the incident light.

(2) Hue is the attribute according to which a sample appears to be similar to one, or to proportions of two, of the perceived colours, red. orange, yellow, green, blue, and purple.

(3) The third attribute refers to the degree to which the perceived colour differs from achromatic. Many terms have been proposed for this class of attribute. For example, in the contributed papers at this symposium, the terms chroma, chromatic

amount, chromatic content, chromaticness, colourfulness, saturation, vividness, and perhaps others have been used. In some cases the exact definition of the attribute, and not just the term used to describe it, is different. For the time being, I will follow Green-Armytage/3/ and refer to this class of attribute as chromatic amount.

4 Colour-Appearance Systems

4.1-Munsell Color System/1,4/

The three scales of this system are called value, hue and chroma. Value describes the attribute of lightness. Equal steps on the scale are intended to represent equal perceived differences of lightness when the samples are viewed against a middle-grey background. Hue has its usual definition as given above. For any given value and chroma, equal steps on the hue scale are intended to represent equal perceived differences. However a given difference of hue at one value and chroma does not in general produce the same magnitude of colour difference as the same difference of hue at any other value and chroma. Chroma is the Munsell version of chromatic amount. It describes the degree to which a chromatic sample differs from an achromatic sample of the same value.

Munsell value and chroma are ratio scales whereas Munsell hue is an interval scale. However the spacing of the three scales is not the same.

4.2 DIN Colour System/5/

The three scales of the Deutsches Institut für Normung system are darkness degree (Dunkelstuffe), hue (Farbton), and saturation (Sättigung). Darkness degree is a scale of lightness relative to the lightness of the optimal colour having the same CIE chromaticity as the sample being considered. At each chromaticity, the spacing is intended to be in uniform psychological steps, so darkness degree is an interval scale of lightness. However, when different chromaticities are compared, there is no simple correlation between darkness degree and perceived lightness. DIN hue has the usual meaning except that a compromise is made in favour of simplicity by defining lines of constant hue to be straight in the CIE chromaticity diagram and invariant with lightness. The spacing is designed to be perceptually uniform. Thus, as in the Munsell system, hue is an interval scale. Saturation is the DIN chromatic amount attribute. It measures the distance from an achromatic sample of the same luminance factor (not the same darkness degree) in psychologically uniform steps. In another compromise, lines of constant saturation in the CIE chromaticity diagram are defined to be the same for all darkness degrees. For a given luminance factor, equal steps of saturation are equally perceptable, but the perceived size of the steps is smaller at smaller luminance factors and larger at larger ones. Thus at each luminance factor, DIN saturation provides a ratio scale of perceived colour difference, but it is a different scale at each level.

4.3 Natural Colour System (NCS)/6/

In this system, colours are scaled according to their degree of resemblance to the six "elementary" colours white, black, yellow, red, blue and green. Any given sample can have resemblances to, at the most, two of the four chromatic elementary colours (yellow, red, blue and green), and the sum of the attributes is defined to be 100 so that there are, as there must be, only three independent scales. Chromaticness (kulörthet) is defined as the sum of the four chromatic attributes and belongs in the "chromatic amount" class of attributes. Hue (kulörton) is defined by one of the elementary chromatic attributes (a different one in each quadrant) expressed as a percentage of chromaticness. Thus colours of equal NCS hue have an equal relative resemblance to two of the elementary hues. This property appears to be identical to that possessed by colours of equal Munsell hue. There is no simple correlate of lightness in the NCS.

The scales of whiteness, blackness, yellowness, redness, blueness, greenness, chromaticness, and each of the four hue scales (in the four quadrants) are all ratio scales of resemblance. Whether they are also ratio scales of perceived colour difference is an open question.

4.4 OSA UCS System/1,7/

Unlike the other three systems, the Optical Society of America Uniform Chromaticity Scale system is not based on the separate scaling of three attributes. Instead, samples are arranged in a regular rhombohedral lattice so that distances between a sample and each of its twelve nearest neighbours correspond to equal perceived colour differences at any point in the lattice. Thus straight lines drawn in any of six directions in the lattice produce interval scales of colour difference. The position of a sample in the lattice is defined by its position along three orthogonal axes labelled lightness, yellowness, and greenness. However, except for lightness, these axes correspond only approximately to the corresponding perceived attributes. Hue and chromatic amount have no meaning in the OSA system.

5. Comparison of Scales

5.1 Lightness of Achromatic Colours

One of the simplest comparisons of colour-order systems is in their scaling of achromatic colours (white, grey, and black). This comparison is made in Fig. 1 where the following four scales are plotted as functions of luminance factor, Y:

1. Munsell value, V, given by $Y = 1.221V - 0.2311V^2 + 0.23951V^3 - 0.021009V^4 + 0.0008404V^5$, / ref 4/.

2. In the DIN system, 10-D where D is darkness degree, given by $D = 6.1723 \log (40.7Y + 1)$, / ref 5/.

3. OSA lightness, L, given by

$$L = \left\{5.9 \left[Y^{1/3} - \frac{2}{3} + 0.042 \, (Y - 30)^{1/3}\right] - 14.4\right\}/\sqrt{2},$$ /ref 7/; and

4. NCS whiteness, W, given by 156Y/(56 + Y), (ref. 8).

Scaling factors have been applied to the Munsell, OSA, and NCS scales so that they cover the range 0 to 10 as Y varies from 0 to 100.

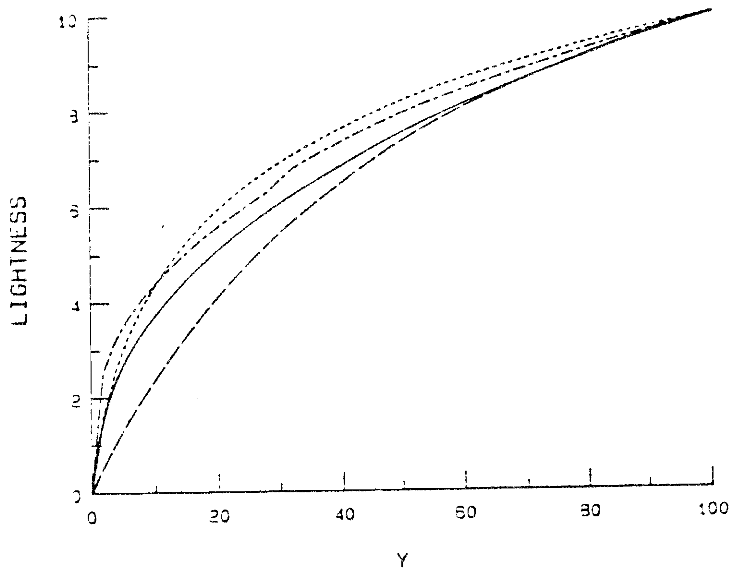

Figure 1. Comparison of lightness scales for achromatic colours

————————	Munsell value (for Y × 1.0257)
---------	10 - DIN darkness degree
– – – – –	OSA lightness (rescaled to 0-10)
—— —— ——	NCS whiteness ÷ 10

The NCS scale represents the proportion of whiteness in the perceived colour, so it is not surprising that the scale is different from the other three. However, at first sight it appears that the other three scales should be identical. The Munsell and DIN scales are both intended to be interval scales of perceived lightness. The OSA scale is an interval scale of total colour difference, but lightness is the only attribute by which achromatic colours differ. (At this point it is worth noting that the ordinate, Y, does not have quite the same meaning for the OSA scale as for the others. The OSA system is specified in terms of the CIE 1964 10° observer whereas the other systems are specified in terms of the 1931 2° observer. However, especially for achromatic colours, the effect of this is probably very small).

One of the most likely causes of the differences between the three lightness scales is in the type of surround used in the scaling experiment. It is well-known, for example, that a difference between two light colours will be seen more clearly against a light background, and a difference between two dark colours will be seen more clearly against a dark background. This effect of background on lightness scaling is illustrated in Fig. 2 which shows how Munsell value should be adjusted for different surrounds. An adjustment of this type was in fact made in the OSA lightness scale.

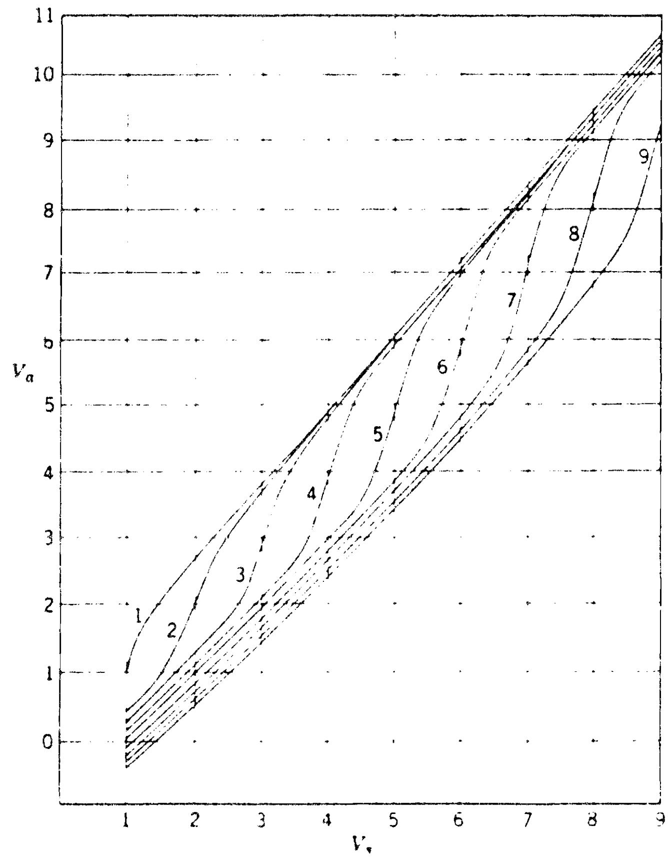

Figure 2. Background-adjusted Munsell value V_a plotted against nominal Munsell value V_s for backgrounds of nominal Munsell value 1,2,......,9. Prepared by Judd and and Wyszecki[9] from a table by Semmelroth.[10]

5.2 Lightness of Chromatic Colours

As one moves away from the achromatic axis, the lightness scales of he various systems become even more different. Munsell value is defined to be a function of luminance factor alone whereas, in fact, the perceived lightness of samples of equal luminance factor increases with increasing distance from the achromatic axis. /11/. This feature of the Munsell system may be regarded as a compromise for colorimetric convenience, of the same nature as the compromises in the DIN system. In the OSA system, the relationship between lightness and luminance factor is modified by a function of the chromaticity coordinates to take account of this variation. DIN darkness degree also depends on chromaticity because it is a function of the ratio between the luminance factor of the sample and the luminance factor of the optimal colour of the same chromaticity. This has the effect that, for constant luminance factor, darkness decreases as saturation increases. However, the changes do not correlate well with perceived lightness/12/. This is illustrated in Fig. 3.

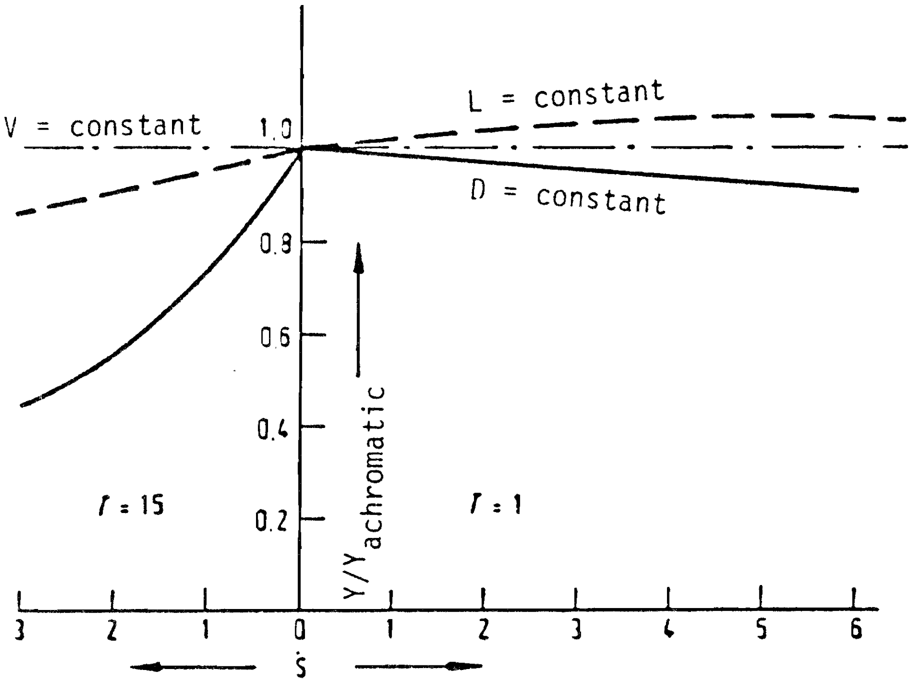

Figure 3. Relationship of relative luminance factor ($Y/Y_{achromatic}$) with DIN saturation for DIN hue planes T=1 and T=15. (From Witt[13]).

— • — • — Colours of constant Munsell value
———— Colours of constant DIN darkness degree
— — — — Colours of constant OSA lightness

5.3 Hue

The DIN definition of hue involves a compromise for colorimetric convenience and the OSA system does not define hue. However, the Munsell and NCS definitions are so similar that one would expect planes of constant hue in one system to be the same as places of constant hue in the other.

The scaling of hue by the two systems should also be similar with one important exception. The NCS system forces the four elementary hues (yellow, red, blue, and green) to be placed at right-angles to each other with the same number of steps in each quadrant. Because of this, the perceptual size of the steps is not the same in each quadrant. In the Munsell system, on the other hand, the five principal hues are chosen so that the spacing of hues is perceptually uniform throughout the hue circle. Comparison of Munsell and NCS hues shows that the largest numbers of Munsell steps is in the red to blue quadrant of the NCS and the smallest number in the yellow to red quadrant./14/ Within each NCS quadrant, however, one might expect the spacing to be the same as Munsell spacing.

Despite these expectations of similarity there are, in fact, small but systematic differences./15/. It would be interesting to know whether these differences are due to experimental uncertainties, to viewing conditions (the NCS judgments were made with a white surround, the Munsell with a grey), or to real differences between judgements of resemblance (NCS) and judgements of difference (Munsell).

Some idea of the differences between Munsell, DIN, and NCS hue can be found by comparing Figs. 4, 5, and 6. Some caution must be exercised in making this comparison however because the lightness levels are different for the three figures. The Munsell data (Fig. 4) are for value = 7, the DIN data (Fig. 5) apply to any lightness, and the NCS data (Fig. 6) are for blackness = 0 (thus the lightness is different at each point in the diagram).

5.4 Chromatic Amount

This is the most difficult attribute to compare because there are, in fact, several attributes in this class, each with a different definition. Many different words are used for these attributes, and often the same word is used in more than one way. In addition there is controversy over which of the attributes is most easily recognized by a naive observer.

Munsell chromas measures the perceived difference of a sample from an achromatic sample of the same Munsell value. At a given lightness level, DIN saturation has the same definition. Thus, one would expect contours of Munsell chromas and DIN saturation to have very similar shapes. That this is not the case is easily seen by comparing Fig. 4 and 5.

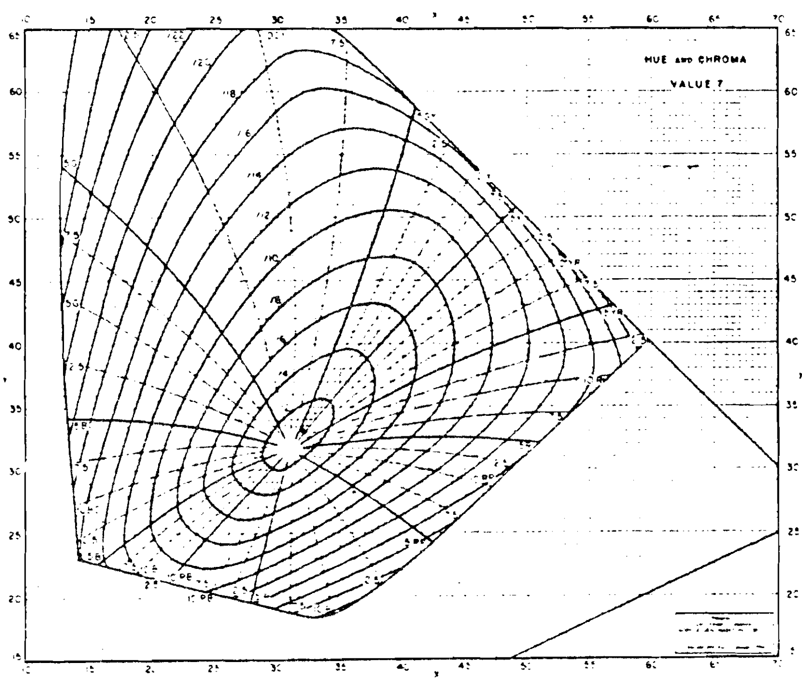

Figure 4. CIE 1931 (x,y)-chromaticity diagram showing loci of constant Munsell hue and constant Munsell chroma at value 7/ of the Munsell renotation system. (From Wyszecki and Stiles[1]).

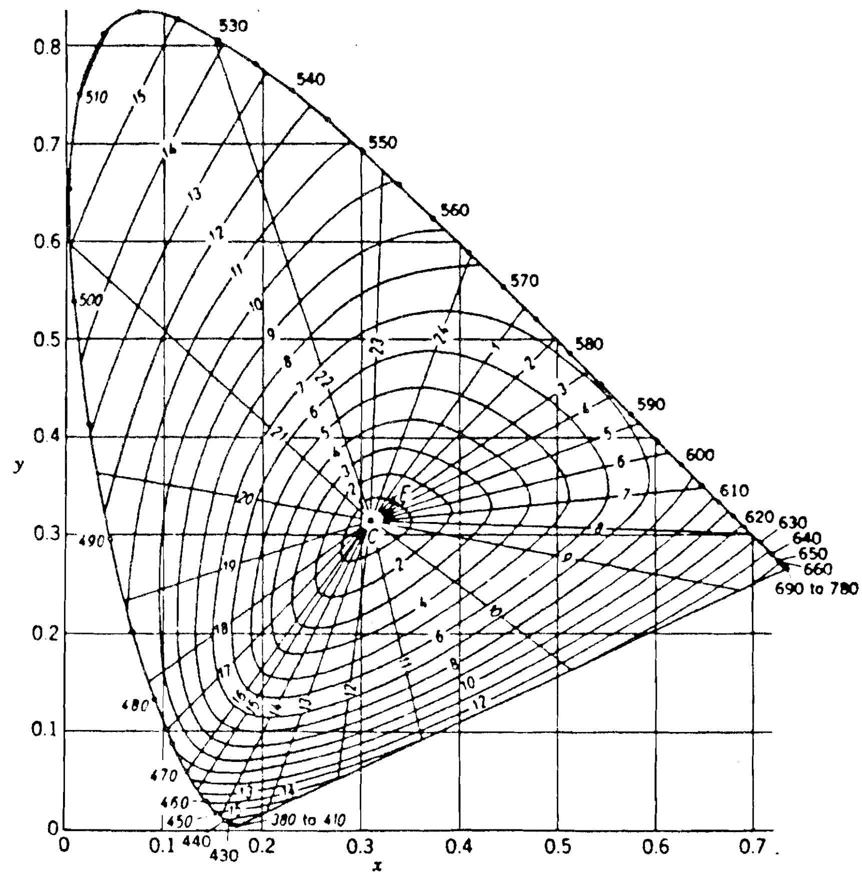

Figure 5. CIE 1931 (x,y)-chromaticity diagram showing straight loci of constant DIN hue and oval loci of constant DIN saturation. The network of lines is valid for all values of DIN darkness degree. (From Wyszecki and Stiles[1], based on Richter.[5])

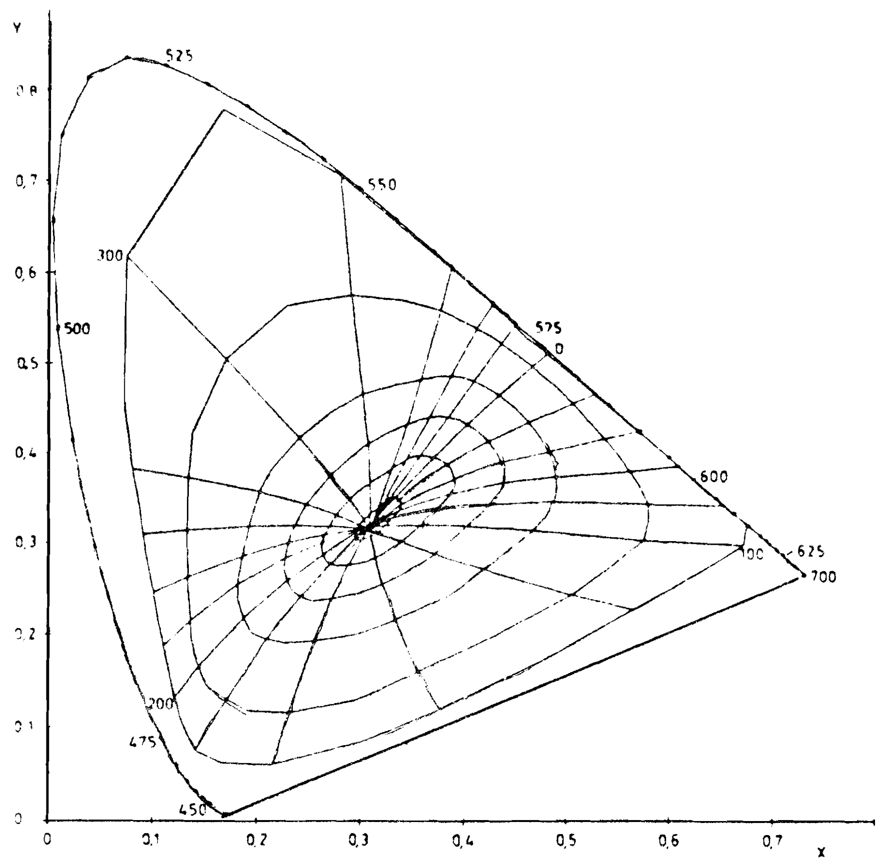

Figure 6. CIE 1931 (x,y)-chromaticity diagram showing loci of constant NCS hue and constant NCS chromaticness for zero NCS blackness. (From Tonnquist[16]).

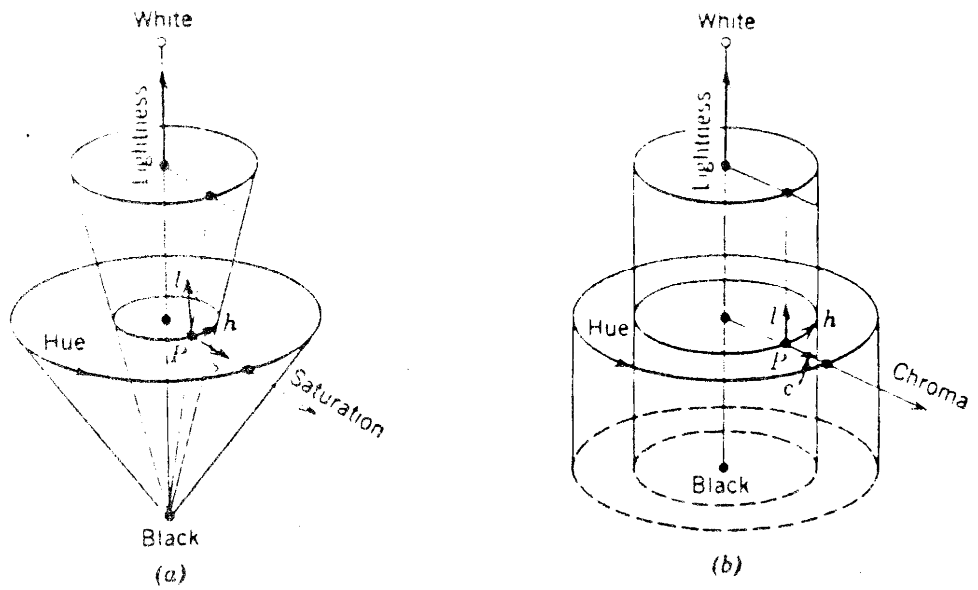

Figure 7. Two geometrical models of color-perception space. (From Judd and Wyszecki[9]).

When colours of different lightnesses are considered, the definitions become different. Equal steps of Munsell chroma are perceptually equal to all lightnesses whereas equal steps of DIN saturation are less perceptible at lower lightnesses (assuming fixed illumination and surround conditions).

In a perceptually uniform colour space, colours of equal Munsell chromas lie on the surface of a cylinder whereas colours of equal DIN saturation lie on the surface of a cone. This is illustrated in Fig. 7.

NCS chromaticness is the degree of resemblances to a maximum, or completely, chromatic colour. The relationship between this definition and the definition of Munsell chromas is by no means obvious, but Judd and Nickerson/14/ have suggested that if the maximum chromatic colour at each hue can be identified in terms of Munsell value and chroma, then a simple relationship might exist as illustrated in Fig. 8. They propose that in a diagram in which Munsell chroma and value are plotted as rectangular coordinates, NCS blackness, whiteness and chromaticness contours might all be straight lines with contours of constant NCS chromaticness being vertical and therefore equivalent to constant Munsell chromas. There would be a separate such diagram for each hue because the Munsell value and chromas of the maximum chromatic colour is different for each hue. They found reasonable agreement between the two systems on this basis, but found even better agreement after development of a non-linear formula. They conclude that a simple relationship does exist between the Munsell and NCS systems.

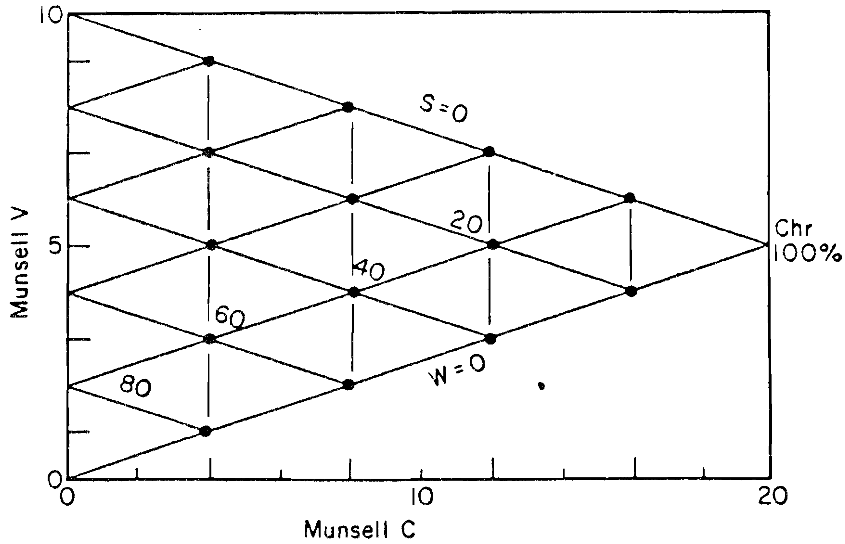

Figure 8. Possible geometric relationship between NCS blackness (s), whiteness (w) and chromaticness (vertical lines), and Munsell value (V) and chroma (C). Chr represents the maximum chromatic colour at this hue and is shown, for illustration, at Munsell V/C = 5/20. (From Judd and Nickerson[14]).

The most common generic word used for the chromatic amount attribute is saturation. However, Wright/17/ has pointed out that saturation is used in two different ways which he has identified as American (the attribute of a visual sensation determining the degree of its difference from the achromatic colour perception most resembling it) and British (the attribute of a visual sensation which permits a judgement to be made of the proportion of pure chromatic colour in the total sensation). The "American" usage fits both Munsell chroma and DIN saturation and therefore needs further subdivision to distinguish between the two. The "British" usage correlates well with NCS chromaticness.

Hunt/18/ has proposed the use of three terms: colourfulness (the attribute of a visual sensation according to which an area appears to exhibit more or less chromatic colour); saturation (the attribute of a visual sensation according to which an area appears to exhibit more or less chromatic colour, judged in proportion to its brightness); and perceived chroma (attribute of a visual sensation according to which a nonluminous related colour appears to exhibit more or less chromatic colour, judged in proportion to the average brightness of its surroundings). These definitions have been accepted by the Colorimetry Committee of the CIE.

Hunt's colourfulness depends on the level of illumination and thus is an attribute not usually considered in colour order systems. His definitions of saturation and perceived chroma correlate with DIN saturation and Munsell chromas respectively provided that "more or less chromatic colour" can be interpreted as "the degree of difference from achromatic". However the definitons leave open the question of whether the defined attributes refer to "degree of difference from achromatic" or to "proportion of chromatic colour".

Clearly the questions of how many "chromatic amount" attributes can be distinguished, which are most readily recognized, which are most useful in colour-order systems, and which words should be used for each, remain open and controversial.

6. Aspects and Controversies

In this Section I will discuss some of the aspects and controversies raised in papers at this Symposium.

6. Description of Systems

Papers by Albert-Vanel(1), Hanisch(11), MacAdam(15), Nemcsics(19), Styne(27), Adams(33), and Hård and Sivik(35) describe various colour-order systems, both old and new. Those authors who introduce new or not well-known systems will have to justify that these systems offer some distinct advantage over the existing systems.

6.2 Effect of Surround

The effect of the surround, and of neighbouring colours in an array of samples, is an important topic that is rarely mentioned, except in passing, in the contributed papers. An exception is Albert-Vanel (paper 1) but his discussion is in terms of aesthetics rather than the effect on the scaling of colour differences or resemblances. This is a subject that warrants more attention.

6.3 Colour Constancy

The importance of colour constancy in the samples of a colour-order system is discussed in three papers: Billmeyer, Berns and Sacher(2); Brill and Hemmindinger(4); and Thornton(40). Each discusses the type of spectral reflectance-factor function that is needed for colour constancy, but their conclusions are startlingly different. Billmeyer et al. find that the best curves are multimodal with secondary peaks having the greatest effect on colour constancy. They give two examples, one with peaks at 465, 580 and 650 nm, the other with peaks at 500, 550, and 600 nm. Brill and Hemmendinger, on the other hand, find that any spectral selectivity greater than is needed to produce each desired colour should be avoided. Finally, Thornton finds that the curves must peak strongly at 450, 540, and 610 nm. Clearly, there are some significant differences of opinion here.

6.4 Comparison of Systems

Papers by Billmeyer and Bencuya(3), Derefeldt and Sahlin(6), Green-Armytage(8), Sivik and Hård(23), Stenius(26), and Tonnquist(28) compare the features of different colour-order systems. Each of these papers gives more details of some of the aspects discussed above.

6.5 Mathematical Models

Several papers discuss mathematical models that describe or define colour-order systems, Hale (10), Hunt and Pointer (13), MacAdam (15), McLaren (17), and Saris (22). Colour-order systems that exist only as a collection of samples with no mathematical relationship to measurable quantities (CIE specifications) have limited usefulness in some applications. On the other hand, if the mathematical model is to be kept reasonably simple, it cannot (with present knowledge) describe uniform perceptual spacing as accurately as a collection of samples.

6.6 Small Colour Differences

Two papers, Hawkyard(12) and Hård and Sivik(14), discuss the evaluation of small colour differences. This is a topic closely related to that of colour-order systems but so large that it is worthy of a separate Symposium!

7. Conclusion

Colour-order systems can be based on many principles, not all of them compatible. Thus, there will always be a need for several systems, each one serving a different purpose. Even among systems based on colour appearance, where the scales are chosen to give uniform spacing of visual attributes, there are differences. Careful study is needed to determine to what extent these differences are due to real differences in the attributes being scaled and to what extent they are due to differences in the conditions under which the observations are made (illumination level and spectral power distribution, type of surround, size of samples, etc. etc.). I hope that we will be able to examine many of these issues in the discussion that follows this paper.

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COLOUR SPACES AND MODELS
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GLIMPSES FROM
DISCUSSION

Sivik (moderator):
According to many remarks earlier, relevant for the present topic, I think that we have to make clear what is a color space and what is a color model. The first requirement for both, in my opinion, is that we define specific variables or parameters of color, along which we order colors.

Then we have the question of how to scale these parameters in steps or distances.

Another question is the number of parameters or dimensions we have to use. It is claimed that three dimensions are sufficient to describe colors, and that may be true for many purposes - but it is certainly not enough to describe all the aspects of color perception.

In order to get an illustration of this multidimenionality of colors we let our French participant M. Albert-Vanel demonstrate his color thinking and color system.

(Here followed a colorful slide demonstration by Vanel of his "Planet color system". See paper W 1:1 in the Preprint).

Sivik:
M. Vanel´s demonstration of the multidimensionality of colors illustrates indeed the fact how many of us who try to be "scientific" by force are restricting ourselves to very few attributes of color - and compared with the complexity of color appearance in its full meaning we are dealing with extracted variables which are often simplified almost into meaninglessness. This must be kept in mind when we now proceed with the discussion.

Wyszecki:
I think this presentation was indeed very useful, to bring out the point of basic concepts. When I came here I thought colour appearance, in particular, colour order systems would be the subject matter, and we have had a great deal of this already. But now we hear there is much more to it and I think that if we should go into this we would have to call the conference "visual appearance" or "appearance of objects", and not just colour appearance. There are, and this is quite normal and it is not presented here for the first time, when you speak of visual appearance you have to deal with all kinds of modes of appearance: gloss, texture, temporal effects and so on. Colour is just one of many modes. It is a separate one, but to mix them all , I agree, would add to the complexity of the problem, perhaps to the confusion and I would say we would be wise to separate them and deal with them separately and possibly discuss how other modes might affect our reaction to colour appearance but to incorporate them all into a single system I think we would have to meet at another conference many years hence.

Kaiser (?):
I think you asked a very good question about the definition of a model and a space. But in a general context it seems that once you have a colour space then, for example, models of what constitute a colour difference or colour constancy may be brought to bear on the single space. You can use the space to a good many colours in a colour harmony if you are an aesthetic interested person or you can use it to figure out what colour constancy is - or anyone of a number of problems that could be brought up.

Witt:
I want to make a comment on the space of DIN colour system. Perhaps the first introduction of the DIN colour system has been to find out the scaling into direction of the three dimensions independent of each other. When you try to construct from these three dimensions a space, you must find some relations between the scaling of the three dimensions in between to put this in a system of order. We tried to find out whether the system could be put into a model or space where some relations can be shown. What we have found out was that the surround condition of the DIN colour system was not so clearly found in the past. But it showed that the situation of the surround should be nearly black.

Billmeyer:
I would like to reply to Alan Robertson´s question bearing on what we have done on the interrelations between the Munsell and the NCS system, and I think the answer is that we have not gone far enough yet to decide whether there is going to be a relationship of the type that Judd & Nickerson postulated on the basis of earlier data. If you look at our paper and leaf through the large group of figures down at the bottom of the poster, which there was not enough space to spread out, and look at the Munsell hue designations you will find that just as Dr Tonnquist´s earlier data showed, there is a significant range of hues, Munsell hues, corresponding to each NCS hue. This certainly is going to complicate the situation and my present guess - and it´s no more than a guess - is that it will turn out that an early complicated, approximate relationship can be made but probably it will be too difficult to get an exact conversion between the two systems. I feel there is no doubt that they are both sampling the same colour space but the complexities of the exact ways in which the sampling is made are going to make it difficult to see clearly the relationship between the two.

Sivik:
Thank you. I find this comparison of Munsell and NCS a very good example to illustrate what I said earlier about different spaces. Can these two be one and the same space, if their variables are differently defined? That´s my question. My opinion is that it cannot be so. Of course, if we were to relate them there would probably come out smooth curves, provided the underlying experimentation is good enough - but if the definitions of the parameters are different the spaces must be different according to such a definition of the concept of space.

Tonnquist:
I think we will have to be careful before we rule out one or the other type of spacing. In both Munsell and NCS we have used the concepts of constant hue and then one would believe that constant hue would be quite an unambiguous concept. But evidently there is something else in it. When Allan Robertson showed his diagrams today I recognised the fact that we have had a different spread for example in the red , and I remember from the experiments when I was responsible for collecting the measurement for the colorimetry results, that I had from earlier literature expected that the elementary red and the unique red would at least at the outer part of the curve fall outside the spectrum locus but this simply was not consistent with the experimental result we had. I also found that compared to Munsell, the degrees of curvature of the loci for constant hue were different. To some extent, of course, this can be explained by a couple of reasons that Alan mentioned, but I would like to add one. When you are working with real colour samples there are evidently the rays at the outskirts of the colour solid which you can´t reach with real samples and where you have to make extrapolations, and of course there is a possibility, perhaps more than a possibility - it is almost certain that this extrapolations will be made differently from one experiment to another. But of course this is something that will have to be looked into in more detail.

Billmeyer:
I would like to respond to Mr Tonnquist on three points. You commented on the fact that in both the NCS and the Munseell system you would have expected the same hue scales to be obtained. I strongly disagree with that because the scaling methods were entirely different. In the case of the Munsell system one is scaling small difference steps between adjacent hues and making the scale points such that the perceptual difference between two very similar hues remains constant around the hue circle. This has been checked by Indow by means of multidimensional scaling in a paper which will appear, I believe, in the next issue to come out of Colour Research and Application, and his results confirm this and also show up a few minor discrepancies in that hue scale which have been well known to people familiar with the Munsell system for a long time.

In contrast, in the NCS system, first the four unique hues were located and then within each quadrant the scaling was such as to divide this interval into uniformed contributions of two of the unique hues. I see no reason in the world to expect that these should lead to the same hue scales and I am quite convinced that they do not.

My second point deals with the deviation of the unique hues and I go back to a paper that Mr Stenius submitted to our journal some time ago on these locations and I sent that to a reviewer who was very familiar with the concept of unique hue in the illuminant mode, coloured lights, and he said that this can´t be right because it shows the NCS unique hue as lying on the spectrum locus and everybody knows that unique red is around on the purple - you recall that and I have come to the belief, without detailed study, that there may be two unique hues depending upon the mode of the colour that is being examined.

My third point goes back even farther than that and it has to do with the extrapolations outside the range of available surface colours and here I have no evidence whatsoever on the NCS system but I do have some evidence regarding the Munsell system because over 20 years ago when I was with a company involved with making transparent plastics we made some very high chroma plastics, in the outer skin of our available gamut which was outside the available gamut of surface colours in the paint system. And we looked in particular at the shifts in the Munsell constant hue lines as one went up and down in value and if you trace out at this skin, this maximum gamut, you find that the constant Munsell hue shifts very drastically from a straight line extrapolation that would be within the spectrum locus to well around toward the middle of the purpose(?). And then you make the colours, a fairly light and a fairly dark fully transparent red and you look at them and you find out that something must be wrong with this extrapolation because the difficulty is to judge constant hue in the presence of a rather large lightness difference, nevertheless it is not difficult to convince yourself that the sample which would plot on the CIE diagram on the same straight line underneath the 5R hue line but at a much lower value level, is much more nearly the same visually perceived hue as the one which would plot on the Munsell 5R line at a low value level which is shifted way round to the purple. I had the privilege of showing these samples to Dr Judd and discussing the matter with him and he agreed with this. Now that area was definitely an extrapolation inserted at the time of the Munsell renotation and I think clearly this is something which needs some day to be reexamined.

Simon:
I am a little disturbed by the cross comparison which seems to be interesting to some people. Maybe I missed the point and to an extent I agree with Mr McLaren. Didn´t you express a transformation into some sort of common language and you suggested CIELAB. And once you have done that I think you have done all that you need to do because several colour order systems have originated from an entirely different concept. Realizing that they are coming from a different view so what, they do, and that´s that and to compare one to another may be interesting but not very productive, at least not for me who looks at things perhaps from a more industrial view than maybe some others.

Tonnquist:
I have come to the conclusion that there might be a difference between the case when you look for unique hues in a spectrograph where you see spectral lights against a dark background - compared to when you are looking for the unique hues in a series of colour samples. I would add one thing and it is that if you are going to compare systems from the CIE coordinates it is very important that those coordinates are obtained from the same colourimeter or spectrophotometer measure, in the same way, with the same illuminating and viewing geometry and all those sort of things.

Hård:
As regards the NCS we have tried to find a definition of what should be meant with constant hue. The last time I met Dr Judd I do remember that he had more or less adopted the same kind of definition, namely "a constant proportion of two chromatic attributes"

But as far as I know the constant hue concept of Munsell is very ostentatious, actually there is no specific definitions of what is constant hue in the Munsell system, it simply says "constant hue in the Munsell system is what is called constant hue in the Munsell system".

Unidentified American:
I think the point I was trying to make was that the Billmeyer data indicates that the Munsell idea of constant hue and the NCS idea of constant hue are at odds to a rather large degree. Another way of looking at either set of figures would be to take a single constant hue chart and compare them to each other to see if defining constant hue could be different and I was wondering if you had done that.

Hård:
Yes, of course. If you take the strongest red which in Munsell is neither yellowish or blueish and look at the what I call the whiteish reds they are in the Munsell atlas blueish definitely. There is no doubt about that and that is not what we call or define as a constant hue. If a whiteish red also is blueish or a blackish yellow is green would you call that constant hue.

Billmeyer:
I think here one must ask precisely what your conditions of observation and lumination were because the perception of hue can vary quite markedly, particularly at that rather low chromas and at lightnesses far away from the background.

Hård:
May I add that according to colour spaces I would say that if its true that Billmeyer says that the intention of the Munsell system is to show equal differences and the intention of the NCS system is to show equal resemblances to certain elementary sensations that we have defined, then these two are definitely two different colour spaces. Another thing is that one single colour space could be illustrated, for instance, in a geometrical model in two different ways.

Hesselgren:
I would ask Mr Billmeyer, am I wrong, do I make a mistake? You know when Ostwald tried to arrange his colours in the system he used a Maxwell disc in order to achieve constant hue. He mixed, for instance, blue with white, and those colours, obtained in such a way they are not perceptually constant in hue. When this was shown to Ostwald he said "Oh yes, then there must be something wrong with our eys. But Munsell arranged his constant hue in this way. Am I right or wrong?

Billmeyer:
I'm not personally familiar with any of the earlier work, but the work that we have studied most recently is the work that led to the 1929 Book of Colour which was after Mr Munsell's death some 11 years earlier and the spinning disc was used there but check me it was not used for the final decisions but just as an aid in formulating, is that correct - yes - and the final decisions were based upon judged equality of distances from adjacent samples. Now this is very much like the judgements that the OSA committee on uniformed colour scales made except that in the case of the Munsell judgements it's my understanding that they were made one attribute at a time whereas McAdam - or perhaps it was Alan - pointed out this morning that the judgements in the OSA system were made in at least two attributes at a time.

McLaren:
Tonnquist made a very important comment a few minutes ago about defining the viewing geometry and other factors. And I think one very important decision could be taken by this particular group, which is probably unique in the whole world. If we could concentrate on the particular configurations to be used. Now the Munsell data is illuminant C two degree observer. For industrial purposes neither of these two are used to any extent at all, industry has gone almost entirely to 10 degree observer which is known to be more reliable. And also illuminant C, because of its deficiency in the ultra violet has been replaced by D65.

COLOUR SPACES AND MODELS — Session d
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WRITTEN COMMENT
Anders Hård

Principally I think that the way Dr. Robertson uses the term "psychometric scale" (which seems to be very much in line with the CIE vocabulary) should be avoided. This term has been used for a long time also in other sciences and means, according to the Webster Dictionary "the measurement of ... mental processes". And this measurement is independent of how it is related to the stimulus that causes the phenomenon. When a psychometric scale is co-related to a stimulus-scale I think it is relevant to call this a psycho-physical relationship. In the same sense as for a physical scale a psychometric scale can be of nominal-, ordinal-, interval-, or ratio-type.

COLOUR SPACES AND MODELS
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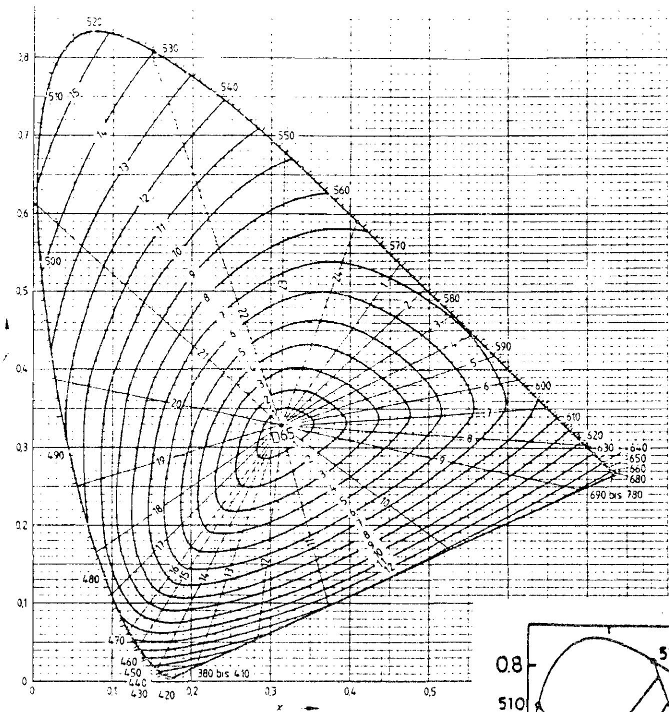
Session d

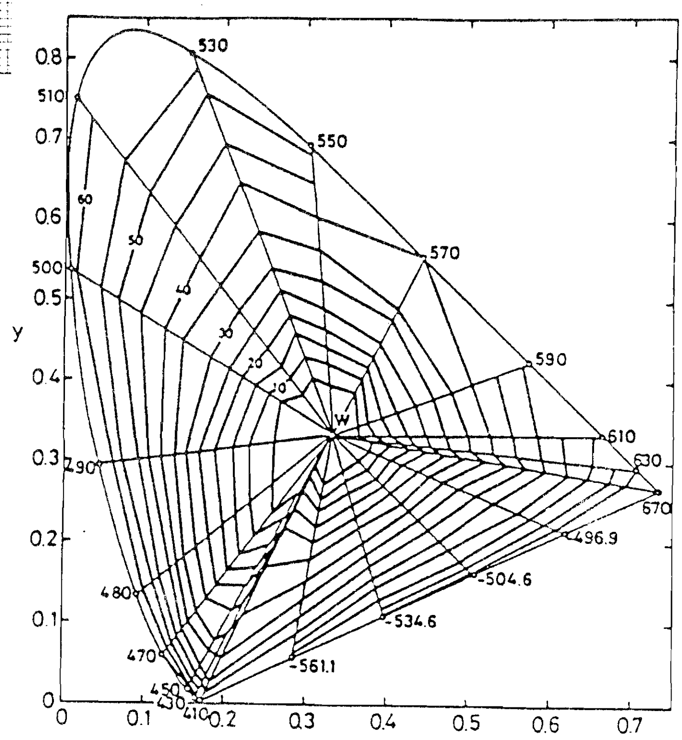
WRITTEN COMMENT
G. Döring

Remark regarding the paper presented by Uchikawa, Uchikawa, and Kaiser:

The scaling experiments for the DIN color system had been done with dark surround, that means with unrelated colors. Therefore the scaling experiments for the DIN-saturation can be compared with those from Uchikawa, Uchikawa and Kaiser. Indeed, in wide regions of the x, y chromaticity diagram, the results of Kaiser et al, give a good confirmation of the constant saturation loci of the DIN color system. Especially in the regions yellow, red, purple and blue, the agreement is rather high.



DIN



COLOR SPACES AND MODELS ***********************

Session d

MODERATOR'S REPORT
Lars Sivik

Yesterday I overheard a remark by Anders Hård concerning the subtopics we had decided upon. He said "During the sessions so far, people have not said what I had expected - but that was what I had expected."

In the meeting of the Study Group on Colour Order Systems discussion focused upon what kind of systems would be included in the bibliography - it was clear that many exist. Not only systems with and without color sample charts, but also historical ones. I would add that there are also both hysterical and esoteric(al) color systems - some of the latter were mentioned yesterday by Paul Green-Armytage. Sometimes I get a desperate feeling that everybody has his or her own private color system.

This apparent confusion is, of course, one of the reasons why some people are bold and crazy enough to try to design color order systems which they want others to believe in. Quite a few of those are here today.

During the actual afternoon session of the conference, attention was given to what was meant by the concepts of color space and color models. Not even this was agreed upon.

Is there <u>one</u> true space of perceived colors in which one can orient axes or color parameters in various ways. Or is it more true to say that there are many spaces which are created in the moment one defines their dimensions and other attributes?

Problems of this kind may, of course, be called semantic-philosophical and I know that many who are dealing with hard, concrete color questions find these discussions unnecessary.

However, during the many years which I have spent in the "world of color", together with Anders Hård, I am more convinced than ever that the theoretical-philosophical-semantic questions are extremely important and relevant.

In order to think, one must have concepts to think with and if these are one-eyed, too restricted or too loosely defined, the thinking will be of the same quality .

In discussions between different groups of color people, there are barriers and misunderstandings due to the different definitions of even common terms.

It is good then to argue and hopefully to be able to sort things out - (I have learnt many additional definitions of old words during these days). Very often I think people do not notice that they <u>do not</u> understand each other; and that is worse - maybe.

Alan Robertson enlightened many dark corners of my mind by his clear review and analysis of the constituent parameters of the most common color systems. He also referred to those conference papers that were relevant to the topic. This lecture was also a good complement to the previous lecture by Dr. Wright on basic concepts and attributes of color systems which, of course, was also relevant to the afternoon theme.

Monsier Vanel´s short presentation of his planet-system was intended to illustrate the multidimensionality of our color vision - in addition to many aspects of feelings and meanings that are associated with color sensations.

The discussion then started with a more earthbound comparison of different color systems - primarily Munsell and NCS.

Discussion was particularly directed to whether or not these two are derived from the same space. This, again, must be a question of definitions - and according to my own opinion, it has to be two spaces, as the basic underlying concepts are different. Another point is that it would be possible to make a synthesis of the two.

Further consideration was given to technical details of importance for the appearance of the psychophysical relationships between stimuli and color, for example, methodological artifacts due to background or luminants, variability among subjects and so forth.

A second round of debate - with a fully perceivable increase of temperature - concerned the theme of lightness-brightness-whiteness. More was to follow later about this.

Among relevant problems which were not discussed during the session which come to mind are, for example, actual shapes and transformations of the graphical models and charts which illustrate the color spaces. I think of the question how well they show the underlying concepts; how easily they are understood in color education, etc.

In retrospect, concerning color spaces and models, it seems as if most of the conference delegates agree that there is a need for many kinds of color systems, from those systems which are purely descriptions of color stimuli to systems which aim at structuring and categorizing the feelings associated with colors.

However, most of us seem to agree that - and here comes another misquotation from the bible - we should try to keep the sheep apart from the goats.

EXPERIMENTAL EVIDENCE
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Session e

INVITED LECTURE

R. W. G. Hunt

PERCEPTUAL FACTORS AFFECTING COLOUR ORDER SYSTEMS

Abstract

The perceptual colour attributes relevant for ordering unrelated, related, luminous, and non-luminous, colours are different in some respects. Colour order systems for related non-luminous colours have been the most fully developed, but different systems depend on different types of experimental data, such as equalization of small perceptual differences, colour scaling, and some relationships to properties of the stimuli. The resulting systems have both similarities and differences, which are worthy of careful study. Chromatic adaptation is an important factor affecting the appearance of samples of colour order systems viewed in illuminants of various colours, and requires further study.

Introduction

The ordering of colours depends to some extent on the type of colours being considered. It is convenient to make two types of distinctions amongst colours. The first distinction comprises:

Unrelated colour. Colour perceived to belong to an area seen in isolation from other colours.

Related colour. Colour seen to belong to an area seen in relation to other colours.

The second distinction comprises:

Luminous colour. Colour perceived to belong to an area that appears to be emitting light as a primary light source, or that appears to be specularly reflecting such light.

Non-luminous colour. Colour perceived to belong to an area that appears to be transmitting or diffusely reflecting light as a secondary light source.

Combinations of the two distinctions result in four different classes of perceived colour, but since non-luminous unrelated colours do not normally exist, so that there are only three classes of practical importance. Luminous unrelated colours include signal lights seen at night, and aperture colours such as uniform fields seen with dark surrounds in optical instruments. Luminous related colours include many light sources, specular reflections of light sources, and "fluorescent" colours. Non-luminous related colours inlude most surface colours and some transmission colours; they are characterized by being able to exhibit a grey content.

Luminous unrelated colours

The dark surround in which unrelated colours are viewed results, for a given stimulus, in much reduced colourfulness (Hunt, 1950; 1952; 1953; Bartleson, 1977), as compared to its appearance when seen as a related colour. This effect persists, although at reduced levels, for groups of related colours, seen with dark surrounds, being still quite large, as shown in Fig. 1, for a mosaic of six colours (Pitt and Winter, 1974), and not entirely absent for more complex arrays (Breneman, 1977). These effects are so large for unrelated colours, that colour order systems developed for related colours are not likely to be directly applicable to unrelated colours, even for those attributes that are common to both.

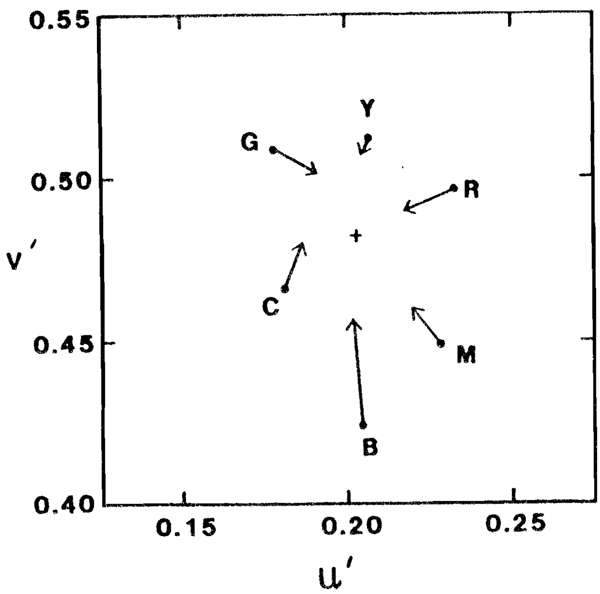


Fig. 1 Chromaticities of colours of a mosaic of six matches (inner points), and (outer points) those of a second mosaic that, when viewed in a dark surround, looked the same as the first mosaic viewed in a light surround of 250 cd/m^2 and colour temperature 5500K (Pitt and Winter, 1974).

The attributes that are relevant to unrelated colours are brightness, hue, colourfulness, and saturation. (The term chromaticness may be used as an alternative to colourfulness, but must not be confused with its obsolete meaning as the perceptual correlate of chromaticity, or its use with the meaning of chroma in the Swedish NCS colour order system.)

The earliest ordering of the brightness of unrelated colours is the astronomer's scale of stellar magnitude, derived originally by perceptual scaling but now defined as a power function of luminous intensity. Similar power functions have also been shown to approximate the experimental results obtained when scaling the brightness of colours of uniform areas seen in dark surrounds (Padgham and Saunders, 1966; Stevens, 1961; Bartleson and Breneman, 1967).

The hues of unrelated colours have been determined for spectral stimuli (Boynton and Gordon, 1965) and for stimuli of all chromaticities (Kelly, 1943) by naming techniques, and for stimuli of all chromaticities by scaling (Bartleson, 1979). The results are broadly similar to those obtained for related colours (to be considered later).

The colourfulness (attribute of a visual sensation according to which the colour of an area appears to be more or less chromatic) of unrelated colours has been investigated by haploscopic matching (Hunt, 1952; 1953), and by scaling (Bartleson, 1979). In fig. 2 some results obtained by haploscopic matching (Hunt, 1977) for an unrelated red colour seen at various luminances are given in terms of corresponding related colours seen in a surround of 8.1 cd/m^2; it is clear from these results that, although colourfulness increases slowly as the luminance is increased, this red stimulus is always much less colourful than when seen as a related colour, and this behaviour is typical of unrelated colours in general.

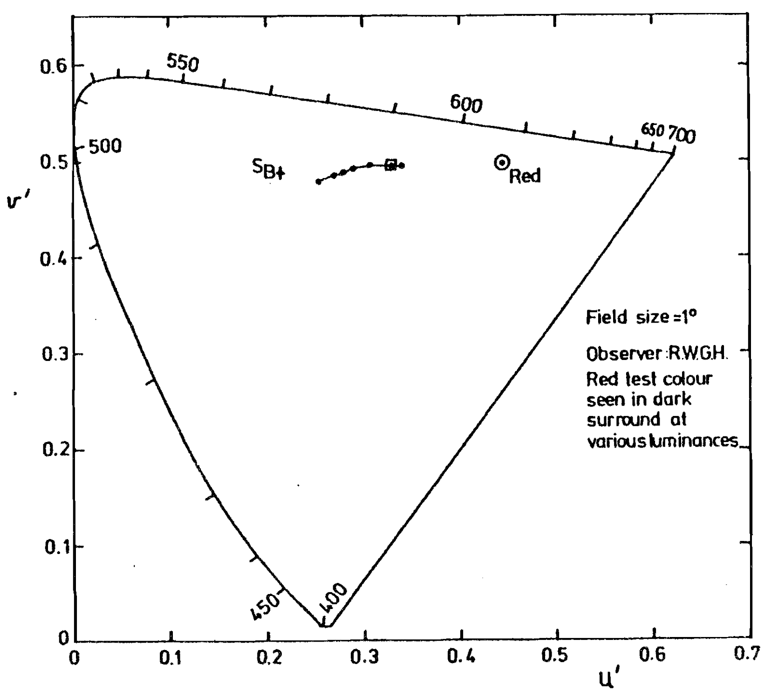


Fig. 2 The chromaticities that, when seen under reference adaptation conditons of Standard Illuminant B at 8.1 cd/m^2, matched a red test colour stimulus seen in a dark surround at luminances 0.30 (point nearest S_B. 0.60, 1.2, 2.3, 4.8, 90.6, and 19.2 (point furthest from S_B) cd/m^2. The circled point is the chromaticity of the colour, and also represents the appearance of the colour when seen at 8.1 cd/m^2 in the reference conditon; the point in the square box represents the appearance of the colour at nearly the same luminance (9.6 cd/m^2). The difference between the circled and squared points represents the loss of colourfulness caused by the dark surround; the points connected by the straight lines show the way in which this reduced colourfulness of the colour seen in the dark surround increases with luminance. The field size used was 1°. (Hunt, 1977).

Saturation (colourfulness of an area judged in proportion to its brightness) has been scaled for unrelated spectral stimuli (Jacobs, 1967) and for stimuli of all chromaticities (Bartleson, 1979; Kaiser, Uchikawa, and Uchikawa, 1983). In the work by Kaiser et al, the maximum saturation allowed for every hue was the same (100), and contours of equal saturation, when plotted on chromaticity diagrams, exhibited some interesting kinks (contours with kinks were also obtained by Rowe for related colours when maximum saturation was similarly restrained; see Padgham and Saunders, 1975). In the work by Bartleson no such constraint was placed on the maximum value allowed for the saturation of different hues and smooth contours were obtained. However, it is not certain whether the kinks are to be associated with the scaling method, or whether some other factors are causing them.

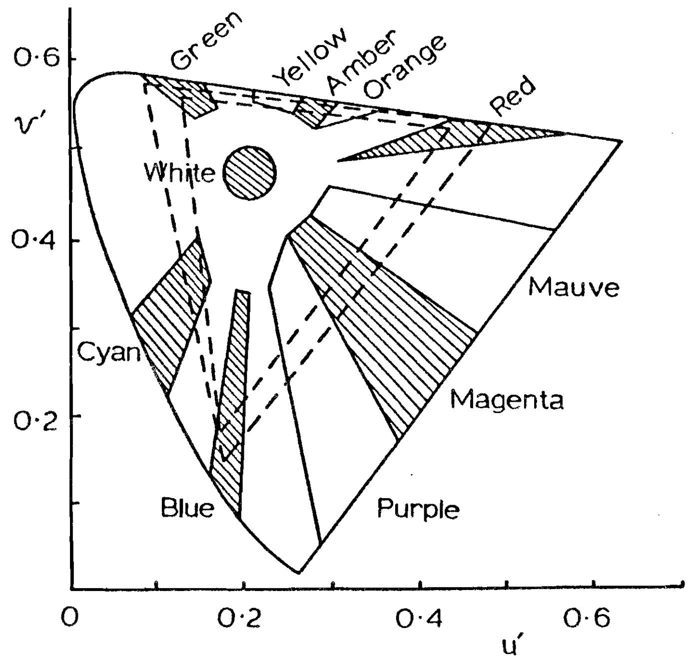


Fig. 3 Chromaticity regions for maximum perceptual colour differences for seven colours (shaded areas) or eight or nine colours (using some of the unshaded areas as alternatives). Broken lines show typical maximum (outer triangle) and minimum (inner triangle) gamuts for shadow-mark tube type of displays (after Laycock, 1983).

Luminous related colours

Luminous related colours, in the form of light sources and "fluorescent" colours, are commonly experienced, but have not usually been much considered in relation to colour order systems. However, the rapid increase in the use of luminous colours in video display units (VDUs), typically in the form of colour cathode-ray tubes and light-emitting diodes (LEDs), has generated considerable interest in colour order systems relevant to them. Of course, colour cathode-ray tubes are very widely used to display colour television pictures, but, in this case, although the display does consist of self-luminous colours, the final perception is usually of a picture composed mainly of areas depicting objects that appear to be non-luminous and possess a grey content. In typical VDUs, however, all the colours can appear luminous; this is particularly the case where the display consists entirely of alpha-numeric or other symbols on a dark background. In Fig. 3 areas of chromaticity are shown for sets of colours chosen for this type of display to provide maximum colour distinction (after Laycock, 1983). If no more than seven different colours are needed, the choice can be made from the shaded areas; if eight or nine are needed, then orange and yellow can be used instead of amber, and purple and mauve instead of magents.

Non luminous related colours

Most of the colour order systems that are in common use are for non-luminous related colours. The Lovibond Tintometer system consists of transmitting coloured glasses carefully graded so that superimposed groups of glasses in each of the three colours provided are equivalent to single glasses of designations numerically equal to the sum of the designations of the individual glasses used in a group. The system is widely used for measuring both transmitting and reflecting samples. Most other colour order systems using non-luminous related colours consist of reflecting samples and are used in connection with surface colours almost exclusively.

For luminous colours, the four colour attributes brightness, hue, colourfulness, and saturation, are applicable; but, for non-luminous colours, two additional attributes apply: lightness (the brightness of an area judged relative to the brightness of a similarly illuminated area that appears to be white or highly transmitting) and chroma (the colourfulness of an area judged as a proportion of the brightness of a similarly illuminated area that appears to be white or highly transmitting). For transmitting and reflecting objects, where brightness and colourfulness generally increase as the illumination level increases, lightness and chroma generally remain approximately constant, and are therefore very important attributes in aiding in the important visual task of recognizing objects. Most commonly used colour order systems are designed for a medium photopic level of illumination, and are intended to represent only orderings in lightness and chroma (or saturation) and not in brightness and colourfulness.

The brightness and lightness of non-luminous related colours have been the subject of studies by several workers (for example, Stevens and Stevens, 1961; Bartleson and Breneman, 1967). In Fig. 4 is shown a summary of results from the work of Stevens and Stevens; scaled brightness is plotted against log luminance of the simuli. Each of the nearly vertical lines represents the brightnesses of a scale of greys at a single level of illumination;the increasing slope of these lines with increasing illuminance represents a gradual increase in apparent contrast. Each of the more nearly horizontal lines represents the brightnesses of a single sample of the grey scale at different illuminances; the line marked $Y/Yn = 0.16$ represents a sample with a luminance factor of 16 per cent and, as it is almost exactly horizontal, it represents the fact that the brightness of a medium dark grey is almost independent of the level of illumination; the slopes of

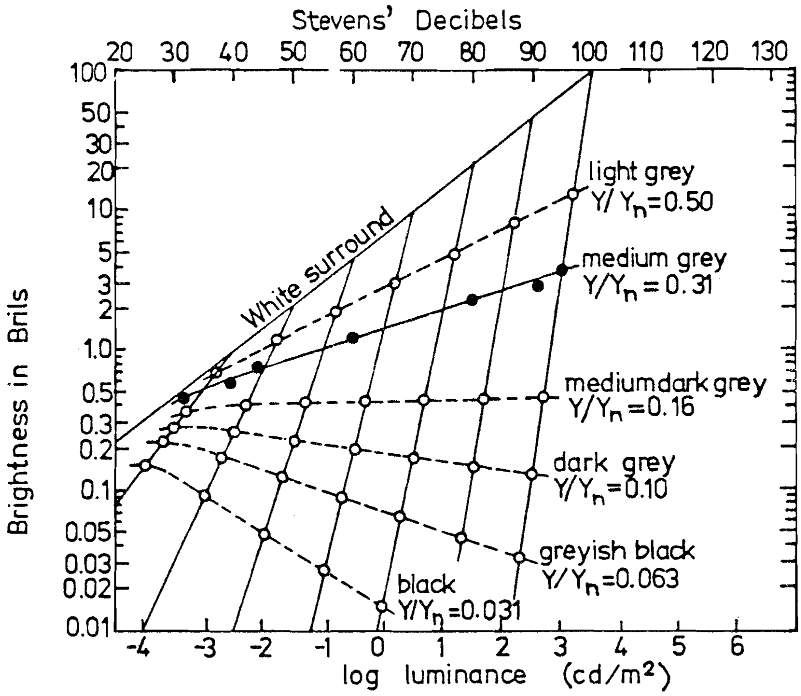


Fig. 4 Scaled brightness plotted against log luminance. The top sloping, line, marked "white surround", shows how the brightness of a white surround varies with its luminance level. The nearly vertical lines show the brightnesses for a grey scale seen at various levels of luminance against the white surround. The more nearly horizontal lines show the brightnesses of particular greys on the grey scale at various levels of luminance. A grey scale seen against a white surround thus loses contrast as the illumination level falls, whites and light greys becoming of lower brightness, dark greys and blacks becoming of slightly higher brightness, and medium dark greys maintaining approximately constant brightness. (Stevens and Stevens, 1961).

the other (more nearly horizontal) lines show that, as the illumination level increases, lighter greys and whites increase in brightness, and darker greys and blacks decrease in brightness.

The method of judging the lightness of samples can affect the results and this is illustrated in Fig. 3 where the CIE correlate of lightness, L*, is compared with the NCS (Natural Colour System; Tonnquist, 1975) parameter, whiteness. The L* function was derived to approximate the Munsell correlate of lightness, Munsell Value, the experimental basis of which was judgements of equality of difference in lightness between neighbouring samples of grey scales. The NCS whiteness parameter was based, on the other hand, on subjective scaling of the amount of white content (as distinct from black content and colour content). It is clear that the two functions shown in Fig. 5 are similar, but have appreciable differences for dark samples. It is also well known that the lightness of the background on which samples are viewed has a marked effect on their lightnesses; the resulting induction makes dark colours lighter when seen on dark backgrounds, and light colours darker when seen on light backgrounds (Hunt, 1965).

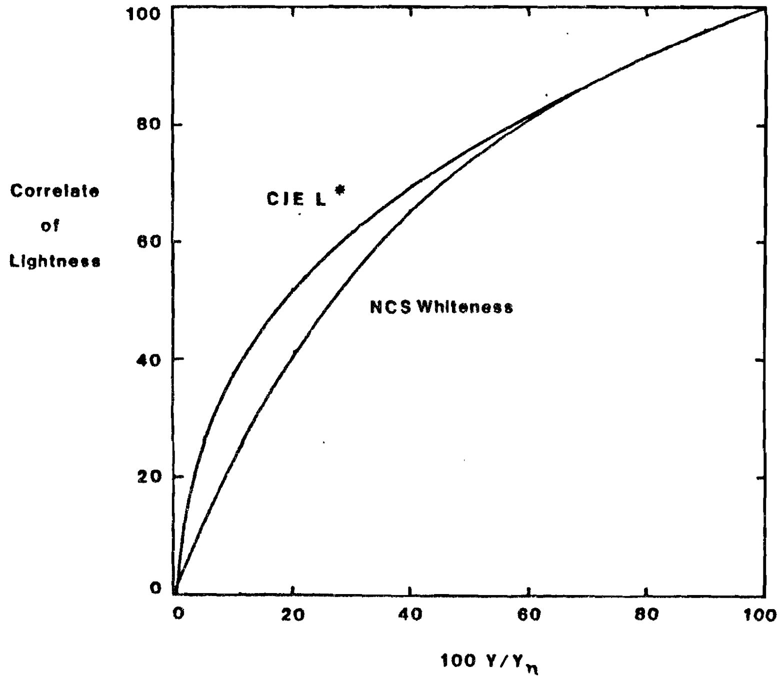


Fig. 5 The CIE L* function (closely representing the Munsell Value scale), and the NCS whiteness function, plotted against percentage luminance factor, $100Y/Y^n$.

The unique hues (reds and greens that are neither bluish nor yellowish, and blues and yellows that are neither reddish nor greenish) have been carefully studied for surface colours in the NCS, and their loci on a chromaticity diagram are shown in Fig. 6. A very interesting fact is evident from Fig. 6: although redness and greenness are mutually exclusive perceptions, the loci of unique red and unique green do not form a smooth transition in chromaticity through the perceptually neutral point. This means that, in terms of stimuli, the criteria for unique red and for unique green must be different: the one is not simply a complement or inverse of the other. The same is also true of unique blue and unique yellow. These facts have implications for the relationships between stimuli and the physiological processes on which the perceptions of the unique hues depend.

The loci of constant hue in chromaticity diagrams have been obtained in several studies, including those in which stimuli of neighbouring purities have been compared (as in the Munsell system, and in studies by Wilson and Brocklebank, 1955, and by MacAdam, 1958), and those in which colour scaling of some sort has been used (as in the NCS). Most studies show broadly similar results, and the loci shown in Fig. 7 are from the work of Wilson and Brocklebank. It is clear that these loci are, in general, not straight, and the presence of curvature points to the presence of nonlinear physiological processes in the visual pathway.

In Fig. 8 are shown the constant hue loci of the Munsell system in plots of u*, v* of the CIELUV system, and in a*, b* of the CIELAB system. The CIELUV system is linear in its treatment of chromaticities, and, as must be expected, does not represent the Munsell Hue loci as straight lines, as would be desired. The CIELAB system, however, does treat chromaticity non-linearly, but unfortunately the Munsell Hue loci are no less curved; evidently the CIELAB system does not, in this respect, introduce the desirable non-linearities.

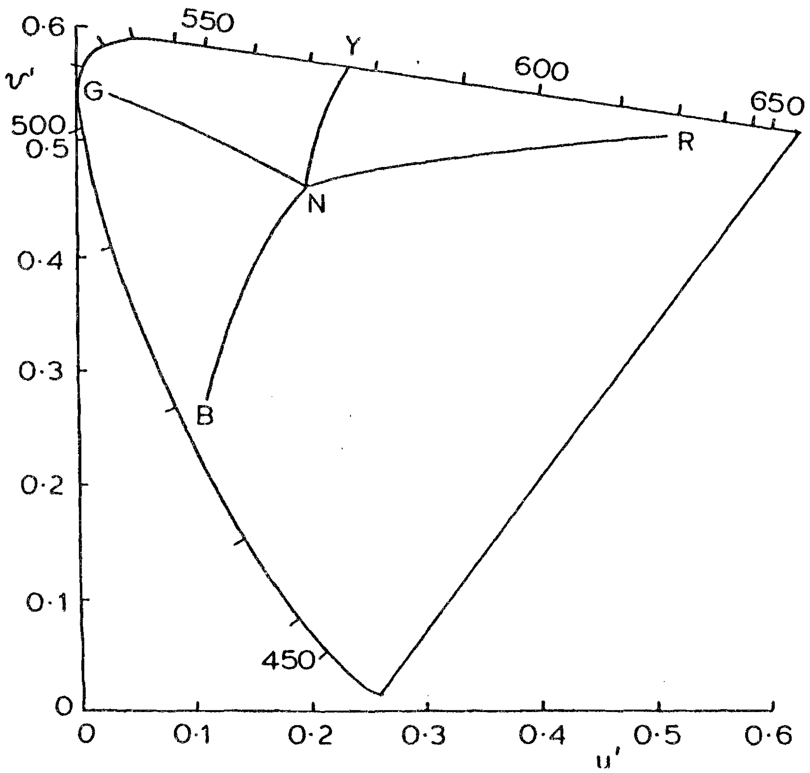


Fig. 6 The chromaticities of the unique red, green, blue and yellow hue loci of the NCS.

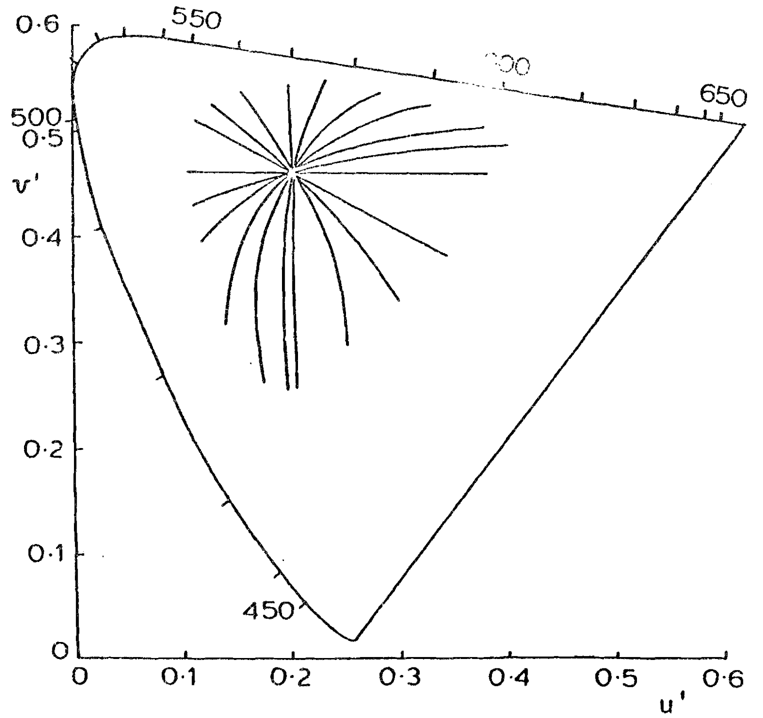
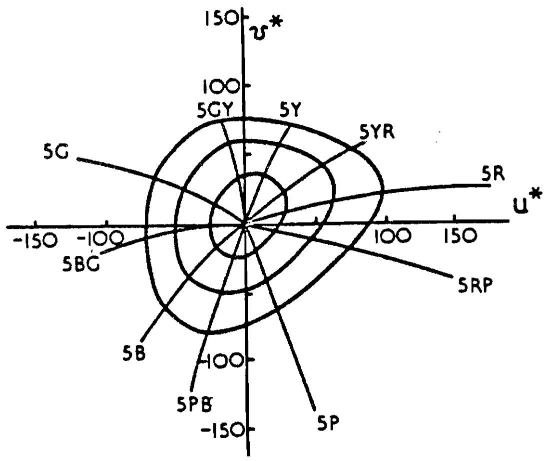


Fig. 7.The chromaticities of constant hue loci (Wilson and Brockelbank, 1955).

(a)



(b)

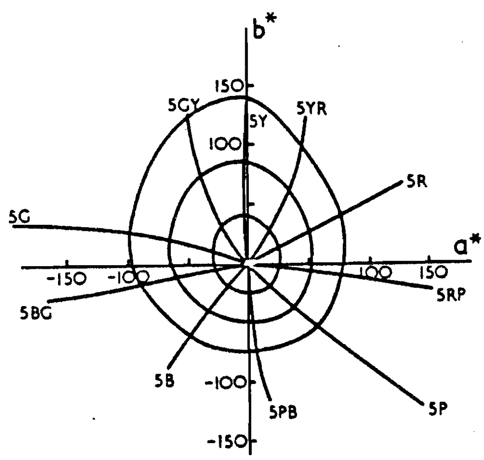


Fig.8 Loci of constant Munsell Hues, and of Munsell Chromas (4, 8 and 12), plotted in the CIELUV u*, v* diagram , and in the CIELAB a*, b* diagram.

Turning now to colourfulness, in Fig. 9 the results of haploscopic matches show, for a reference field of surround luminance 8.1 cd/m^2, corresponding colours for a series of both greater and smaller surround luminances (Hunt,1953). It is clear that colourfulness increases markedly as the level of surround luminance increases and it is, of course, common experience that scenes become more colourful as illumination levels increase.

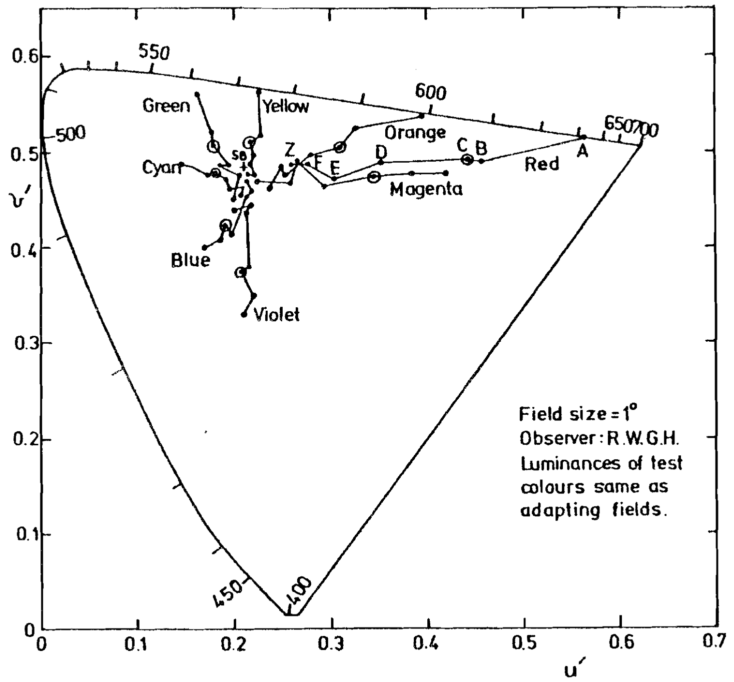


Fig. 9 The chromaticities of colours that, when seen under adaptation conditions of Standard Illuminant B at 8.1 cd/m^2, matched a set of eight test colours seen under various levels of Standard Illuminant B. The points A, B, C, D, E, and F, show how the appearance of a red colour stimulus becomes less colourful as its luminance and that of the adapting field are reduced from 1080 (A), to 65 (B), to 8.1 (C), to 2.7 (D), to 0.32 (E), to 0.075 (F) cd/m^2; the point Z refers to the F luminance for the colour, but zero luminance for the adapting field. The points marked "orange" show similar results for an orange colour stimulus; and the points marked with the other colour names show similar results for the other six colour stimuli. If the average reflectance of a typical scene is taken as 20 per cent, these luminance levels correspond to the following levels of illumination in lux: A, 16900 (cloudy daylight); B, 1020 (dull daylight); C, 127 (twilight or living room); D, 42 (twilight or good street lighting); E, 5.0 (poor street lighting); F, 1.2 (ten times full moonlight). Field size 1°. (Hunt, 1953)

With regard to chroma in the Munsell system, Munsell Chroma was derived experimentally by judging neighbouring samples (of the same hue and lightness) for equality of difference in chroma. In the NCS, however, colour-content was based on the subjective scaling of the amount of colour present in samples (as distinct from their white-content and black-content). In Figs. 10a and 10b a selection of results is shown for the Munsell system, and in Figs. 11a and 11b, a similar selection for the NCS, in plots of CIE L* against CIE C^*_{uv}. It is clear from these figures that Munsell Chroma and NCS colour-content are both represented in these plots by rather similar patterns of near vertical lines, indicating that, in spite of the different experimental bases used, the same perceived attribute, chromas, must have been isolated in both cases. If, however, contours of constant Munsell Chroma and constant NCS colour-content are plotted on a chromaticity diagram, it is found that, as shown in Fig. 12, while the contours are similar in the red-yellow, the yellow-green, and the green-blue quadrants, they are appreciably different in the blue-red quadrant; in this quadrant the Munsell samples require lower purities to maintain the same level of chroma. This may, perhaps, be caused by the use of the fifth, non-unique, hue, purple, in the Munsell system; the combinations blue-purple and red-purple, can be regarded as blue-blue-reds and red-red-blues, and this might cause over-estimation in the judgement of equal chroma for different hues in this quadrant.

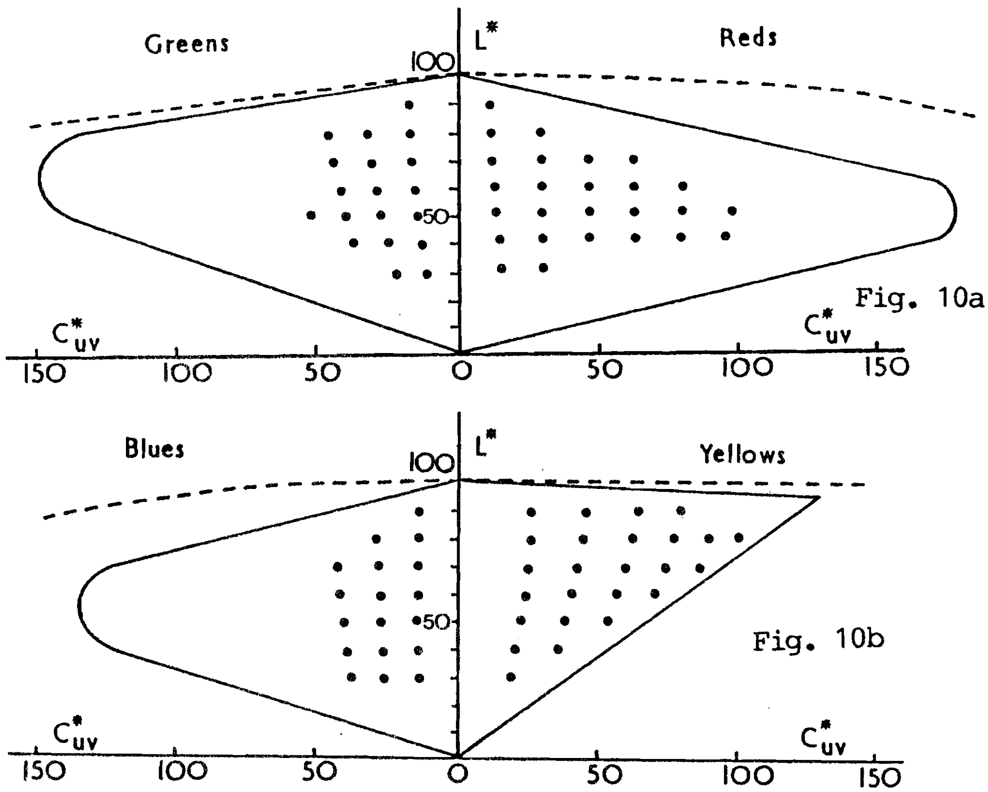
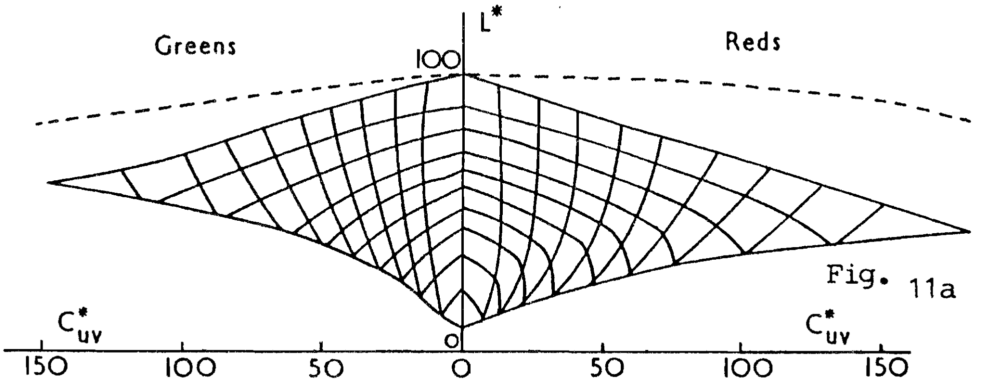


Fig.10 Plot of L* against C^{*uv} for (a) green and red colours, (b) blue and yellow colours. The outer full line is the focus of the optimum colour. The points represent samples in the Munsell Book of Colours (matte sample version) for Munsell Hues 5.OR, G, Y and B. Samples having the same Munsell Value lie on horizontal lines; samples having the same Munsell Chroma lie on the approximately vertical loci defined by the columns of points shown. The broken lines are loci of colours having the same lightness as the white.

In the DIN colour system, series of colours are provided in which the luminance factor is varied while the chromaticity is kept constant. These "shadow series" of colours, for which the attribute saturation is usually constant, would be represented in Figs. 10 and 11 by straight lines radiating from the "black" point, for which L^* and C^*_{uv} are both zero.



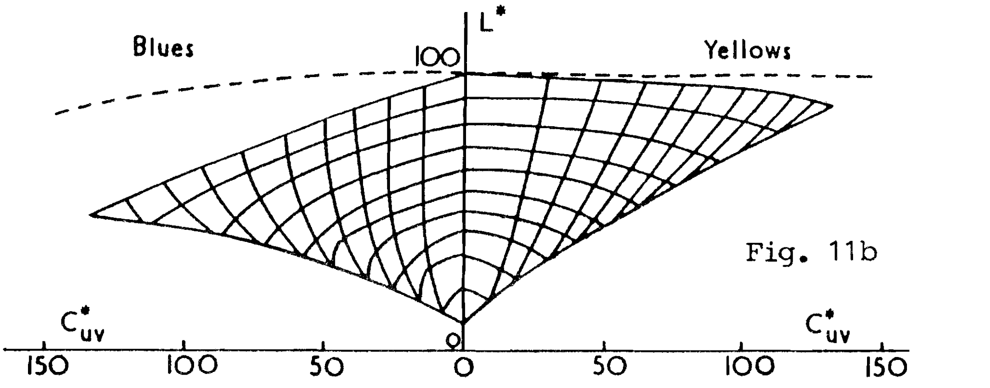


Fig.11 Same as Fig. 10, but showing the NCS loci of colours having constant black-content (arcs approximately concentric with the zero point), and of constant colour content (approximately vertical lines).

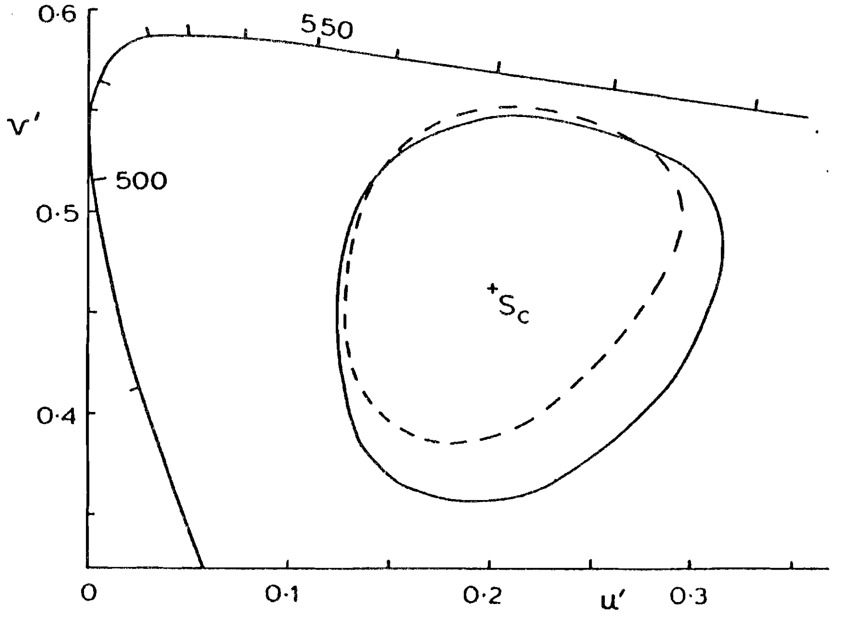


Fig.12 Broken curve: chromaticities of a locus of constant Munsell Chroma (for samples of Munsell Value 5). Full curve: chromaticities of a locus of constant NCS colour-content (for samples of similar Munsell Value).

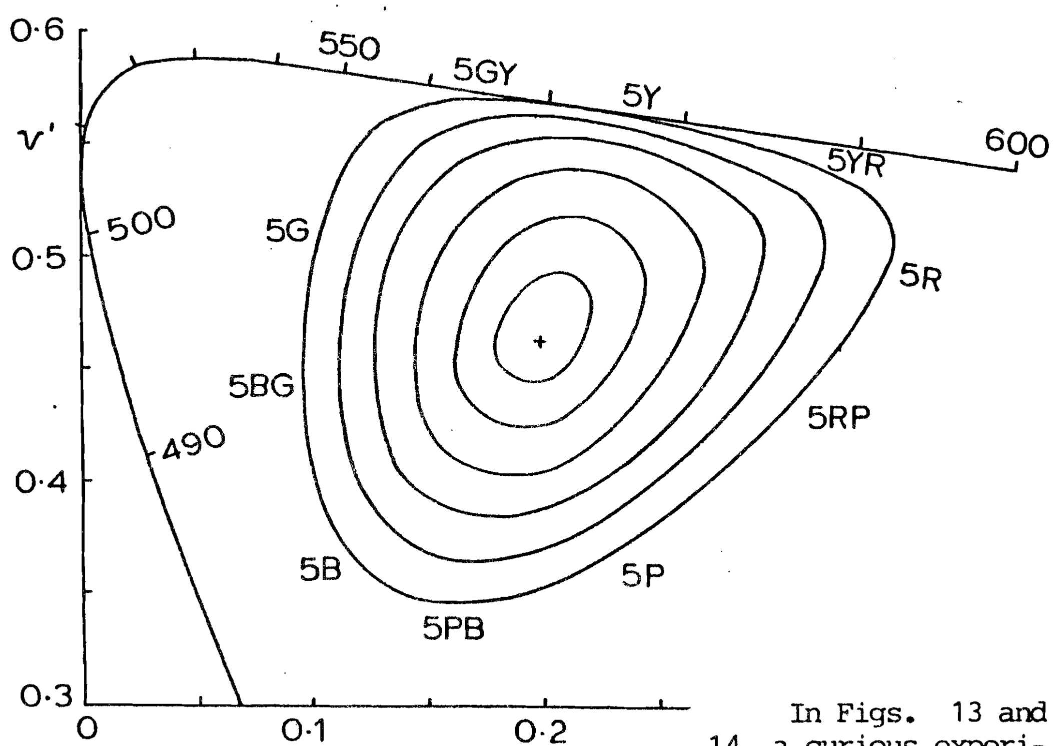


Fig.13 Chromaticities of loci of constant Munsell Chroma (Value 5); +marks the illuminant point (C).

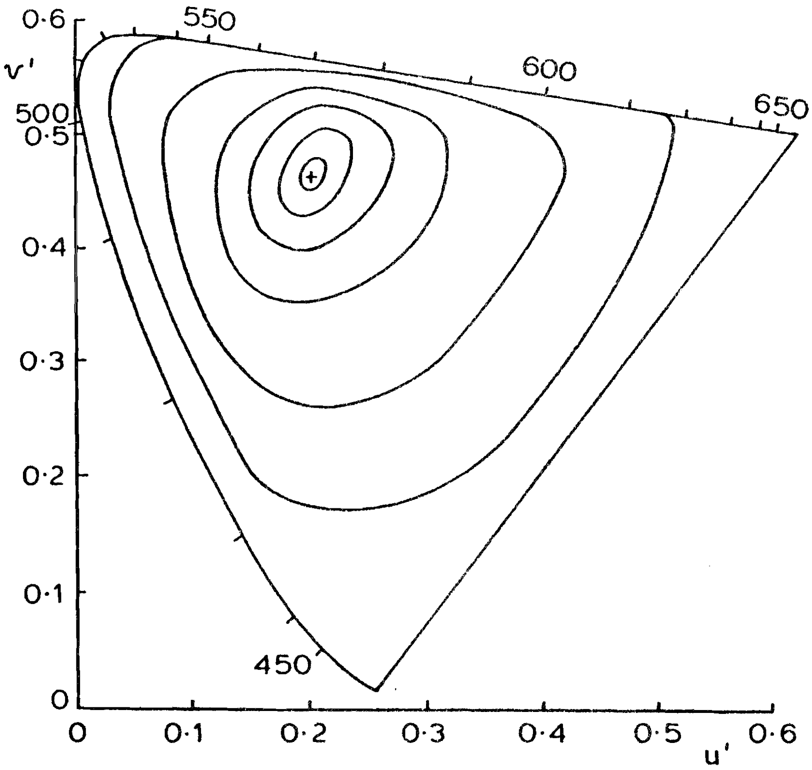


Fig.14 Same as fig.13, but for constant NCS colour-content.

In Figs. 13 and 14 a curious experimental fact is illustrated which is common in both the Munsell system and the NCS (and is also found in some other studies). Fig. 13 shows contours of constant Munsell Chroma and Fig. 14 contours of constant NCS colour-content. In both cases the contours converge on the illuminant point eccentrically. Such an eccentricity could be an artefact of the particular chromaticity diagram being used. But, as the diameter of the contours decreases, the eccentricity becomes decreasingly dependent on the particular chromaticity diagram used, and seems to be a real phenomenon in any physiologically reasonable diagram. This suggests that there is an asymmetry between the physiological treatment of stimuli for the perception of blues and yellows: and similarly in the case of reds and greens. This seems worthy of further study, and may be connected with the different criteria that must be operating for opposite pairs of unique hues, noted earlier.

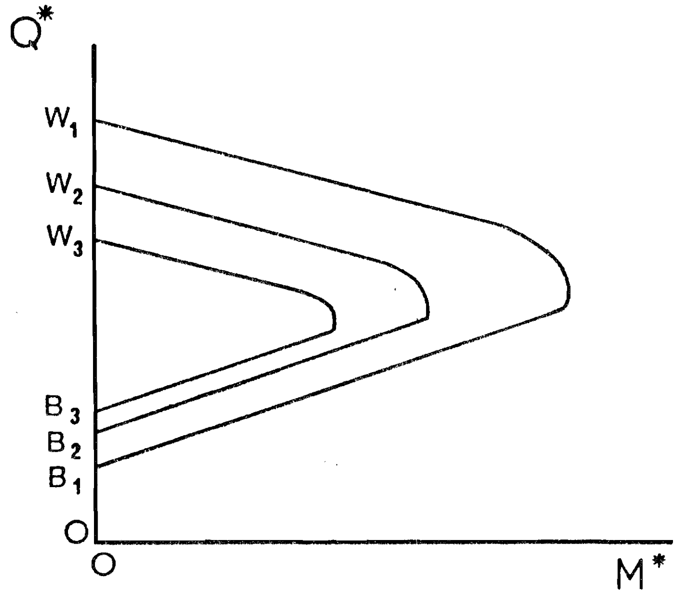


Fig.15 The three triangular shaped contours represent the gamuts of optimal related colours for a single hue at three different illuminances. A correlate of brightness, Q*, is plotted against a correlate of colourfulness, M*. White is indicated by W and black by B; the suffix 1 indicates the highest illuminance, 2 the medium, and 3 the lowest.

In Fig. 15 an idealized colour order system for surface colours is shown, in which brightness and colourfulness are considered. A correlate of brightness, Q*, is plotted against a correlate of colourfulness, M*. At a medium level of illumination, whites would plot near W_2, blacks near B_2, and colours of high chromas (for the particular hue considered) near the extremity of the middle of the three curves. At a higher level of illumination the same colours would plot on the outer of the curves, and at a lower level on the inner curve. A system of this type might be useful for workers, such as architects and interior designers, who have to consider the appearance of their colours at various levels of illumination.

Chromatic adaptation

Designers can be confronted, not only with changes in the levels of illumination, but also in the colour of the illumination. The chromatic adaptation of observers compensates for the effects of changes in the colour of the illumination to a large extent, but not necessarily completely. It would be useful to be able to predict the changes in colour appearance that the samples in any given colour order system would undergo for a specified change in the illuminant. This requires, not only a knowledge of the spectral power distributions of the samples under the two illuminants (from which the usual colorimetric tristimulus values can be obtained), but also a knowledge of the correlations between tristimulus values and colour appearance attributes in both illuminants. Experiments to provide data on which such correlations can be based have been carried out in various ways. Use has been made of both real surface colours, and also pseudo-surface colours, in which self-luminous areas have been viewed with surrounds designed to produce the illusion of surface-colour appearance (Bartleson, 1977; Pointer, 1982). There is growing evidence to suggest that the data obtained in some of these types of experiment is not the same for real-surface and for pseudo-surface colours (Hunt and Pointer, 1983). It must, of course, be true, if all the viewing conditions are identical, then it cannot matter whether the stimuli are provided by real-surface or by pseudo-surface colours. But, in practice, real-surface viewing fields, even in special viewing booths, are usually more complex than the simpler fields commonly provided by pseudo-surface colour displays. An important factor may be what Judd referred to as "discounting the colour of the illuminant" (Judd, 1960). By this is meant that, even if chromatic adaptation is physiologically incomplete, if the observer is able, by means of clues in the visual field, to guess the colour of the illuminant, he then makes subconscious allowance for its colour and his perceptions correspond to what would have occurred with much more complete physiological chromatic adaptation. A striking example of this occurs in two-colour additive projection using red and white light (Land, 1959a; Land, 1959b). If the two images are badly out of registration, an observer sees only red and white, and pink mixtures of them; but, as the registration is improved, a point comes when suddenly a whole new gamut of blue-green colours is added. The observer has now abandoned his original guess that the illuminant was a mixture of red and white, for a new guess that the illuminant was pink; and the basis for this new guess if the subconscious discovery that the scene slots into a more meaningful set of perceptions when interpreted this way. This process is not simply a question of recognizing well-known objects, because the effect is scarcely impaired when random arrays of geometrical shapes are used instead of pictures of scenes of actual objects. The pseudo-surface type of display may perhaps result in a less pronounced ability to discount the colour of the illuminant because of its extreme simplicity, in the same way that confidence in recognizing what is a white (as distinct from a grey) in a scene is reduced if the scene has only very few elements. With real surface colours, on the other hand, even in a viewing booth, there will usually be surfaces at different angles to the light, some shadows at edges of objects, and other clues to the nature of the illuminant; and in real life situations, of course, there are usually many other clues. The result of these clues in practical situations may result in rather effective discounting of the colour of the illuminant, and thus aid the phenomenon of colour constancy with its important consequences for recognizing objects. These phenomena deserve to be further studied.

Conclusions

The effect of the dark surround on the appearance of unrelated colours is very large, and implies that they may require colour order systems designed specifically for them. Luminous related colours are now an important class of colours, because of their widespread use in video display units and colour order systems applicable to them are required. Non-luminous related colours are the colours for which most colour order systems have, so far, been designed. The different systems in use have similarities and differences, both in their experimental bases and in their relationships to stimuli. Chromatic adaptation must be allowed for in understanding the characteristics of colour order systems for surface colours seen in illuminants of different colours, and the extent of adaptation and its dependence on the viewing conditions merits further study.

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GLIMPSES FROM DISCUSSION

On the demonstration by Prof. W. D. Wright

Unidentified speaker:
We use our awareness of the context: one surface is in sunlight, another is in shadow. We have that knowledge - we see they are different, but judge them to be the same.

Billmeyer:
Look at the relationship between these two colours. They bear the same relationship to each other here and there, but they look different in the two cases. What is changed is their brightness, and what remains the same is their lightness.

Hård:
In a higher illumination both are brighter

Wright:
I was surprised you accepted what Dr Billmeyer said. I thought the yellow looked more saturated in the sunlight.

Billmeyer:
Oh! that too

Hunt:
It's also more colourful. The chromas is constant. The colourfulness is increased. We need perceptual terms, which remain more or less constant with change in level of illumination and these are lightness and chromas.

Wright:
I don't go along with that.

McLaren:
Some of these remarks are brighter than others!

Passigli:
In Italy we have only one word for this, so I am trying to understand what is meant by the two English words

Wyszecki:
Abandon lightness in favour of brightness compared relative to white - and we wouldn't really need the word lightness. Use relative brightness for this kind of relationship.

Hunter:
Hård said brightness gets confused with chromatic changes. Why not use vividness for the chromatic change of brightness, and just use brightness for the illuminant changes? Does that make sense? Vividness was certainly the most reliable word that I played with for equating with Munsell chroma and NCS chromaticness. It seems to be the least susceptible for misinterpreation.

McLaren:
When I said that saturation was unimportant for surface colours, I should have added - as far as industrial applications are concerned.

Wyszecki:
I would like to issue on another term: colorfulness, I think that should be abandoned as a not very useful term .... As far as attributes are concerned, we can continue to live quite happily with the attributes of chroma and saturation.

Hunt:
The dense slides I showed seem to be misleading. Bartlesen did very extensive work at the City University. The haploscopic results have shown that this is a real effect. The same is true for brightness.

Wyszecki:
We are talking about effects, and this is agreed. The argument is whether this is actually attributes

Hunt:
Well, it is an attribute, I believe, in the same sense as brightness.

Nayatani:
I and my colleagues made pseudo-object estimations of object colors under daylight and incandescent lamps, at various adapting levels. I always found that the observers tended to assess chroma and saturation rather than colourfulness, which is very difficult to assess. I always found that colorfulness is quite different under different adapting sources. This may be one of the reasons for colour constancy. The difference between real surface colours and pseudo-object colors may be ... (A question to Dr Hunt:) How to assess the colorfulness by subjective estimation?

Hunt:
This is another factor. Bartleson found that observers assessed both saturation and chroma and colorfulness, all three.

CIELAB and CIELUV as colour order systems

Brill:
With respect to Prof. Hunt's presentation, I want to comment on the use of CIELAB or CIELUV as a color order system. It has been said that a system is free, but an atlas is expensive. We do not need an atlas in order to specify a system completely and a catalogue of spectral reflectances, particularly if the illuminant change is an issue.

Hunt:
Yes, I agree with that ... wants to draw attention to the fact that in CIELAB and CIELUV the hue lines are not straight ...

Brill:
Then there are two arguments for not taking the CIELAB or CIELUV as a color order system.

Billmeyer:
I appreciate your point and that is one that I have also considered. When one plots results on any colour system or diagram, such as a CIELAB or CIELUV diagram, then there are two things that are evident. One is the defects in that diagram which can be very important in terms of perceptual quantities. The other is how the system you are examining behaves and it is difficult to disentangle these two and separate them. I don't know the answer to this because we don't have any perfect diagrams. in which we can display the results. Many people take the Munsell system as one having perfect spacing, and plot everything else there.

Hunt:
I agree entirely with what you say ... and I think CIELUV and CIELAB is the best we have at the moment.

Hammond:
In industry it is often recommended to use the CIELAB and CIELUV formulas as color order systems, but I understand that Dr Hunt is against that. Why?

Hunt:
I was pointing out that the hue lines are not straight, so the h-measures are not very good approximations. We need something better.

Billmeyer:
We are still lacking other diagrams.

Hunt:
As a framework for plotting, yes - but as a measure of constancy of hue I would not use hab or huv.

Hammond:
I think that this reveals an important thing. Some of us think of the ideal color order system. Others think of a practical system. As long as we recognize the limitations, there will be no problem ... We will need probably at least two color order systems, one that we can use today and one for tomorrow with the psychological aspects.

Pseudo-object colours

Vos:
I am shocked by the remark that pseudo-object colours and object colors differ markedly. I presume that there must be some clue, whether there is an object color or a pseudo-object color.

Hunt:
I think that in looking at real surface colors there are clues which the observer unconsciously uses to recognize what is the colour of the illuminant and having recognized that, there is a discounting of the illuminant in the same sense that Land demonstrated in his two-colour projections. In the pseudo-object projection these clues are absent. Very small specular reflections, even from supposedly matte samples may also be part of the answer.

Wyszecki:
We find that the calibration of the real surface and the pseudo-surface which appears to a hole against a white background is absolutely crucial. Very tiny differences (the colors may even look reasonably the same) make all the difference when it comes to comparing two sets of data. I suspect there is no real difference. If everything is done properly (no texture differences and things like that) you indeed get no difference between pseudo and real surfaces,

Robertson:
As well as you get clues (about the illumination) when you are looking at real surface colors, it frequently happens when you are looking at pseudo-surface colors that you can get clues, such as fingermarks on the optics and highlights where there would be none from a surface color.

NCS whiteness/Munsell value

Hård:
The curves for NCS whiteness and Munsell value plotted against the physical measurements of luminous reflectance factor are so close that the difference could be the result of experimental errors only - or of a different concept. I have never seen standard deviations or correlation indices of the Munsell system.

Billmeyer:
Yes, but were not the experiments somewhat different? I would in fact like to ask you about that. The Swedish standard 019100 describes the conditions for visual assessment. The color samples about 40x50 mm were seen against a white background in a light grey surround. But how big was the white background and what really was the adjacent surround which governed the adaptation? Was it the white background or was it the light grey surround, and what was the luminous reflectance of the light grey?

Hård:
We used a light booth which was painted grey with a luminous reflectance of about 55%, and the samples were placed on a white cardboard about 10x50 cms with a luminous reflectance of about 85%. The reason was that we wanted to develop the NCS for practical use in environmental design. We first had in mind a grey background, but we knew that, for example, an architect might run into problems getting the right grey paper. A white paper is more uniform.

Billmeyer:
Well, that is quite a difference against the conditions that were used in the Munsell judgements and I think that one would have to look into that.

Berns:
During the Munsell scaling they used three different backgrounds, which had quite a large effect on the lightness scale; in the order of magnitude of the differences between the Munsell and the NCS system.. It was very critical, in particular for low chroma and neutral observations, and for that reason they chose a value 5/ (about 20%).

Hård:
We made the same kind of experiments and found the same thing.

Billmeyer:
I don't think we have any evidence in any direction, but my question is: Are there any figures published anywhere on the confidence intervals of the judgements of the Munsell value scale?

Simon:
I think that all the evidence is smeared in the fact that there is an equation describing the Munsell value scale. The experimental evidence is gone. Munsell value is described by a quintic parabola, and there it is.

MacAdam:
The Munsell value scale was determined long before the quintic parabola, which Judd determined from measured data on existing Munsell samples, I believe that the Munsell samples have changed appreciably since that day, and the fundamental of the Munsell value scale is the set of cards that were distributed around 1939. There is no evidence left - I believe - from which we could determine standard deviations.

Simon:
There was a paper by Sloan & Godlove on the scale. As I recall it there is no evidence as to the experiments.

Plaza:
It has been used by thousands of people for more than fifty years, and all have found that it was quite well.

MacAdam
Most folks are polite.

EXPERIMENTAL EVIDENCE Session e
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WRITTEN COMMENT
Michael H. Brill

Summary of Comments from the Forsius Symposium

My remarks concerning the subject matter of this conference pertain predominantly to colour constancy. First of all, colour constancy is a powerful perceptual phenomenon and therefore ought to be explained and not ignored in theories of color vision. The power and immediacy of colour constancy has been repeatedly demonstrated by Dr. R.W.G.Hunt, for example at AIC Color 81 in Berlin:

When a colour slide of a room interior containing a yellow cushion is covered completely by a blue filter, the cushion still looks yellow; however, when instead a piece of the filter is cut to the shape of the image of the cushion and pasted over it, the cushion appears saturated green. The yellowness of the cushion in the first instance is seen immediately despite the bluish cast of the whole slide. The bluish cast diminishes after several seconds of chromatic adaptation. This difference in time course is an important distinction between color constancy and chromatic adaptation.

Another difference is that current models of chromatic adaptation exhibit color constancy only for physically unrealistic reflectances. This was shown for Von Kries adaptation by G. West and myself at AIC Color 81 Berlin (see also J. Math. Biol (1982 15, 249-259). The paper by Berns and Billmeyer in the present Symposium shows unrealistic reflectances for the model of Nayatani, et. al. It may be said parenthetically that, because the Nayatani transformation does not completely normalize out the illuminant intensity (i.e. is not scale-invariant), the approximately-color-constant reflectances of Berns and Billmeyer should change when the assumed light intensities are changed by a constant factor. Hence the framework of Berns and Billmeyer, whose like is required to test claims of color constancy for any chromatic adaptation model, will in general have to be exercised extensively to cover the gamut of illuminant intensities under which color constancy is caimed to hold for any non-scale-invariant adaptation model. However, since the reflectances of Berns and Billmeyer constitute a negative result for a single reasonable intensity of each light in their analysis, their result must be deemed significant as it stands.

What kinds of color constancy models are left if chromatic adaptation models (which nonetheless account for other data) fail to produce such constancy? A few years ago I presented the volumetic theory (J. Opt. Soc. Amer. 69 (1979), 1405a; J. Theor. Biol. 71 919780, 473-4780), whereby the tristimulus values of three reference reflectances (recognized ahead of time from other qualities such as shape, as in the tricolor American flag) are combined with the tristimulus values of an unknown reflectance (under an unknown illuminant) to infer the unknown reflectance spectrum (assuming it to be approximately a linear combination of the three reference reflectances). This model had the disadvantage of requiring three recognized references, perhaps unrealistic for a visual system. Other published models include those of G. Buchsbaum (J. Franklin Inst. 310 (1980). 1-26) and J.W. Weinberg (Gen. Rel. and Gravitation 7 (1976), 135-169). An unpublished model by M.H. Brill (1974) is a volumetric model in logarithmic coordinates, but displays only limited color constancy.

A looser model is presented in the paper by Brill and Hemmendinger in this Symposium. We model color constancy as illuminant invariance of hue ordering in tristimulus space, not by the invariance of a continuously variable parameter. The use of three reflectances in a color-constant relationship was motivated by work by Dr. J. Lettvin and L. Linden at the Massachusetts Institute of Technology (see L. Linden, Master´s Thesis, MIT, 1974), which showed that the prevalence of spatial trihedral vertices in the visual field constrains the dimensionality of color space. Our model can be used to rank-order the reflectances used to make a color atlas. The figure of merit might be the lowest-order principal component of reflectances that participates in a reversal via the criteria of our paper. The higher the number, the more color-constant the atlas.

Finally, I would suggest as a test for the extent of human color constancy an experiment such as that of J. McCann et.al. (Visual Research 16 (1976), 445-458) but in which the reflectance context is held constant between two lighting environemtns (the background under the reference light should be a Mondriaan with a patch missing instead of a uniform reflectance).

EXPERIMENTAL EVIDENCE Session e

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WRITTEN COMMENT

Anders Hård

In his lecture Dr. Hunt presented a diagram (fig. 15, ed's remark) in which he exemplifies how "his" parameter colourfulness and brightness will give different sizes to the contours depending on the level of illuminance. From a phenomenological standpoint this will mean that the phenomena behind the terms of colourfulness and brightness are functions of the illumination. In the NCS, however, the the variables of whiteness/blackness and chromaticness are illustrated by by a triangle, valid for one and the same but arbitrary situation of illumination. Dr. Hunt's figure is interesting and very much in line with our own hypothesis that the "powerfulness" of object colours, both chromatic and achromatic, increases with illumination - and that could be illustrated by different sizes of the NCS colour triangle. A hypothetical question is if this is a function of the possible discriminable steps that can be perceived between the endpoints of the scale, or with other words, if the distinctness of the border between two object colours increases with illumination. So from that point of view I fully agree with Dr. Hunt's ideas and both, I believe, we consider this what I would call "powerfulness" an essential attribute of colour perceptions.

EXPERIMENTAL EVIDENCE
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Session e

MODERATOR'S REPORT
Fred W. Billmeyer, Jr

The session on Experimental Evidence was opened with Dr. R.W.G. Hunt's invited paper. He quickly reviewed some 22 papers in the Symposium that were relevant to his topic, in the categories of transparency, children's preferences, bases of assessment, attributes, comparison of systems, chromatic adaptation, and saturation. He next attempted to place these papers into context by means of an ordered discussion of color attributes and their scaling. His discussion was based on the topics of unrelated colours; luminous related colors (including fluorescent colors and those seen on video display units); nonluminous related colors (including transparent colors, surface colors, and those seen on video display units); and chromatic adaptation in relation to pseudo-surface colors and real surface colors.

The discussion for this session could be divided into three broad categories. First, some concerns were expressed over the attribute of colorfulness. Dr. Wyszecki questioned whether it might not be an artifact seen only in cases of incomplete chromatic adaptation. Others had concerns over whether and how it could be scaled independent of saturation and chroma, and over its importance relative to saturation and chromas. Dr. Hunt responded that, although the demonstrations accompanying his lecture were necessarily crude, he remained confident of the validity of the concept of colorfulness, and was sure that the concerns that had been raised were groundless.

A second topic of discussion was differences between the use of real-object colors and pseudo-object colors in scaling. It could be pointed out that there is a whole range of effects, between surface-colored samples that can be picked up and moved about by the observer, and colors seen in Maxwellian view, perhaps with the aid of a bite-bar. Somewhere in the middle are colors that could be either type, depending on clues that might be deliberately or inadvertently introduced. Production of pseudo-object colors has the advantage that any color effect within a wide range can easily be produced, but problems of calibration allowing one to know exactly what color he has are severe. On the other hand, although it is more difficult to produce exactly the desired surface colors, once they are achieved, their calibration by color measurement is simple.

Finally, there was considerable discussion of the spacing of the samples in the Munsell Value scale. Supporters of other scales argued that there was no current evidence for the equality of its spacing, and no tolerance limits on its scaling. While it was admitted that much of the experimental evidence is buried in the past, nevertheless the scaling experiments are well documented in the literature, and there is no reason to doubt their validity. It was pointed out that physical scales were the original evidence, with mathematical formulations applied only for convenience and uniformity in calculation. It was also pointed out that uniformity of spacing depends strongly on experimental conditions, including (in the broader case) the spectral character and illuminance of the illuminating source, the spectral character and luminous reflectance factor of the surround, among many others. If these are not precisely defined and adhered to in the scaling experiments, then it cannot be said that the scale is precisely defined, despite the application of statistics to the experiments.

PHYSICAL EXEMPLIFICATION Session f
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INVITED LECTURE

C. S. McCamy
(read by F. W. Billmeyer, Jr.)

Abstract

The production of color standards exemplifying a color-order system requires a complete written definition of the system, including the specification of all pertinent visual conditions and measurement conditions. The choice of materials requires consideration of the spectral and geometric aspects of the optical nature, some aspects of the mechanical nature, stability, durability, availability, acceptability to users, and cost. The value of the color standards depends on the precision and accuracy with which they are produced. Efficient production and the long-term reproducibility of the system depend on well defined methods of color measurement.

Definition

Most of the problems that may be involved in producing a physical exemplification of a color-order system could be avoided by clearly and completely defining the system at the outset. Since the color of an object depends on viewing conditions, we must specify the spectral nature of the illuminant, illumination level, the nature of the surround, geometry of illumination and viewing, and any other conditions that could affect the appearance. These conditions should be specified with due consideration for existing or imminent national and international standards for such conditions and the practical needs of users.

The crucial role of definition may be illustrated by the Munsell Value scale. As Munsell defined it, it is a scale of lightness, ranging from the blackest conceivable black to the whitest conceivable white, there being ten steps that are visually uniform. A neutral series that looks uniform at one illumination level may look quite nonuniform at another level. Thus, the physical exemplification must be associated with a level of illumination. If necessary conditions are not specified as part of the initial definition of the abstract system, they must be specified in connection with the exemplification.

The definition should be published, not only to make the system generally known, but to provide a permanent basis for the stability of the system as it is passed on from one generation to the next. In formulating the definition, it might be well to bear in mind that conditions that might seem so obvious as to require no mention may not be so obvious at another time or in another place.

Choice of Materials

When choosing materials for producing a physical exemplification of a color-order system, the first consideration is, of course, the optical nature of the materials. A fundamental guiding principle is that the comparison of the colors of objects is made easier and more precise if all other aspects of appearance are identical. It is for this reason that there is a general preference for comparing liquids to liquids, transparent solids to transparent solids, and opaque surfaces to opaque surfaces.

A comprehensive color-order system should accommodate all colors, so the materials chosen to exemplify the system must be capable of producing a large gamut of colors. Ideally, the large gamut should be produced with a small number of colorants. This simplifies formulation. When it is feasible, it is desirable to use the colorants commonly used in the field of application or seek spectral similarity to common specimens. The application of this principle tends to minimize metamerism. It may also be used to limit the gamut from which designers may choose, so they don't specify colors that can't be produced. It is desirable to choose formulations that maintain constancy of colors and color relationships under common illuminants.

A general rule, fluorescent or phosphorescent materials are avoided unless they are typical of specimens in the field of application. If the materials are fluorescent, the spectral power distribution of the illuminants under which they are used is critical.

A number of important considerations related to geometric aspects of appearance. The most widely used materials have surfaces that are either smooth, matte, and non-directional, or smooth and glossy. In the textile industry, textile standards are preferred because they provide better spectral similarity to specimens. The texture may be more similar, and the drape of cloth can improve the simulation of the general appearance of specimens. The Munsell system historically associated with an exemplification in matte or glossy paint on paper, is now also represented by textile swatches. This collection is known as the SCOT-Munsell system. (SCOT is an acronym for "Standard Colors of Textiles"). The switches are shiny on one side and dull on the other, to simulate the two major classes of textile finishes.

For most applications it is desirable to have standards that change little, if any, in appearance as the angle of illumination or angle of view changes. In particular, it is usually undesirable to have directionality, which is a change in appearance as a surface is rotated in its own plane, as characterized by brushed aluminum.

Translucency can introduce two kinds of problems. Such materials spread light laterally within a sheet and the light may merge from the surface some distance from the point of incidence. The measured amount of light reflected may vary, depending on how much of this laterally scattered light is collected. The measured reflectance factor of a translucent sheet is also strongly influenced by the reflectance of the material behind the sheet.

The size of a color chip is a geometric property with a spectral effect. It is in the nature of human color vision that the angular subtense of a chip can influence its color. It is for this reason that the CIE has separate standard observers for 2° and 10° fields. At the normal reading distance of 250 mm, 2° is subtended by a circle about 9 mm in diameter and 10°, about 44 mm. When colors are compared in a light booth, it is common practice to view specimens at about 600 mm. At that distance 2° and 10° are subtended by 21 mm and 105 mm, respectively. A common size for chips is about 16 mm on a side, which subtends 2° at 458 mm and 10° at 91 mm.

The variance of measured color usually increases with the ratio of specimen area to measuring port area (the sampling aperture). The larger the relative area of the specimen, the more different places can be measured.

Irregular departure from flatness of the surface of a glossy standard can contribute to variations in measured reflectance factor, when measurements are made with a sphere and the specular component is excluded. The specular component can be excluded for flat specimens but surface irregularities reflect more or less light to the remaining sphere wall.

In choosing materials for color standards, stability is a major consideration. By "stability" I mean constancy of color when the standard is subjected to no more than the stresses of ordinary atmospheric conditions, as distinguished from "durability", the ability to endure stresses such as impact or abrasion.

Some materials that are stable and durable in all other regards may change color reversibly with variations in temperature; they are said to be "thermochromic". Some change color with humidity, some hysteresis being involved; I call them "hygrochromic". Some change color reversibly on exposure to light; they are called "photochromic". Some materials react with oxygen, sulfur, or other gases in the atmosphere, with a resulting color change, which is often evidenced as yellowing of near-white colors or fading of strong colors. This may take place even though the surface is not exposed to light. Normal evaporation of components initially present or gradually evolved, or changes in the state of polymerization can distort or crack surfaces or delaminate them from a substrate. Some paints are susceptible to chalking, the development of a powdery surface due to disintegration of the binder. Some paints and ceramic enamels suffer bronzing, the erratic formation of an irridescent surface layer that imparts a faint metallic luster under some viewing conditions. When a material is applied to a substrate, the stability of the substrate must be considered. There are known instances of minute traces of products of slow degradation of a substrate having discolored a coating.

Standards should have a reasonable degree of durability when exposed to the stresses to be expected in their use. They should not fade excessively on exposure to light. They should not be too easily scratched, abraded, or damaged by impact or bending. Mat or low-gloss materials are particularly susceptible to burnishing, the development of a shiny surface when impressed with a smooth hard surface, such as one surely finds on measuring instruments. Some such materials may when mounted in a book increase in gloss merely by coming in contact with the facing page.

To avoid the necessity of changing the formulation of colors for standard, it is important to select materials that one can reasonably expect to be continuously available for the foreseeable future. One should question the advisability of materials available from a single source, proprietary materials, or materials that may be subject to proprietary restrictions on their use. On the subject of availability, from the point of view of the user, it is important that whole sets and replacement parts of sets be readily available.

To be acceptable to users, colorants should not rub off on hands or clothings, and the standards should have no objectionable odor, toxicity, allergenicity, or radioactivity.

All of these demands must be met at a reasonable cost. However, the total cost includes so much cost of formulation and correction, process control. quality assurance, assembly, distribution, etc., that the cost of materials is usually not an overriding consideration. Happily, in most of science and industry we do not have, as many gem dealers do, a fortune invested in color standards.

Precision

We must ask how repeatable the production process is. How nearly alike are the standards that are nominally the same? This is in part determined by the uniformity of the production process itself and in part by the repeatability of the measurement system used to control the production process. The use of measurement in process control is a well-known science that need not be elaborated here. However, the application of process control to the measurement process itself is not as widely practiced as it should be. In the Munsell laboratory, colored ceramic standards are frequently measured and the results are analyzed automatically by a computer and the statistical analysis with reference to the whole history of such measurements is displayed in the form of control charts on a CRT screen. In this way, it is known at all times whether the measuring process is in control and, by trend analysis, corrective action can be taken before the process goes out of control.

Again with respect to precision, but in a little different vein, we ask how well a given standard can be reproduced at some later time, when new stocks of materials may be required, old stocks may have changed, and there are new facilities and personnel. As with short-term repeatability, reproducibility depends on the inherent reproducibility of the production process and the measurement process. The key to reproducability is documentation. Materials and methods change. People forget, or leave, or die. Keep records. Thomas Jefferson gave us sage advice when he recommended that copies of vital records be stored in several places, to diminish the probability that all will be lost.

Accuracy

Being able to produce color standards very nearly alike does not mean that the average color is what it is supposed to be. Accuracy is the degree to which the color produced matches the true color. The true color is that specified by the fundamental definition of the color-order system. If the definition thoroughly specifies all necessary details, the true color can be known exactly. If the definition is vague and the inderminate the true color may not be well known. Even if the color is well defined, it may not be easy to exemplify it or to prove its validity by measurement. It took the Colorimetry Committee of the Optical Society of America years to come to final agreement on the Munsell renotations. This was because the system was defined in visual terms and it was necessary to do the visual scaling and then measure the resulting colors. The intention by measurement; the method of determining the Munsell notation from CIE x, y, and Y has been standardized. The accuracy of that method depends on the accuracy of the color measurement method.

Colorimetry

The accuracy of a color measurement is a measure of how close the measured color coordinates are to the true coordinates. The true coordinates are those that would be obtained using a laboratory measurement system embodying standardized geometric and spectral conditions and performing necessary calculations in accordance with existing standards.

There is no unique set of standard measuring conditions. There are many standard illuminants, two general geometric specifications, the possibility of measuring with the specular component included or excluded, 2° and 10° observers, and the possibility of spectophotometric measurements with various band widths and wavelength intervals. Documentary standards for spectrophotometry are like a Chinese menu, where you choose one from column A, one from column B, etc. The number of standard combinations is of the order of 100. Therefore, the parameters must either be specified in the definition of the color-order system or clearly identified for the purpose of controlling the exemplification.

In particular, the illumination should be specified for viewing the exemplification so that appropriate illumination can be selected for the measurement. Two illuminant spectral-power distributions are usually involved in the color measurement process: the spectral power actually incident on the specimen and the standard illuminant, a table of numbers, used in the colorimetric computations. The spectral nature of the power actually incident is of particular importance if the color standards are fluorescent.

When color is measured spectrophotometrically, as it most often is today, the bandwidth, wavelength sampling interval, and wavelength range can affect the results and should be clearly identified.

The geometric conditions of measurement are major factors in determining the values measured. I believe this is the principal source of discrepancy among color measuring instruments at the present time. Although the impact of geometry has been fully appreciated and well standardized in densitometry, the special field of color control employed in photography and color printing, it has never been taken very seriously nor standardized in the general field of colorimetry. At a recent meeting of the Council for Optical Radiation Measurements, I showed that the existing CIE specifications for geometry are too loose to serve any useful purpose. For example, one may design two spectrophotometers or colorimeters meeting the specifications for $45^{\circ}/0^{\circ}$ geometry that can differ by 1.4 to 3.45% when measuring the reflectance factor of such highly diffuse materials as opal glass, pressed barium sulfate, and smoke magnesium oxide. Imagine the differences with practical materials, such as textiles! The CIE would do well to follow the lead of the ISO committee on photography in these matters.

The exact meaning of "excluding the specular component" of reflected light has not been standardized in geometric terms and there is rather widespread misunderstanding of the colorimetric significance of this factor. This misunderstanding results from confusion of the concepts "specular reflection" and "first-surface reflection". Light reflected by the first surface of a nonconductor is not colored by the reflector but retains the color of the incident light. If the light reflected from the first surface can be excluded from the measurement, the saturation will be higher than otherwise. However, that light is concentrated in a beam that can be excluded only when the surface is flat, smooth, and glossy. In that case the specular component is most first-surface component. A matte surface diffuses that light so it can't be separated from light diffusely reflected from colorants in the body of the material. Light reflected from the first surface of a conductor, such as copper, is colored by that reflector. This gives metals their characteristic colors. In that case, excluding the specular component does not increase saturation. If the viewing conditions, specified for the color standards are such as to avoid specular reflection to the eye, it would be appropriate to exclude the specular component during measurements. The chosen practice should be documented.

Colorimetric quantities are usually derived from spectral measurements by computation. Choices must be made between various standard illuminants, 2° and 10° observer, and colorimetric quantities. Unfortunately, there is no general agreement on the exact methods of computation when the spectral bandwidth, spectral sampling interval, and wavelength range of the measurement do not agree exactly with those used in preparing the standard tables of weighting factors. This matter is being studied by a committe of the American Society for Testing and Materials. Methods of computation should be documented.

Summary

Unfortunately, a recital of the do's and don'ts of physical exemplification is a dreary litany of mostly don'ts, mostly meaningful only to weary supplicants of long-standing at the altar of exemplification. Exemplifying a color-order system requires a certain religious zeal. I wonder what Moses would have come back with, if he had gone to the mountain on the day that a Great Lawgiver was concentrating on exemplifying color-order systems. I suppose it might have gone something like this:

I. Thou shalt have no definition of a color-order system but the true one; explicit, detailed, comprehensive, and enscribed.

II. Thou shalt not use materials that are optically unsuitable as to their gamut, spectral similarity to common specimens, fluorescence, phosphorescence, texture, translucency, directionality, or size; for an unsuitable material is an abomination to the Lord,

III. Thou shalt not use materials that go with the weather, transient, fleeting, fading, cracking, chalking, bronzing, and doing all manner of ungodly things.

IV. Thou shalt not tolerate materials that fail to endure the ravages of abrasion, scratching, burnishing, pressure, impact, bending, or exposure to light; for soon they will bear false witness and thy flocks will be led astray.

V. Thou shalt not embrace materials that are here today and gone tomorrow, nor place thy faith in one source alone, nor covet the mines of a vicious king; for thou are bound forever and I will visit the iniquity of the fathers upon the children unto the third and fourth generation.

VI. Thou shalt not present as an offering any thing that smudgeth my lily-white hands, poisoneth me, maketh me to sneeze, wheeze, or inflame with hives, nor smelleth to high heaven.

VII. Thou shalt not exact a ransom, nor make thy offering too dear; for verily thou shalt be left holding the bag.

VIII. Thou shalt not offer two of the same name if a child seeth they differ; for the Lord will not hold him guiltless that confuseth a child. Honour thy father and thy mother: that thy offerings be like unto theirs; and so be it from generation to generation.

IX. Thou shalt not bring forth any thing that beareth not the truth; for all of the same shall be the same and be the same as it was in the beginning, is now, and ever shall be, world without end.

X. Thou shalt not use false measure, but holding all to the true light, follow the rainbow, regarding its width, length, and interval; and the sacred directions of the light that cometh and goeth; and the way that thou shalt multiply and add, showing thy true colours; for, as Lord Rayleigh shall attest, science ain't science without measurement.

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GLIMPSES FROM
DISCUSSION

Colour constancy

Billmeyer:
McCamy mentions that you should make the samples of a color order system as nearly like the samples they will be used with.

McLaren:
Attempting to minimize metamerism is always a waste of time, as you will never reach it. A good color constancy is more important. (Example from an olive green page in the Munsell color atlas seen under a Philips T84 lamp. Entirely different pigments were used, and they are brought out by the three-band lamp.)

Hunt:
When we go into tungsten light, we don't get colour constancy. Colours do change in appearance. I believe one of the reasons why tungsten light is so popular for domestic purposes is because the colours have changed, and colours look warmer and complexion pleasant. Colour constancy is of scientific interest but perhaps not of too much practical important.

2° or 10° observer

Terstiege:
Most color collections have 600-1000 or more samples of small size, but they also have bigger sizes for architects and others to work with. Shall we then have 2° or 10° observers?

Hård:
We must carefully describe how the measurements were made. In a page of constant hue, the notations - taken very critically - are no longer true, because the samples are seen in another situation. The variations of perceived colours with the size of the sample can be studied with the NCS.

Stanziola:
I think the 10° observer would be better to use.

Terstiege:
Henry Hemmendinger has measured Munsell samples for the 2° observer. Is there any attempt to convert them also for the 10° observer?

Brill:
I think the calculations could easily be done.

Nayatani:
My colleagues have calculated Y for various Munsell samples for the D65 and 10° observer.

Witt:
We have decided to give an additional 10° definition for the DIN system of the same color samples.

Hård:
We are working to calculate CIE values for the NCS notations using D65 and 10° observer.

Specular component

Brill:
If you exclude specular component you may exclude 85% from one sample and 82% from another sample. You would be better off if you include.

Witt:
I measured samples of different gloss with 0°/45° and with sphere, gloss excluded. The changes are very serious in high saturated and dark colors. I suggest 0°/45°, because when you look at colour samples in a color matching booth the viewing situation is nearly 45°/0°.

McLaren:
I would support that ... but the majority of spectrophometers have spherical geometry.

Witt:
What is the difference between (1) to exclude the gloss with a gloss trap and (2) to include and subtract mathematically?

Simon: My recommendation is to measure included and calculate the excluded.

Unidentified speaker:
It is too difficult to find the right correction factor for semi-glossy samples.

Tersteige:
They may not occur so often in industry.

McLaren:
On the contrary. The "eggshell" surface is very common.

Tolerances

Terstiege:
How precise shall the samples be to the original data?

Witt:
With the, DIN color system there is a tolerance given of about 5 CIELAB units, which is too large. In the high glossy finish we try to keep the first sample of each color within 0.5 CIELAB units; in the production about 1.0 CIELAB units.

Billmeyer:
The original Munsell AAA-tolerances ("triple A") were 0.5 value steps, 0.2 chroma steps and 2/C hue steps. The present thinking is that this is non-uniform and not satisfactory. (1 FMC2 approx. = .5 CIELAB unit)

Terstiege:
NCS tolerances?

Hård:
It's published. We wanted to make a practical tool to a reasonable cost. As the atlas exemplies the system in steps of 10 units, we set a tolerance of 2 NCS-units. 75% of the samples are 1NCS unit, approximately 1 CIELAB unit. We have made some compromises, especially in the outskirts of the color solid in order to include clear and "sharp" (?) colors.

MacAdam:
In OSA-UCS we have tried to keep tolerances within 0.1 of the distance to the next color (approx. 1 CIELAB units). Again, for the most extreme colors we also relaxed the tolerances.

Billmeyer:
In Munsell, the tolerances are never relaxed.

Witt:
It's also so in the DIN system.

Hård:
It's a nuisance to decrease the tolerance so that it will cost you 100% more to produce the samples. if most of the people using them don't care about that kind of precision.

Styne:
The very small selection of centroid colors that I handed around the other day follows the same principles. On that level of fineness - as it's called in the Universal Color Language, we have the color solid divided into 267 blocks and have 251 samples.

PHYSICAL EXEMPLIFICATION Session f
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MODERATOR'S REPORT
Heinz Terstiege
(Reported by Fred W. Billmeyer, Jr)

This session was opened with the invited lecture by Calvin S. McCamy. In Mr. McCamy's absence, the paper was read by Fred W. Billmeyer, Jr. Mr McCamy reviewed the need for the complete definition of the system, the requirements on the physical and optical properties of the colorants and other materials used, and the requirements for and methods of achieving precision and accuracy in the physical exemplification - which he clearly distinguished from the concept of the underlying system. He closed with the presentation of "ten commandments" for producing a physical exemplification of a color order system.

Dr Terstiege attempted to organize the discussion around the topics in Mr McCamy's paper, but this was not entirely possible. The first topic of the discussion was the selection, range, and number of colorants needed in the physical exemplification (hereafter, the atlas). Mr Stanziola re-emphasized the importance of producing the atlas so as to have maximum similarity to the samples with which it is inteded to be used. Thus existing atlases (Munsell, NCS, OSA, etc.) made in paint systems are best used for comparison to paint or plastic samples, the new SCOT-Munsell system, made in textiles, should be used for comparison to textile samples, etc. The similarities should extend to spectral similarity in order to reduce the chances of metamerism between the samples of the atlas and those of the materials with which it is to be used. To achieve this it might be necessary to break Mr. McCamy's commandment that the minimum number of colorants be used, by providing low-chroma colorants to produce the low-chroma atlas colors as well as high-chroma colors for us in producing the more highly chromatic colors. Most systems are in fact made this way. The problem is more difficult with textile samples.

A related but separate requirement is control of color constancy, and this introduced the next topic of discussion. Ideally, a color atlas should exhibit a high degree of color constancy, and it is particularly important that hue constancy, or at least consistent hue shifts, be maintained among all samples on a given page of the atlas.

Methods of achieving and assessing color constancy were the subject of several papers in the Symposium, and in one instance (the work of Berns et al.) significantly new results had been obtained since the preprints were submitted. Mr Berns briefly described his new work, building on the use of Dr. Nayatani's chromatic-adaptation transform to produce (presumably) color-constant CIE coordinates for selected samples form the Munsell atlas for a range of Macbeth daylight type illuminants (7500 K to 3200 K plus CIE A). A variety of linear-programming techniques was used to produce "realistic" spectral reflectance functions yielding as closely as possible the above mentioned CIE coordinates. Major emphasis was placed on preserving hue constancy. The reflectance functions were invariably multimodal, with maxima and minima occurring within well-defined ranges of wavelengths which could be related to regions in which one CIE standard-observer function is much greater than the others, for example. It was recognized that more work is needed, to extend the results to other illuminants with discontinuous spectral power distributions, to test the von Kries chromatic-adaptation transform, to compare the extreme regions of the reflectance function to fundamental cone primary curves, etc. Dr. Hunt believed that the von Kries transformation would lead to better hue constancy, but Dr. Nayatani thought not: He believed that experimental results obtained to date to test chromatic-adaptation transforms show too much variation among observers to be reliable. Mr Brill described other mathematical considerations that led him to believe that unimodal rather than multimodal curves would be required for color constancy; the discrepancy between the two studies is yet to be resolved.

Dr. Terstiege next asked for comments on the sizes of samples in physical exemplifications of color order systems. Some comments were made that a size of roughly 5 cm x 5 cm should be adequate for scaling, though it could be pointed out that industrial experience suggests the need for much larger samples (e.g. A4 size) for best results in scaling small color differences. It was also felt desirable to develop methods to compare the appearances of small and very large samples of the same physical stimulus, or to predict the appearance of a very large sample from that of a small one.

Much interest was expressed in transforming the notations of a color order system from one coordinate system to another, e.g. from illuminant C to D_{65} or from the 1931 to the 1964 standard observer. Some progress on this monumental task was described: Independently Hemmendinger in the USA and Takahama and Sobagaki in Japan had measured the samples of the Munsell atlas and adjusted the spectral reflectance functions to correspond to the exact notations of the aim points (in this case the 1943 Munsell renotations). Hemmendinger had done this by formulation shading calculations based on the colorants used; the Japanes workers by principal component analysis. Coordinates could be obtained from these curves for any desired combinations of illuminant and observer (none have been published yet), but it should be pointed out that, inevitably, uniformity of scaling will not be maintained when changes in the conditions are made; even the small changes mentioned above could be important.

A final topic for discussion was the accuracy with which the samples of the physical exemplification should correspond to the aim points of the underlying system. It appears that for the major current systems (Munsell, NCS, OSA, DIN) except for the most highly chromatic samples, the tolerance is of the order of one CIELAB unit up to 10% of the difference between adjacent samples. For the most highly chromatic samples, this tolerance is maintained in some atlases (Munsell, DIN) but relaxed in others (NCS, OSA).

APPLICATIONS OF COLOUR ORDER SYSTEMS

Session 9

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INVITED LECTURE

Paul Green-Armytage

ABSTRACT

A selection of colour order systems and their applications, from simple to comprehensive, is described together with some of the associated problems and controversies.

The relative merits and uses of colour spaces with a whiteness-blackness structure and those with a lightness-darkness structure are described and discussed. It is suggested that, for applications in art and design, both structures embody important information and that a colour space for artists and designers should be elastic - able to change shape. An elastic system could be distorted to present each structure in turn.

In conclusion, it is suggested that the present confusions resulting from rival systems might be resolved by relating them all within a modified version of the Universal Color Language.

INTRODUCTORY NOTE ON LAYOUT

The illustrations, which were an important aspect of the presentation are briefly described on the left hand pages opposite the main text. These descriptions are in two columns to correspond with the two screens used. Reference to the illustrations in the main text is by a bracketted letter/number code; L and R (for Left and Right Screens) precede sequential numbers.

Acknowledgements and references are combined in a single list at the end. This is arranged alphabetically but the listings are also numbered. Reference to this list in the illustration descriptions and main text is by the corresponding numbers in italics.

L 1 The sky in Western Australia Photographed above my house at noon. A uniform blue. *18*

R 1 Buffet lunch prepared by design students. Natural colours of food altered by food colouring dyes. *18*

L 2 Scale of colours produced electrically on titanium. Required Voltages marked beside each colour. *72*

R 2 Guide to titanium colouring. Table lists colours (described by names) and indicates thickness of oxide films responsible for each colour together with the temperatures and voltages required. *70*.

Ladies and Gentlemen:

First, I would like to thank the members of the organizing committee for inviting me to present this lecture. It is a very great honour and a privilege for me to address such a distinguished audience.

To introduce myself: I am a designer and a teacher. I hope to direct your attention to some of the issues raised in the papers and to offer some ideas of my own. I am going to touch more or less briefly on many subjects in which I am not a specialist. These include jewellery, printing, fashion, manufacture and marketing, art criticism, heraldry, philately and horticulture.

You may accuse me of a superficial approach but for me such a breadth of interests itself constitutes a kind of specialisation. I believe strongly that connections can be made between one field and another which can lead to productive ideas and insights.

Two years ago I heard a lecturer pose the question: "What came first, reading or writing?" His answer was "reading. The messages read were animal tracks". I liked that answer but to animal tracks I would add the messages of colour. Colour is a language through which we learn about our environment, which we use in many ways for communication and which can have a profound affect on our emotions.

This is the sky in Western Australia (L1) (since we are in the Northern Hemisphere I have put the slide in upside down). It is restful but, in a way, also invigorating. There is a message in this colour, it affects our feelings. Lars Sivik *61* has shown how colour messages depend not just on hue but also on nuance. Blue, yes, but what blue?

He makes good use of the NCS to record his findings, an application of a colour order system as a tool for research.

This is a buffet lunch prepared by my students (R1). Nobody ate very much. The food colouring has produced some contradictory messages which are most disturbing. Here the language of colour is working at many different levels. To make the best use of this very rich language we need to be able to describe colour, to measure it, to produce it and reproduce it. All of which implies a need for some kind of order.

Here are some examples:

An oxide film can be formed electrically on the surface of titanium which produces colour by interference (L2,R2). The titanium is immersed in a bath and current is passed through the electrolyte to the metal. The resulting colour depends on the thickness of the oxide film which is controlled by the voltage. This is a colour order system with a very specific application which is being explored in jewellery.

L 3 Brooch.Titanium strips stamped, coloured and woven.Mounted in a silver frame. by David Walker. 74

R 3 Titanium strips, stamped, coloured and woven.Mounted in a silver frame. by David Walker. 75

L 4 Experimental piece. Titanium coloured by masking and immersion by David Walker. 73

R 4 Brooch. Titanium with graded colourin and 'painted' pattern, behind a brass grid. by Belinda Mele. 46

L 5 Rhombohedron colour solid by Harald Küppers. 36

R 5 Cube Colour Solid by Harald Küppers..

R 6 "Shelf" from Küppers' cube. Each shel is a chart which indicates the percentage of magenta,cyan and yellow inks required to mix each colour. 39

L 6 Hexagon colour diagram by Harald Küppers. 37

R 7 Numerical code indicates chromatic and achromatic content of colours in Küppers' hexagon diagram 37

L 7 Colour chart/mixing guide indicating percentages of black,yellow and magenta inks required to mix each colour. 39

L 8 Louisiana Iris "Clyde Redmond" Grown and photographed by John Betts. 5

R 8 Colour charts of the Royal Horticult ural Society (RHS). Fans 1,2,&3. 59

L 9 Louisiana Iris seedling. Grown and photographed by John Betts. 5

R 9 RHS Fan 2 opened to show violet-blue group (Nos.88-99). 59

L10 Louisian Iris seedling. Grown and photographed by John Betts. 5

R10 RHS Fan 2 opened to show "violet-blue" colours 96A-96D. 59

These are two brooches by my colleague, David Walker, our Senior Lecturer in Craft Studies (L3,R3). The metal strips were first stamped into shape, then coloured and then woven together.

It is also possible to "paint" the titanium by attaching one of the leads to the ferrule of a brush. You can brush on the electrolyte and change colour as you go simply by altering the voltage. You can also mask off areas where you don't want colours to appear. David Walker is exploring these possibilities in this experimental piece (L4). In this brooch (R4) by Belinda Mele, one of David's students, the graded background colour was achieved by withdrawing the plate slowly from the bath while altering the voltage. The diagonal strokes were achieved afterwards with the brush technique.

At a more sophisticated level, a comprehensive colour system with particular application to colour printing is that devised by Harald Küppers [36]. His rhombohedron colour solid (L5) can be transformed for convenience into a cube (R5) which can serve not only to illustrate the world of colour; it also embodies the recipes for producing each colour. These are expressed in terms of percentages for each primary ink, and can be read off charts which are "shelves" within the cube (R6). Here the three colours used are the printers' mixing primaries, magenta, cyan and yellow.

A further transformation gives us his colour hexagon (L6). This is associated with a numerical code (R7) which indicates the relative chromatic and achromatic content of each colour. From this he has developed a mixing principle to take advantage of the fact that regular colour printing presses are also equipped to print a fourth colour, which is usually black. His mixing charts with different percentages of black (L7) offer a very beautiful range of colours, where much greater control would be possible.

From producing colours to recording them:

Another of my colleagues, John Betts, Head of the Department of Pharmacy, breeds Louisiana Iris (L8). He uses the Royal Horticultural Society (RHS) Colour Charts to record their colours (R8). The charts use basic names like red, red-purple, purple, etc., to identify groups of colours which are then individually numbered and lettered.

Iris colours range mainly between "red-purple" and "violet-blue", about 30 steps on the charts.

John's particular interest is in the violet-blue range (L9,R9). His ambition is to get beyond the violet-blues and grow a true blue iris. The first blue is number 99. His closest so far is 96c (L10,R10) [4].

Incidentally, I asked him about the influence of lighting. This is evidently a problem but if there is a "Standard Illuminant" for horticulture, it must be the light which filters through the white canvas of the tents at the Chelsea Flower Show which is the ultimate arena for growers.

L11 Australian four penny stamps first World War period. Colour, range from "brown-orange" to "lemon yellow". *18*

R11 Stanley Gibbons Colour guide for stamp collectors. *67*

L12 Colour circle and grey scale. Collage with basic colour terms. *15*

There are similar problems of colour identification in philately but here there can be more at stake than glory. Western Australia's leading stamp dealer, Robin Linke allowed me to take some photographs in his shop (L11,R11). During the first world war shortages and inconsistencies in paper stock and inks resulted in a large number of subtle colour variations.

Apparently the Stanley Gibbons colour guide *67* is not regarded as particularly useful as an arbiter in Australia. Identification of a stamp's colour and, therefore, its value, is a matter to be agreed between buyer and seller *41*.

This can lead to very delicate negotiations. Tantalisingly, Robin did not have the crucial example in stock but even without it, it is not difficult to appreciate that a "pale orange yellow" could easily be bought as an "orange yellow" at $75.00 and sold as a "yellow" at $400.00.

Some of the problems associated with the identification of stamp colours can be appreciated from this advice in the Australian Commonwealth Specialists' catalogue *45* :

a. Work only by daylight.
b. Rest eyes every few moments. Most important.
c. Admit only stamps with clean white margins. Soiled stamps mislead.
d. Beware of heavy postmark. It makes shade appear darker.

Workers in colour will recognise:

a. the importance of an agreed standard illuminant,
b. the effect of prolonged stimulation on apparent saturation. (After a while an "orange" could turn into a "brown"),
c. the value of a reference white, and
d. the influence of the spreading effect.

Stamp collecting is a particularly interesting field where many of the current issues in colour science come into focus. No doubt colorimetry could be employed to settle disputes but there would be a strong need to maintain some link between the numbers of a measurement and the words of a description that people could understand. Many participants here have expressed the need for such a link. Also, since philatelists come from all walks of life, any colour system for their purposes would have to be equally acceptable to physicists, physiologists, psychologists and artists as well as ordinary men, women and children.

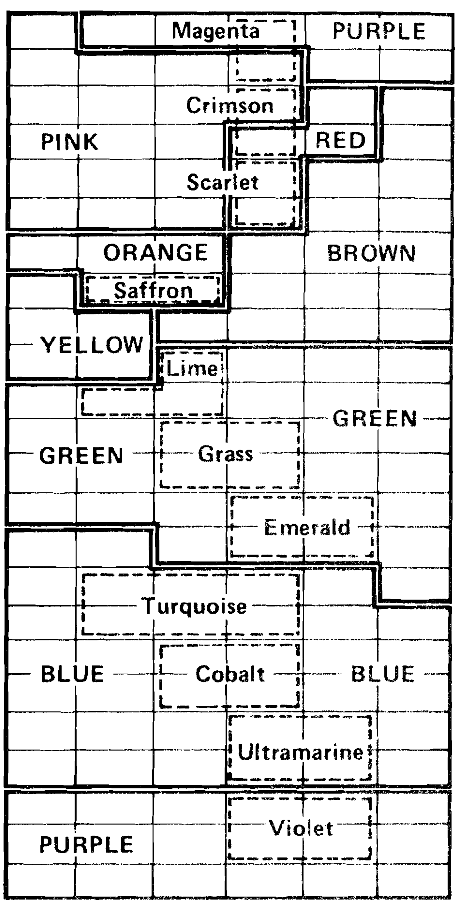
In fact, one could reasonably judge any proposed "International Standard System" by how well it meets the needs of stamp collectors.

Here, then, is the world of colour (L12) a great range of problems and very few universally understood basic colour terms for describing colour.

Alexander Styne *68* has provided an account of the Universal Colour language (UCL) with its six levels for describing colours with varying degrees of accuracy.

R12 Sample colours for interior decoration, artists' paints, lipstick and motor cars matched with Munsell chips. Comparison between basic colour terms (level 1) Munsell notation (level 4) the names used by industry for marketing and their conversion to the ISCC-NBS method of naming (level 3). *15*

L13 Colour array subdivided according to the application of the basic colour terms: red, yellow, green, blue, brown, purple, orange, pink. *14*



L14 Heraldry in action: Fourteenth Century armoured Knights with "Coats of Arms". *43*

R13 The metals and colours of heraldry: gold, silver, red, blue, green, black, purple, (orange, magenta). *77*

This seems to be gaining acceptance as a useful concept. Its application is illustrated in these colours (R12) which people might encounter in various circumstances. At level one they are all simply "red". Munsell notation is much more precise at level 4. Level three would relate the names used for marketing to the ISCC-NBS method of using the basic names with modifying adjectives.

Lars Sivik and Anders Hård *62* refer to the classic study of basic colour terms by Berlin and Kay *3* and they describe their own investigations of the range of colours which would be described by basic terms as well as by some other common colour names. My own serious investigations into colour began with the problem of colour names in 1976. With limited resources and unorthodox means, I mapped the application of the basic terms in 1978 like, this (L13) *14* . I used one subject, my 3 year old daughter Emily whose vocabulary was limited to the basic terms and who did not think of using such expressions as "greenish-blue".

This is how she named the colours and I doubt if a wider survey would have produced significantly different results.

Clearly the terms are used with greatly different degrees of precision. For example, it is a more precise statement to say that something is yellow than to say that something is green. This difference in the precision of basic colour terms leads, of course, to many of our problems.

As a possible solution, I have considered an extended vocabulary. I have tried to subdivide the colour solid into segments of roughly equal size and to find an appropriate name for each segment. Taking the "yellow" segment as the standard size, the much larger "green" segment had to be subdivided into smaller segments with names like "lime", "olive", "jade", and "emerald".

However, I have found this to be a dangerous approach. Apart from the problems associated with any "equal" subdivision of the colour space, the nature of colour names is such that they will not fit neatly into any regular grid that we might impose. Rather than impose an order of our own choosing on colour names we should look to see if colour naming has any order of its own. This seems to be a more promising line of investigation and is the one being followed by Sivik and Hård, who are using the NCS to map the ranges of colours described by the various names. Whatever this leads to, I believe that the Universal Colour Language should make room for names other than the basic terms. These might be called "sub-basic" or "secondary colour terms" and they include names like turquoise, lime, magenta and beige.

Further insight into the meaning of colour is provided in Giovanni Passigli's *55* study on children's colour preferences. Children are clearly sensitive to the symbolic possibilities in the language of colour and its ability to identify and differentiate.

Colour is used for this purpose in the science of heraldry (L14) and it is interesting that heraldry (in England, at least) admits a very limited colour range (R13)

L15 The CIE chromaticity diagram. *36*

R14 The CIE System represented in thre
dimensions. *36*

R15 The Munsell System. *50*

L16 Itten's version of Runge's
Colour Sphere. *29*

It is further interesting that two of the colours have been used so rarely that they are generally ignored. These are "tenné" (tawney or dull orange) and "sanguine" (a purplish red or magenta).

There could be no room on the battlefield for any uncertainty when confronted with helmeted soldiers in muddy surcoats where correct identification of red (friends) or orange (enemies) could be a matter of life or death.

(A similar problem was presented during the Symposium excursion: how to choose ten colours for the different routes of the Göteborg transport system which can be distinguished and described with no risk of confusion).

At level six of the Universal Color Language we meet the CIE Standard Observer and the measurement of colours with instruments (L15,R14).

Many participants speak of the usefulness of the CIELAB System in Industry. Among its applications I can see colour matching and the setting of tolerance which could be written into a contract between a supplier and a manufacturer. Keith McLaren suggests *44* a modification of the Universal Colour Language to accommodate CIELAB and further suggests that present techniques admit an even greater level of accuracy - a level 7.

There has been some debate about the desirability of a colour system which relates directly to colour measurement while being comprehensible in terms of colour vision.

If I understand correctly, the Eurocolor System *10* claims to be just that. Hendrick Saris *60* makes a similar claim for the A.C.C. System *1* , and I believe the Coloroid *52* system also falls into this category.

I am getting out of my depth here, but can appreciate that such systems must be very valuable.

Gunnar Tonnquist *69* refers to a proposed I.S.O. Colour notation system which might finally put an end to the confusion between rival terminologies. Perhaps such a system should also have a built-in link to the measurement-based systems and the whole scheme be housed in a modified version of the Universal Colour Language.

I want to focus now on an issue of particular concern to me and one which has received some attention in the discussions. Professor Wright *78* proposed two broad groupings of colour order systems:

Group A - the lightness group (R15) includes Munsell *49* , DIN *9* , OSA-UCS *53* , ACC *1* , Coloroid *52* , and Eurocolour *10* .

The CIE System and its offspring CIELAB and CIELUV also relate to the lightness group.

Group B - the whiteness group - includes Forsius *20* , the Sphere of Philip Otto Runge which was adopted by Johannes Itten *29* ,(L16) Ostwald *31* , Müller *48* , and N.C.S. *21* .

L17 Cross section of the Ostwald system showing yellow hue 2. *31*

L18 NCS chips of nuance 3050 and hues: Y, Y50R, R, R50B, B, B50G, G, G50Y. *18*

L19 Munsell chips from R18 laid on top of NCS chips from L18. *18*

L20 Colour circle with concentric rings full hue, tints, tones and shades. *51*

L21 Flowers which are examples of basic colour schemes: monochromatic, adjacent, complementary and triadic. *51*

L22 Three-colour combinations (or "chords") plotted at equal distances within Ostwald cross section. *31*

L23 Complete cross section of Ostwald system showing hues 8 & 20 *31*

L24 "La Chambre a Arles" 1889, by Vincent van Gogh. *71*

L25 Textiles designed and woven by Herbert G. Astin. Colour combinations determined by ring star principles. *31*

R16 Cross section of the Munsell System showing yellow hue 2.5Y. *49*

R17 NCS and Munsell Structures Superimposed NCS chips of hue Y70R in positions that would also be occupied by similar looking Munsell chips of hue 10R. *17*

R18 Munsell chips of value 5, chroma 8 and hues: 5Y, 5YR, 5R, 7.5P, 10B, 5BG, 5G, 5GY. *18*

R19 Equal nuance NCS chips 3050Y and 3050 R50B juxtaposed and compared with juxtaposed equal value/chroma Munsell chips 5Y 5/8 and 7.5P 5/8. *18*

R20 Cross section of colour solid with white, grey, black, tint, tone, shade full hue. Also shows Monochromatic, ajacent, complementary and triadic colour relationships on colour circles.

R21 Irregular colour schemes. Adjacent and triadic colours are not equally spaced. *23*

R22 Outline cross section of Ostwald system with lines which would connect related colours. *31*

R23 Outline cross sections of Ostwald system illustrating "ring star" relationships. *31*

R24 Hues in painting "La Chambre a Arles" plotted on Ostwald colour circle. *31*

R25 & R26 Colours in painting "La Chambre a Arles" plotted on cross sections of Ostwald colour solid. Illustration of ring star relationships. *31*

Group A Systems have a different basic structure from Group B Systems. This can be seen most clearly with yellow. This is a comparison between Ostwald and Munsell (L17,R16). For some hues the structures can coincide. Here the NCS and Munsell scales are superimposed (R17) and NCS Y70R chips occupy essentially the same positions that would be filled by very similar looking chips of Munsell IOR.

Unfortunately, the difference between lightness structures and whiteness structures is a subtle one and difficult for ordinary people to grasp. Until very recently, and to preserve the sanity of my students, I had hoped to make a definite choice of one basic structure. I was favouring the lightness structure. But I am now convinced that, for artists and designers, at least, both structures illustrate important information. I was led to this conviction by Werner Spillman's paper *66* . He points out that colours of the same NCS nuance (L18) have an inner relationship which is lacking in colours of the same Munsell value / chroma (R18).

But a painter friend of mine, Ben Joel *34* , while agreeing that the NCS group is "calmer" preferred the Munsell set for its greater visual drama. He described what he was getting from the juxtaposition of the equal value Munsell chips as "full juice". There is more "electricity" across the border where the two equal value colours meet. here are the two sets together and the extreme examples (L19,R19). Inner relationships and calmness with NCS, visual drama or full juice with Munsell.

The group B whiteness systems seem to be best suited if you wish to apply the well established principles of colour harmony first proposed by Chevreul *8* and developed by Itten *29* . Here they are illustrated in the Flower Arranger's Guide to Colour Harmony (L20,R20) *51*.

A colour scheme may be satisfying when the colours are seen to have some attribute or attributes in common, e.g., the same or similar hues (L21). Or a scheme is satisfying if it is balanced, the hues are opposite or located at equidistant points around the circle.

Deryck Healey (R21) gives similar advice for interior design but suggests slight deviations to make a scheme more lively *23*.

In his book on the Ostwald System, Egbert Jacobsen *31* , proposes many ways of relating colours for harmonious effects (L22,R22). Prof. Hesselgren *26* , referred to his bad experience with Ostwald's methods (L23,R23) but Jacobsen offers a kind of "proof" of their validity. He takes famous paintings (L24), acknowledged masterpieces of colour harmony, and locates each colour in the Ostwald Solid (R24). Their relationships can then be demonstrated (R25,R26).

From this it might be said to follow that what a painter like Van Gogh can achieve intuitively a designer can also achieve by following the rules.

These textiles were designed on such a principle (L25).

L26 "Diagon 31^2,Red/Green" alterable object, 1956, Nitrocellulose on aluminium sections by Karl Gerstner. *13*

R27 Diagram showing hue intervals of "Diagon 31^2 Red/Green" plotted on a hue circle. *13*

L27 "Color Sound 4D" 1973, Nitrocellulose on phenolic resin plates by Karl Gerstner. *13*

R28 "Color Sound 2A" 1973, Nitrocellulose on phenolic resin plates by Karl Gerstner. *13*

L28 Colour composition by a student at the Bergens Kunsthåndverksskole. *65*

R29 Variation on student's composition. *65*

L29 Colour composition by a student at the Bergens Kunsthåndverksskole. *65*

R30 Variation on student's composition. *65*

To quote Jacobsen:

"We cannot say that any modern painters knew or applied the Ostwald principles, but we may say that the principles help us to understand their colour choices and why these seem harmonious to us. Without artists, we might never have been aware of the wonders of colour harmony; without scientists we should not be able to explain them".

Colour order systems can be used, therefore, for analysing a colour scheme and for planning one.

An artist who uses a colour order system in planning his work and whose approach might be described as particularly "scientific" is Karl Gerstner *13*. He acknowledges a debt to Philip Otto Runge and has used Müller's colour atlas.

This painting (L26,R27) was planned for a kind of mathematical precision and completeness. Successive colour bands double in width while the hue intervals are halved. The hue intervals are plotted on a 31 step hue circle.

In a later series of works which he calls "colour sounds" (L27,R28) Gerstner is exploring the way in which a journey of visually even steps through a colour solid is accompanied by very uneven changes in colour meaning. There may be a clue here for colour naming studies. Does a large change in colour meaning occur as a colour name boundary is crossed? It can be seen that the colour changes in the paintings would follow quite complex curved paths through a colour solid. These are two of a series of which Max Lüscher *42* has written:
"In its technical perfection the construction produces emotional surprises. The metric regularity of the changes of colour tone... is subject to abrupt mutational leaps in its psychical expressiveness. The finely graded optical order reveals itself to be an apparent regularity. Emotional reality, on the other hand shows that certain colour tones have a highly individual antiauthoritarian quality".

Grete Smedal *64* has described her approach to teaching colour theory and has presented a magnificent exhibition of work done by her students at the Bergens Kunsthåndverksskole. She has provided a totally convincing argument for the value of a colour order system such as the NCS in the training of designers in all fields (interior and graphic design, textiles, ceramics, etc). Here (L28,R29) a student has produced a colour composition and has used the NCS, first to plot the relationships between the colours and then to plan a series of possible variations. In these two examples, the arrangement of areas to be painted in different colours, the network of boundaries, is the same, but we read a different pattern in each case. The diagonal band that dominates one composition is missing from the other. Students can look at the colours and their NCS notations and learn. (L29,R30).

Such variations can be tightly controlled or almost random. The NCS can be used to take students into unfamiliar territory where exciting discoveries can be made and recorded.

L30 "Israel/Lebanon". 1981 Two sided screen. Oil on marine ply by Ben Joel (Inside view). *32*

R31 "Israel/Lebanon" 1981. Two sided screen. Oil on marine ply by Ben Joel (Outside view). *32*

L31 "See Above" 1983, Acrylic on canvas by Ben Joel. *33*

R32 Detail of "See Above". *33*

L32 Colour composition by Adrian Roderick, student of the School of Art and Design, Western Australian Institute of Technology. *19*

R33 Colours of Adrian Roderick's composition plotted on diagrams. *19*

L33 Colour composition by Greg Tothill, student of the School of Art and Design, Western Australian Institute of Technology. *19*

R34 Colours of Greg Tothill's compositions plotted on diagrams. *19*

Group B (whiteness) Systems are also preferred by Werner Spillman [66] for his work in environmental colour design. His paper reads like a consumer's guide to colour order systems. I have already referred to his observations about the inner relationship that exists between colours that are equally whitish and blackish; for his work this relationship is of prime importance.

Turning now to applications of Group A (lightness) Systems, I have also referred already to Ben Joel's [34] interest in the lightness or value dimension. He painted this screen, with its complex illusions in 1981 (L30,R31).

He speaks eloquently about the value of a colour order system in his work. He describes a colour solid as "a world you can wander into". It can widen your vocabulary of colour. The colours that you can squeeze out of tubes of paint can be limiting and the range of colours available are not ordered as was pointed out during one of the discussions by Keith McLaren.

Ben Joel echoes many of the points made by Grete Smedal but the colour world he wanders into is not the same shape. His mental model is a lightness one and he uses it to predict colour mixtures and effects and for what he calls "trouble shooting". It tells him how to change a colour area so that it appears in front, behind or on the same plane as another colour area, how to increase or suppress the legibility of forms. For him light-dark or "value" relationships are crucial.(L31,R32).

Here he wanted the whole painting to be "seething, crawling, but still have forms that are legible". The illusion of three dimensional form is very powerful and is achieved by control of value contrast. He achieves his restless effects by building each value area with small strokes of equal value but strongly contrasting hue. I find the painting very disturbing. This was the effect Ben Joel wanted and he can achieve such effects because he has a system in his head. He knows what is possible and he knows how to fix things when his painting is not coming out according to his intention.

My students have been doing colour exercises of a similar kind and for similar reasons as Grete Smedal's students, [63] but we are working with a lightness structure (L32,R33). This is very recent work, only four weeks old, and I find the results rather promising. The colours can be plotted on diagrams where they appear in a distinctive pattern, like a constellation, and their relationships can be readily appreciated. The constellations can then be systematically rotated, expanded or contracted and a new combination can be generated. In this example, (L33,R34) the transformation from top left to bottom right is very clearly expressed. For variation B the constellation has contracted towards the achromatic point, the colours are less saturated, but they have moved far apart on the value line. The light/dark or value contrast has greatly increased.

L34 Tichener's colour solid, 1887. *12*

L35 Constant hue triangular slices through Pope's colour solid. *7*

L36 Diagrams illustrating the colour space used by Jacques Fillacier & Michel Albert-Vanel. Scales of equal value and equal saturation are shown. The hue circle at full saturation is at an angle-not horizontal in relation to the vertical achromatic scale. *11*

L37 Routes of Colour scales plotted in the Fillacier/Albert Vanel solid. *11*

L38 Model of Esso-Standard Oil Refinery at Port-Jerome. *11*

L39 &L40 Part of the completed Oil Refinery at Port-Jerome. *2*

L41 Analysis of local colour: Naturally occurring materials from district around Le Vaudreuil - earths, rock, etc. *40*

L42 & L43 Traditional Colour treatment on Colonial Buildings in Parati, Brazil. *58*

L44 &L45 New Colour treatment on Buildings in São Paolo, Brazil. *58*

R35 Arthur Pope's colour solid, 1929. *7*

R36 Diagrams showing the many possible ways in which colours can be related in the Fillacier/Albert-Vanel Colour solid. *11*

R37 Examples of colour scales from the Fillacier/Albert-Vanel solid. *11*

R38 Model of Port-Jerome Oil Refinery. *11*

R39 & R40 Part of Port-Jerome Oil Refinery. *2*

R41 Analysis of local colour, Vernacular architecture with traditional colour treatment. *40*

R42 Colour palette adopted for Le Vaudreuil with examples of possible application. *40*

R43 &R44 Traditional colour treatment on Colonial Buildings in Parati, Brazil. *58*

R45 &R46 New Colour treatment on Buildings in São Paolo, Brazil. *58*

If artists and designers need to be conscious of whiteness/blackness relationships, I believe they also need to be conscious of lightness/darkness relationships.

We need both structures. But is it possible to present both kinds of information in one system?

Tichener's Solid (L34) can be interpreted as an attempt to do this, so can Arthur Pope's (R35). Whiteness and blackness can be read from the triangles for each hue (L35). The different shapes of the triangles puts colours into their proper positions for reading light dark relationships. A similar structure is used by Jacques Fillacier and Michel Albert-Vanel [11] in their analysis of possible colour combinations for an oil refinery (L36,R36). This enables them to explore a very wide range of colour combinations which are related in different ways.

Many colour scales can be extracted from such a colour solid (L37,R37).

Here are photographs of a model of the refinery showing the colour scheme (L38,R38). And here are photographs of the finished project (L39,R39. L40,R40).

As part of their study, they used their colour system to record local colours so that the refinery, by echoing these colours, could be made to harmonise with its surroundings. A similar procedure was used by Jean-Philippe Lenclos [40] in planning colour treatment for the proposed new town at Le Vaudreuil (L41,R41), his object being a degree of integration between new and existing buildings (R42).

Sonia Prieto [57] has described two contrasting examples of colour in architecture, one in harmony with the environment, the other creating a new environment of its own. Both are in Brazil.

The town of Parati (L42,R43) is a protected historical site where the traditional colour treatment can be seen on the 17th and 18th century colonial buildings. The walls are whitewashed and the woodwork painted in a limited range of vivid colours, the paints being prepared from locally available substances (L43,R44).

The success of this treatment, as Sonia Prieto suggests, may not be so much in spite of as because of the limited range of colours and because this range is limited by the environment itself.

By contrast São Paolo had become the proverbial "concrete jungle" (L44,R45). In such an artificial environment many pressures contributed to the colour revolution that began in the 1970's (L45,R46).

Most notable was the desire to recapture the colours of remembered landscapes and the need to establish the purpose of buildings converted from domestic to commercial use.

L46 Colour range of the Jotun Multi-color System. *35*

R47 Range of 39 colours for carpets. Selected by Anders Hård. *56*

L47 Cover of book "Color Me Beautiful" by Carole Jackson. *30*

R48 Illustration of colours that do and do not suit an individual. *30*

L48 Spring palette from "Color Me Beautiful". *30*
L49 Autumn palette from "Color Me Beautiful" *30*

R49 Summer palette from "Color Me Beautiful". *30*
R50 Winter palette from "Color Me Beautiful". *30*

L50 Representative colours from each "Color Me Beautiful" palette for comparison: reds/pinks, greens, blues. *30*
L51 Introductory Colour System colours arranged in zones of similar value. *16*

R51 ICI fibres predicted colour range for Spring and Summer, 1983. *28*

R52 Introductory Colour System Colours arranged in Zones of similar Chromatic amount. *16*

Before summing up, there are two more papers to be considered.

Urban Willumsen 76 has presented a very sound approach to the problem of selecting a colour range for such products as paint, carpets and furnishing fabrics. He is associated with Jotun and here (L46) is that company's range of paint colours - systematic, comprehensive and described with NCS Symbols.

Here (R47) is a much smaller range of colours for carpets. Use of the NCS for planning the range has ensured that no major colour area has been left out and that the colours are related.

O'Connor Whitfield and Wiltshire 54 put the case for a basic set of International Standard Colours to be specified by some internationally agreed method which would overcome present difficulties in manufacture for export. The methods outlined by Urban Willumsen could be used to plan an appropriate range of colours.

A similar approach might be adopted by the textiles industry. In her book "Colour me Beautiful" (L47,R48) Carole Jackson presents a surprisingly convincing case for four basic types and four corresponding palettes - ranges of related colours which particularly suit each type of person:

Spring - predominantly warm and delicate colours (L48)
Summer - predominantly cool and delicate colours (R49)
Autumn - Predominantly warm and strong colours (L49)
Winter - predominantly cool and strong colours (R50)

One of her aims is to liberate people from the tyranny of colour trends, but fashion dictates that this can't always work (L50,R51). In a particular season there may be a critical shortage of your particular colours.

This is my own version of a basic set of colours from my Introductory Colour System (L51,R52).

To conclude, a possibility seems to be emerging:

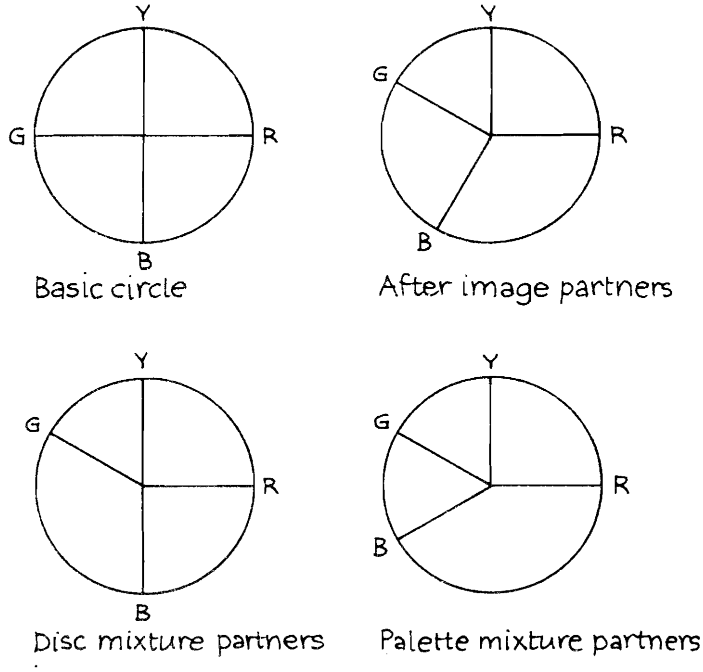
Terminology and a notation system blessed by the International Standards Organisation.

A set of colour chips which are related to colour measurement, are accepted visually and which can be arranged to show equal lightness <u>or</u> equal whiteness.

All this to be accommodated in a revised version of the Universal Colour Language which will have more levels, (a possibility already suggested by Alexander Styne 68).

I see a big hole between levels 2 and 3 of the Universal Colour Language which could be plugged with a level for the sub-basic or secondary colour terms, and a level for a basic colour range such as I have just described. And Keith McLaren 44 has proposed a new level at the top.

For this possibility to become a reality, I think it will be necessary for the whole structure to be made of elastic.



L52 Comparative Colour Circles. Relative positions of unique hues vary according to different definitions of complementary colours. *17*

L53 Painting by Sydney Harry, 1972.[22]

R53 January, 1973: 14 Screenprint by Patrick Heron. *24*

I am considering such a structure quite seriously and it would not be the first . Harald Küppers 38 rhombohedron -cum-cube-cum-hexagon is an elastic system which changes shape most usefully to illustrate different principles. In an elastic structure a vivid yellow can move up to show its lightness or value in relation to the grey scale and back down again to show its relative whiteness and blackness.

Also each chromatic type or hue must be free to move a few steps back and forth around the circle to show the different so-called "complementary" relationships (L52).

Here a basic circle of NCS type is compared with three other circles in which opposite hues are complementary according to different definitions. In this situation, the unique hues are essential reference points.

This morning, Professor Hunt 27 showed us that lines connecting opponent pairs of unique hues change direction when they pass through the achromatic point. The pattern they presented on the chromaticity diagram seemed to me to be like the second pattern here where I have moved unique blue and unique green from 6.00 to 7.00 o'clock and from 9.00 to 10.00 o'clock respectively to bring them opposite their after-image partners. This may or may not be significant.

I would like to leave you with two paintings (L53,R53) and three quotations.

The paintings are by artists whose work I greatly admire. Sydney Harry, on the left, is fascinated by the way in which colours may be physically the same but look different with a change in the neighbouring colours.

Patrick Heron is exploring the relationship between what is read as figure and what as field, and how these can reverse. He is also exploring the way colours can appear to change as the eye travels along a border dividing two colour areas and the paradox that different colour areas appear to lie on different planes although we can see that they are physically on the same plane.

The quotations, I feel, are particularly relevant to this Symposium:

"The artist must have his measuring tools in his eye not in his hand as it is the eye that judges"

Michelangelo 47 .

"We must be content with discovery and be on guard against explaining".

Georges Braque 6 .

"Painting's role in civilization is that of man's laboratory for the disinterested exploration of visual appearances as such, an exploration carried out uninhibited by any practical demands whatsoever".

Patrick Heron 25 .

And the findings of such exploration can be recorded in a colour order system.

Thank you very much.

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77- WOODWARD, John and BURNETT, George. *Woodward's a Treatise on Heraldry British and Foreign.* Newton Abbot: David and Charles Ltd. 1969.
78- WRIGHT, W.D. *Basic Concepts and Basic Attributes of Colour Order Systems.* Invited lecture for The Forsius Symposium.

THE DISCUSSION
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following this lecture was very lively and stimulating and we regret indeed that the tape on which it was recorded has been destroyed.

APPLICATIONS
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Session g

WRITTEN COMMENT
G. Döring

Remark regarding the lecture given by Paul Green-Armytage:

Mr Green-Armytage has demonstrated with some slides that the NCS color samples show something what he called "inner harmony", and the Munsell color samples do not. It is also one of the aims of the DIN color sytem to show harmonic colors and color combinations. For this reason the lightness scaling of the DIN color system, the Dunkelstufe, is related not to the luminance factor of the ideal white (Y=100), but to the luminance factor of the corresponding optimal color. For instance, a blue and a yellow color of the same DIN saturation look harmonic if they have the same Dunkelstufe, they look inharmonic if they have the same luminance factor (this has been demonstrated by a color-slide).

APPLICATIONS
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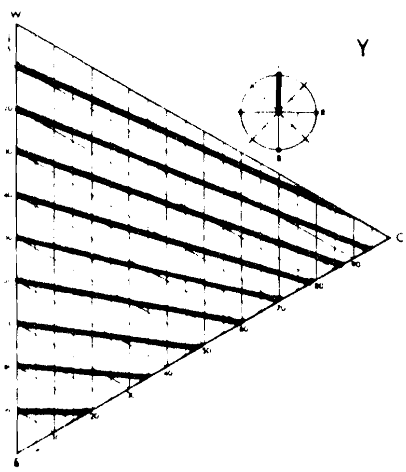
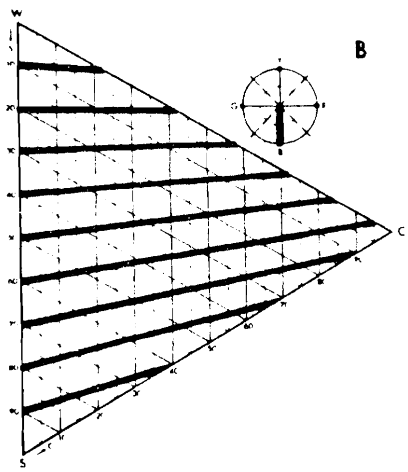
Session g

WRITTEN COMMENT
Anders Hård

In his lecture Paul Green-Armitage often refers to the difference between a lightness-space (like Munsell's) and a whiteness/ blackness-space like the NCS and he indicates that e.g. Pope has made a synthesis of these two in his model (which, in fact, was also done by Tryggve Johansson in his interpretation of Hering's natural colour system). However, I cannot see any disadvantage in the way "constant lightness" is shown in the NCS triangles. Instead of distorting the "quality triangles" we have drawn lines of constant lightness as shown below.





From this example we see that a maximally chromatic yellow has a lightness equal to the gray with s=10 (Y=77) while a maximally chromatic blue in lightness is equal to a gray with s=65 (Y=16).

APPLICATIONS
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MODERATOR'S REPORT
Gunnar Tonnquist

Session 9

After an intense discussion how to produce and check coloured materials to be put on the market by dyers, printers, etc., and colour samples illustrating colour order systems, we now turned to the use of colour order systems by designers, artists, teachers and "ordinary" people.

A variety of papers were assigned to this session:

V. J. Georgijevic (not present)	Calibration of colorants for computer colour matching.
Anders Hård Lars Sivik	Basic concepts of the NCS and its use for studies of colour rendering
Tomas Hård	NCS colour samples and collections - working tools for environmental colour design.
M C & R D Ingalls	Small colour differences and colour order systems
Keith McLaren	A colour order system for industrial colour control
G. Passigli	Psychological differential color order systems according to children's preferences
Sonia Prieto	Colours in the Brazilian architecture
Lars Sivik Anders Hård	Is color naming the most natural colour system?
Grete Smedal	NCS as a basis for colour education ...
Werner Spillman	A colour order system for environmental design
Åke Svedmyr	Absolute colour estimations by the NCS method
Urban Willumsen	Systematic colour assortments

The discussion was introduced by Mr Paul Green-Armytage, who made an elegant presentation of all possible and even impossible colour systems, and how they are used and misused in everyday life. His paper will appear in the proceedings; therefore I will only mention one or two of his points.

Paul Green-Armytage referred to the grouping of systems made by Prof. Wright (in session bc), whether they use lightness or whiteness (blackness) as a fundamental variable. He stated that artists and designers need both kinds of variables, as they both give important but different characters to a colour combination.

Equality in blackness - as in NCS - give calm, harmonious patterns. Equality in lightness doesn´t necessarily mean disharmony, but the colour patterns become more vivid. The artist and practitioner wants a colour model that gives him what he wants.

Dr Green-Armytage concluded by making a few citations, one of which gave echo in the following discussion:

"We must be content with discovery and be on guard against explaining".

In the discussion there was an unanimous condemnation of various odd systems such as that of Küppers, pseudo-psychological colour tests as that of Lüscher, and unscientific rules for personal colour schemes like the book "Colour me beautiful" now very popular in the USA. Dr Green-Armytage, who had mentioned these in his introduction, stated that he had done so only to give examples of various kinds of applications, even bad ones.

In an additional statement to his previous paper, Prof. Sven Hesselgren explained, why he regarded the NCS as the only system applicable to design problems. The character of a pair of colours remains essentially the same as long as each colour is varied within the same quadrant of the colour circle, i.e. between its adjacent unique hues. However, the character changes very dramatically, as soon as one of the colours is moved across one of the unique hues, which act as "shifting points".

Dr Green-Armytage had shown a picture of a painting by van Gogh and said that an analysis of its colours in terms of a colour order system would help other artists. This was criticized by Dr. Wyszecki, who didn´t believe in such short-cuts. The chances that the same colours used in another pattern would give anything like a good piece of art are very small.

After a while, artists and designers, who had been rather quiet during the symposium, gradually took greater part in the discussion. It was emphasized that artists do not want to be hampered by rules. They may use them, but they must feel free to leave them whenever they want. What they and many others want from a colour system is a possibility to describe each colour in words. Prof. Billmeyer pointed out that philatelists for that reason still prefer the old Ridgway atlas from 1912.

To conclude the report from session g, one might hopefully describe it as a beginning dialogue between colorimetrists and artists as to the possibilities and requirements for colour order systems, not only to produce coloured materials but also for the use of them to create certain colour sensations.

Following this report, Dr Green-Armytage stated that

"If a colour order system liberates your thinking, it is a good system, if it restrains your thinking, it is a bad system.

You cannot categorize all systems as either ´all good´ or ´all bad´."

COLOUR ORDER SYSTEMS AND ENVIRONMENTAL COLOUR DESIGN Session h
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INVITED LECTURE

Werner Spillman

(Illustr
no. in
margin)

What can an environmental colour designer contribute to an international symposium of such distinguished experts in colour science? Clearly, you will not be expecting a scientific lecture. I shall try, rather in a sort of essay, to elucidate a few aspects of the relationship between colour order systems and environmental colour design which might interest you. I shall also offer some insights into problems which an environmental colour designer has to face in his work, whose main task is to combine various colours in a suitable way.

In the first part of this essay I shall trace some outlines of the history of colour order systems which bear upon the question of aesthetic colour combining (syntactic aspect). The second part will try to define the position of colour in the field of environmental design (psychological, contextual and structural aspect). The function and usefulness of colour order systems in the process of environmental colour planning and realisation (pragmatic aspect) will be discussed in the third and last part.

Colour combination theories in the history of colour order systems

If we look briefly at the history of colour order systems, it is quite clear that traditional colour order systems for the most part were not primarily developed for their usefulness in the process of environmental colour design, though this does not prevent some of them from being helpful for this discipline. I refer to my paper for the Forsius Symposium, reporting from a personal viewpoint the search of an environmental colour designer for a suitable colour order system.

While ancient Greek philosophers were occupied with the I:1
question of colour perception /1/, since the times of Forsius, I:2
who gave his name to our symposium, scientists, painters and
philosophers have started to develop models for bringing order
into the variety of colours, a theme well-known to you.

As far as environmental colour design is now concerned, it I:3
is really fascinating to see how often these ordering efforts I:4
have been accompanied by thoughts or theories describing what
colour combinations are better or look nicer than others /2,3/, a
question really essesntial for environmental colour design. So I
shall try to give a survey of some different concepts:

The concept of analogy to music

We know that Isaac Newton (1643-1727) compared the seven I:5
hues he saw in the spectrum with the seven tones of the music
scale.

Louis Bertrand Castell (1688-1757) took over from Newton the analogy of hues and musical tones. He distinguished twelve hues (according to the half-tones in music) and he even proposed the construction of a colour piano.

Wilhelm Ostwald (1853-1932) who called Newton the creator of scientific colour theory was very sceptical on this single point. He even criticized this concept by calling the way Newton explained this analogy between hues and tones "arbitrary and tricky".

The concept of "complementary" hues and symmetrical hue chords

Johann Wolfgang Goethe (1744-1832) derived his fundamental law of colour harmony from the experience of the physiological phenomenon of the negative after-image. According to his hue circle containing six colours he mentioned three fundamental harmonious hue-pairs: I:6

yellow - redblue
blue - redyellow
red - green

Rudolf Adams (born 1820) published in 1865 a colour circle consisting of 24 hues. He calls it "chromatoaccordeon", an "apparatus for finding harmonious colour combinations". With the help of a set of master plates, one can demonstrate symmetrical colour chords of 2, 3, 4, 6 or 8 hues.

The concept of "complementary" hues and symmetrical hue chords can be found later with modifications in Ostwald and others.

The concept of colour contrast

Rudolf Adams dealt at length with the question of colour harmony: "The most perfect harmony is found where the greatest variety of parts belonging together are bound to highest unity". In addition to hue-contrasts he sees the necessity of value-contrasts and proper area relations concerning the chromaticness of colours.

Albert Henry Munsell (1859-1918) also laid particular stress on the use of value and chroma-contrasts in painting and he declared that even unsymmetrical hues (which do not compensate each other to neutral grey in colour mixture) can be used so long as the laws of value and chroma-contrast and area balances are observed. I:7

The well-known concept of the seven colour contrasts developed by the painter Adolf Hölzel (1853-1934) played an important role in art schools for quite a long time.

The concept of attribute equality

For ordering surface colours Wilhelm Ostwald (1853-1932) proposed a regular double cone. While the painter Munsell stressed the necessity of value and chroma-contrast, the scientist Wilhelm Ostwald (1853-1932) tried to define precisely the way in I:8

which contrasting colours can be bound (fitted together). /4/ As I:9
the first principle of colour harmony he formulated: "Only such
colours can appear harmonious, the attributes of which stand in
certain simple relations". His so-called ring-star demonstrates I:10
the fundamental harmonious relations to a specific colour:

- wertgleicher Kreis
  (circle of colours of different hues but
  equal in whiteness and blackness)
- weissgleiche Reihe
  (scale of colours equal in whiteness)
- schwarzgleiche Reihe
  (scale of colours equal in blackness)
- reingleiche Reihe
  (scale of colours equal in chromaticness)

I:11

Ostwald mentioned other possibilities of scales of related
colours: I:12

- Binnenreihen
  (inner scales, colours with the same proportion of
  blackness and chromaticness)
- Schattenreihen
  (shadow scales, colours with the same proportion of
  whiteness and chromaticness)
- Nebelreihen
  (mist scales, colours with the same proportion of
  whiteness and blackness)

It is quite interesting to see how much time it took before the attention in the theory of colour combining was concentrated on the nuance (Farbwert) of colours. On the other hand, this fact is not very astonishing if one considers that the development of colour order systems also started with the ordereing of the different hues long before one began to structure the whole three-dimensional space of surface colours.

But Ostwald's discovery of the importance of the amount of whitness and blackness did not please the artists for whose work he thought his theory would be essential. They certainly did not see in his theory an aid to their artistic activity. On the contrary, they must have become afraid of imposed restrictions.

Aemilius Müller (born 1901), a Swisss admirer and successor I:13
of Wilhelm Ostwald, editor of marvellous colour atlases, published a "Modern Theory of Colour Harmony" in 1948 /5/. He tried to find a solution for the conflicting situation already mentioned by stating that his own theory was not at all obligatory in free arts but rather a help for all those disciplines having as their aim the production of aesthetic objects as, e.g. applied arts, fashion, environmental design. So, Aemilius Müller is one of those theorists on colour order systems who aim to contribute to the development of colour culture not any longer in the art of painting but especially in the field of environmental colour design.

Having in mind Ostwald's colour scales being of the same I:14
hue, Müller showed that scales of the same hue generally have a I:15
certain tendency to look slightly monotonous and that they can be
made more attractive by using systematic deviations in hue,

provided that so-called "inversions" are omitted. What is such a colour inversion according to Müller?

The concept of natural lightness ratio of hues

In the spectrum as well as in the circle of full colours (Vollfarben) the different hues have their specific relative lightness, yellow being the lightest, blueish violet being the darkest. According to Müller, colour combinations of different hues can only be harmonious if they correspond to the natural lightness ratios of hues. The inversion of natural lightness ratios of different hues is for Müller even a definition of colour disharmony. I:16 I:17

A similar idea was also brought forward by Arthur G. -Abbott in 1947: I:18

"A very important element of harmony is that of comparative brilliance. The relative brilliance of the colours in a harmonious composition must generally agree with that found in the spectrum"/6/.

Attempts at a synthesis

It cannot be denied that in the history of traditional theories of colour harmony conflicts sometimes arise between artists and scientists: For many artists the theory of Ostwald seems to be too narrowly limited an therefore dangerous. For scientists Müller finds the concept of the seven colour contrasts of Hölzel too vague and therefore of little use. /5/.

One should not dramatize this conflict but rather try to combine the positive aspects of both approaches. When I started to go into the matter of colour combining, I soon felt (as certainly other colour designers must have too)/2/ that colour contrasts (Hölzel) and colour liaison (Ostwald, Müller) are two complementary aspects of the problem of colour chord, two faces of the same medallion.

A colour chord needs contrasts which produce tension and change as well as colour liaisons which produce concord among contrasting colours so that the primary aim can be realized: variety in unity or continuity in complexity. I:19 I:20

I am therefore especially satisfied about the fact that from the scientific side has been proposed a conceptual framework for studying the problem of colour combination (Anders Hård, Lars Sivik: Outlines of a theory of colours in combination, 1979)/7/. This theory is clearly descriptive and per se non-evaluative. It contains the same three main aspects I have mentioned above: Colour chord, colour contrast and colour harmony (what I have called colour liaison in order to sound less evaluative).

I am sure that a fruitful collaboration between scientists and designers will be possible in the forthcoming AIC Study Group on Environmental Colour Design.

In this first part we have dealt exclusively with interrelations of colour elements, the syntactic aspect of colour combinations and different kinds of hypotheses concerning their aesthetic evaluation. It would be a real asset for the theory of environmental colour design if these concepts could be experimentally tested, scientifically criticized, refined and further developed. But we must also not forget that colours in the enviroment are parts of a much wider complex.

Colour in environmental design

Man is exposed to space and the forces of nature. He pro- II:1
tects his body by means of some sort of clothes. He builds his II:2
home and tries to create a suitable framework for his social activities. Any manipulation of the existing environment might be called "environmental design". However, I shall restrict my consideration to the field of architecture.

The architect defines architectural space by forming physical limitations made of specific materials which present specific colours and textures exposed to specific illumination conditions. So, colour is only one single design means among a series of others, but nevertheless it influences the appearance of building structures and of indoor or outdoor rooms in a crucial way.

In environmental colour design, not only the interrelations among colour elements (shown in the first part) are of importance, but also, and even more fundamentally, some exterior relations:

- colour to human beings
- colour to building surroundings
- colour to building structure

Relation of colour to human beings

(Psychological aspect)

In everyday life we experience how much colour can affect II:3
man in different ways: unconscious effects, spontaneous associa- II:4
tions, general symbolic or specific conventional meanings. We know that Goethe started by being interested in the psychological aspect of colour. He had a series of successors among painters such as Wassily Kandinsky/9/, and psychologists as, for instance, Henrich Frieling /10/.

How can colour order systems help in this respect? Quite a lot of former attempts in describing psychological effects of colours were lacking a clear colour denotation. Does an American who writes about the effects and meanings of the colour "purple" describe the same colour sensation as Goethe writing about "Purpur"? I am afraid they do not.

Any colour order system providing a collection of real colour samples might be useful. And the NCS colour denotation is clear even without the NCS colour atlas. The method of isosemantic maps used by Lars Sivik in his "Studies of Colour Meaning" published in 1975 shows how useful colour order systems, especially if based on human colour perception, can be for such purposes. /11/

Furthermore, this investigation made clear what important roles are played by chromaticness, blackness and whiteness in colour meaning. While studies on the psychological aspect of colour concentrated for a very long time on the difference of hues, only later did one start to look exactly on the nuances of colours, a feature we have already seen in the development of colour combining theories.

Another point concerning the relation between colour and human beings is the problem of proper chromaticness-dosing. Man has spent more than 99% of the time of his evolution as a plant- II:5
collector or/and as a hunter in a given environment with vegetation. So one could suppose that this determining condition of his existence might be of significance for his compatibility with chromaticness. An anlysis of the chromaticness-degree of greens II:6
in vegetation shows that they lie in a middle area between the most chromatic green and black. More chromatic colours appear in nature only for a short time (red sky at sunset) or on small dots II:7
(flowers and fruits). So, colours with moderate chromaticness in environments for long stay seem to be more appropriate for human II:8
organism than dominating strong, vivid and brilliant colours. On the basis of moderate chromaticness, vivid colours can fulfil II:9
their function of accentuation of single parts and neutral colours can offer welcome interval and rest.

Looking at some superchromatic excesses during the seventies II:10
of our century /12/, we can appreciate that serious research on this biological aspect would be really valuable for environmental colour design. It is also clear that for this purpose a perceptive colour order system will be very helpful.

Relation of colour to building surroundings

(Contextual aspect)

Every building is part of given natural or/and artificial II:11
surroundings. It is an element of a superior system. Any given II:12
surroundings have a specific colour-character which can only be fully comprised in the course of the year's seasons. Such a context of landscape or townscape is a complex matter. Attempts to describe or define complex colour combinations have been made by Anders Hård and by Michael Albert-Vanel /13/.

Buildings can have different kinds of relations to their surroundings:

II:13
- camouflage II:14
- subordination (Unterordnung) II:15
- equal ordination (Gleichordnung) II:16
- superordination (Ueberordnung) II:17
- isolation II:18

I presume that Hård's concept of "distinctness of borderline" plays a primordial role in the determination of the visual relation of a building to its surroundings.

Relation of colour to building structure

(Structural aspect)

Meaningful articulation and ordering of multi-membered building structures and complex room-systems is very important for human perception of the environment, and colour plays an essential role in this process. I would mention some elementary operations of organising visually an architectural Gestalt: II:19 II:20

- synopsis of parts
  by using the same colour
- differentiation of parts
  by using different colours
- grouping together differentiated parts
  by using relatively small contrasts
- separation of different groups
  by using relatively big contrasts
- binding (fitting together) contrasting parts
  by using attribute equality or other means of
  colour liaison

Again colour contrast as well as colour liaison are involved.

We have seen in this second part that the colour designer has to make a series of fundamental design decisions:

1. He has to find colours and colour combinations according to human needs, consonant with desired human behaviour or compensating for inconvenient factors in the environment. (Psychological aspect).

2. He has to find colour combinations for buildings which create a sensible visual relation to the colour complex of the surroundings. (Contextual aspect).

3. He has to find meaningful colours for the various parts of the building structure and to choose proper kinds and sizes of contrasts for a sensible interpretation of the building structure in order to create a convincing architectural Gestalt. (Structural aspect).

All these difficult questions are not answered for him by any colour order system. A colour order system can only fulfil an instrumental function. But towards the end of the design process, when all these decisions are made and when the contrasting colours have to be bound and fitted to a well-assorted colour chord, a colour order sytem offering a suitable number of colour samples is of great help to the designer.

We have also seen that the problem of interrelations of colours (syntactic aspect) does not stand at the beginning of the design process, because the exterior relations of colour in environmental design must be clarified before the interrelations of the used colours can be precisely determined. The most harmonious colour combination will lose its harmony, if it does not correspond with the specific human needs and activities, if it does not fit with the given surroundings or if it does not sensibly interpret the building structure.

Therefore, in the discipline of environmental design, the problem of colour harmony cannot exclusively be solved on the level of isolated colour combinations, but must be considered from a higher viewpoint to survey the wide field of problems occurring in environmental colour design.

Colour order systems in the process of environmental colour planning

If one examines how colour planning is usually practised in environmental design, one detects that colour is often treated as a supplement which can be added at the very end of the process. It is obvious that, used in this way, colour can hardly become a well-integrated element of the architectural structure and that this procedure handicaps a well-coordinated optimal design solution.

It is for this reason that the lecturer proposes to his students as well as to post-graduate architects attending his colour courses, a method of conceptual colour planning which he practises himself in his function as a colour consultant for architects. The essential point of this method lies in the elaboration of an overall concept of the use of colour and material in a properly early stage of planning./14/

In the third part, I shall briefly characterize the various planning stages and show how colour order systems can be useful instruments in this process (pragmatic aspect). The discussed stages are the following:

1. Problem analysis
2. General consequences
3. Colour and material conception
4. Real material and colour choice
5. Supervision of building works
6. Suitability control

Problem analysis

(at the fundamental stage)

This is a study of the activities which will take place in the planned environment of the human needs, including emotional ones, and of all sorts of circumstances and given conditions.

As far as colour order systems are concerned, I shall choose a single problem: How does the design become aware of the surrounding colour complex at this early planning stage? I have already mentioned two attempts at describing complex colour combinations. Until now, the designer has been doing it by a sort of intuitive and more or less conscious input of the given colour conditions.

General consequences

(at the preliminary project stage)

The designer asks himself what general design measures can answer to human needs, can favour desirable behaviour or compensate for inconvenient factors in the given conditions. The consequences which he draws from the problem analysis concern the whole spectrum of design means, one of which is colour. These results are integrated in the preliminary project.

Colours are not yet specified as points in a colour order space but rather as bubbles. So, colour specification on this planning stage is only on level 2 or 3 of the so-called Universal Color Language by Kell and Judd, reported in the paper of Alexan- III:1
der Styne./13,15/. III:2

Colour and material conception

(at the building project stage)

The designer visualizes his fundamental conception for the use of colour and material for his client and argues for his design decisions based on his problem analysis:

- A deduction of the main colours III:3
  from the human needs and the given circumstances demonstrates how the used colours are related to the task.

- More or less schematic representations III:5
  give a survey of the use of colour and material in the main III:6
  areas with different functions and make clear colour differen- III:7
  tiation and continuity throughout the environment. III:8

- A juxtaposition of the main colours III:4
  demonstrates the colour chord and enables the client to perceive the interrelations of the colours being used.

Colour denotations on this planning stage is on level 4, III:13
which means colour standards of any suitable colour order system III:14
can be used. The availability of standardized colour papers is a great help for the designer as special colour mixing for the demonstration plates can be avoided.

Real material and colour choice

(at the detail planning stage)

The real material and colour choice including floor coverings, wall tiles, upholstering materials, curtains etc., takes place while the architectural and technical detail planning is still going on. Many of the significant colour impressions emerge from the collection of various building materials. This shows that proper environmental colour design is not usually achieved by combining a few paint colours after the building structure has been realised. Colour choice starts earlier with III:9
those elements developing from restricted building material col- III:10

lections, and paint colours are precisely coordinated with those III:11
elements later, so that a well-assorted colour chord can be III:12
realised.

At this planning stage, essential colour elements of the surroundings as well as of the used building materials are analysed on level 5 (visual interpolation). As far as single colours must be determined, visual interpolation can be easily done with the help of the Munsell Book of Color which has the parameters, value and chroma. As soon as aesthetic interrelations in a colour chord are involved, the parameters blackness and whiteness with chromaticness, as found in the NCS, seem to me more appropriate.

For refined colour chords, it is inevitable that interpo- III:15
lated colour samples are used. Fortunately, a proper colour order system permits the designation of such interpolated colours. But in the practice of environmental colour design, it is not enough to designate a precise colour. The designer must deliver real colour samples of a suitable size, sometimes determining even a specific illumination under which sample and reproduction must look the same. Therefore, at this planning stage, there is an urgent need for colour paperes representing interpolated colours, available at special order.

The result of this planning stage is a collection of materi- III:16
al and colour samples, a list giving a survey of their application and architectural plans completed by corresponding colour and material indications.

Supervision of building works

(at the realization stage)

Materials and colour sample collection, application list and colour plans are suitable tools for the supervisor of building works.

At this stage of the process, communication with executive members is usually done on the basis of real colour samples. In case of deviation from the sample, the acceptability normally depends on the question of whether the whole colour chord is still intact or impaired.

Methods and colour order systems used by the executive industry for colour reproductions, for determination of tolerance and for quality control, are well known to you.

Suitability control

(during the usage phase)

Further development of proper scientific methods for suita- III:17
bility control of environmental design solutions would be of III:18
great value for this discipline.

Science and environmental colour design

Let me finish my essay by adding a few remarks on the relation between science and environmental colour design:

Although a lot of work has been done /16/, especially in the III:19
field of colour order systems, the vast and complex problem III:20
concerning the effects of colour in the environment on human organism, feelings, mind and behaviour still awaits more scientific investigation.

The environmental designer welcomes every scientific study in this realm offering real help to his work. On the other hand, he needs to keep his eyes open for visual and behavioural phenomena occurring in everyday life as well as in specific environment, because he is still left with many problems, the answers to which depend upon his own resources: upon his sensibility and common sense. And last but not least, he requires a considerable degree of courage in decision-making in a problematic world, for he cannot wait until science in a distant future might have removed every uncertainty in the colour-man-environment relationship. He is forced to propose a design solution for impending tasks today.

GLIMPSES FROM
DISCUSSION

Following Professor Spillman's lecture, a very interesting discussion took place about the need for colour order systems in environmental design. in colour communication and in studies on colour combinations. Demands from architects and designers on a useful colour order system was discussed, and finally it was claimed that a colour order system could be a very useful tool to bridge the gap between artists and designers on the one hand and scientists and technologists on the other.

Unfortunately, the tape recorder did not work properly during the main part of this discussion, so we can only report here on the last contributions of the session.

Fred Billmeyer:
Many studies, including my own, have shown that within the range described as normal colour vision, there are as big differences as corresponding to the difference between daylight and incandescent light. So the designer who creates a pleasing arrangement of colours may find that these are not pleasing to someone who is at the opposite end of the spectrum of normal colour vision. Is any thought ever given to this aspect of the problem?

Alexander Styne:
In my long practice I have a few cases of colour vision deficient clients and with some luck one becomes aware of this very early in the proceedings by hesitancy in expressing anything about colour or in some cases if you are really lucky they come straight out and say: I am colour blind!

In normal colour vision I have never found the differences so great that I had any problems with them, but as soon as you work with a group of people, an executive for a building committee - it happens very frequently in church work, from which I have learned to stay away whenever I can - they can have differences of opinion that may result into violent arguments and the designer is made a scapegoat.

Paul Green Armytage:
I would like to try a little idea here if I may, it is just sort of forming up, and the psychologists here too may have something to say. It seems to me from my amateur studies that there are two apparently contradictory things going on so that when you look at our surroundings and try to make sense of them, there seem to be two things:

First of all I think we have a need for stimulation, for variety. But at the same time I think we are looking for order trying to make sense of things. And if we are confronted with something for which there are two or more alternative interpretations we will generally chose the simplest interpretation.

So I think what that can imply is that we have a desire for order and a need for stimulation. You could say it is a kind of a 'theme and variations' that the theme provides unity and the variations provide contrast.

Jack Evrin:
Is it not so that a strict order also can be stimulating. A repetition, for instance, does not necessarily need to be boring. A rhythmic repetition can, on the contrary, be quite stimulating.

Paul Green Armytage:
If there is order without variety then it can be boring. If there is too much variety without order then it can be chaotic and disturbing, so you have got to steer a path between monotony on the one hand and chaos on the other.

Ralph Stanziola:
I sometimes get the impression that meetings like this gather people with very different experiences of colour - from technical scientists to designers and artists. I think that colour order systems might be in fact a bridge between them. Grete Smedal just mentioned the problems in trying to describe colours in works and therefore colour order systems obviously provide a very important tool for colour communication.

Osvaldo da Pos said earlier in the week that in the Italian language, lightness and brightness are expressed by one and the same word. Therefore a colour order system can provide him with the need of communicating with someone in another language.

On the other hand if an artist spent six months of his life painting a beautiful picture and then ran out of paint and wanted to buy some new tubes of paint to continue his work, and if the colour of those new tubes were not controlled too well, he would be very upset, and it will be handed on to the technologists to take care of those problems.

The same thing with an architect who creates an effect which will be very pleasing. If the paint company cannot deliver the right colour for this effect, the architect would be quite upset. So perhaps a colour order system will provide a bridge here that would be very useful.

COLOUR ORDER SYSTEMS
AND ENVIRONMENTAL COLOUR DESIGN
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Session h

MODERATOR'S REPORT

Alan Whitfield

The session commenced with an extremely lucid coverage by Professor Werner Spillman of the history of colour order systems and their potential role in environmental design.

Following this introductory lecture the session focused upon questions pertaining to the utility of colour order systems. It may be claimed that a consensus of opinion was expressed on two points:

1. A need exists for colour order systems as an aid to environmental design.

2. Colour order systems should be 'useful'. It may be noted that concern was not so much with the use of systems to specify or identify colours, but rather with their use in determining "structural" (Whitfield & Wiltshire 1980) and aesthetic relations amongst colours. It was not clear, however, from either the discussion or conference papers exactly which "structural" aspects were of interest. It may be suggested that clarification of the functions to be peformed by such instruments would be extremely useful, and greatly facilitate selections amongst competing systems.

As an overview it may be claimed that the design applications field is characterized by a wealth of opinions but a dearth of evidence. Effectively, there is little evidence available to indicate actual consumer requirements of colour order systems. It is suggested that questions regarding the utility of a particular system to designers can best be answered by investigating designers' requirements.

This criticism is not only applicable to the design applications field. Earlier sessions were bedevilled by questions concerning the meaningfullness of dimensions of colour appearance; for example, should systems employ blackness, lightness, greyness, colourfullness, etc. It is suggested that there are questions which are ammenable to empirical investigation by reference to people's natural classifications of colour. It is further suggested that both sets of questions fall naturally within the sphere of experimental psychology; a discipline somewhat neglected at the conference.

Given that those present at the conference were not necessarily representative of the population of potential colour order systems, answers are required to a number of questions.

1. Do architects and designers need colour order systems? After all, it can be argued that they have managed very well for centuries without them. Perhaps they used their own natural colour systems.

2. What do they need colour order systems for (or what could they use them for)? Information here would be invaluable in its contribution to questions regarding the structure and dimensionality of systems.

3. Will the use of colour order systems lead to better design? Unfortunatley this raises the further question of what is 'better' design and to whom. It may be noted that the domain of aesthetics is even more intractable than colour order systems, and contains diverse theoretic orientations. From the standpoint of aesthetics, the preoccupation with colour order systems and their applications in achieving order, balance and harmony, can be interpreted as representative of a 'classical' orientation. Other orientations, however, do exist (see Whitfield & Slatter, 1978).

4. How do we get answers to the above questions?

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AESTHETIC ATTITUDES TOWARDS SCIENCE

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SPECIAL LECTURE

Lennart Holm

Director General
Swedish National Board of Physical
Planning and Building (Statens planverk)

Mr Chairman, Ladies and Gentlemen

The results of the research that you are working with will, to a high degree, be used in building and environment planning. The purpose then is to reach aesthetic effects, to raise the comfort for inhabitants and users. That is why a large part of Swedish colour research is financed by the Council for building research. From the viewpoint of this Council, in which I have been in charge for more than 25 years, I will give you some reflections on how scientific results are met and treated in the design process - it may then be results of social, psychological, physiological, economic, natural or technical science.

You are, of course, aware of the fact that many people make a distinction between the "two cultures" - the polarisation of the scientific and humanistic world views, referred to by C.P.-Snow. And we cannot help but notice Society´s great respect for Monsier Courbet who naturally lets us, the bourgois, raise our hats and bow to the creative genius, to the aesthetic approach to life.

This gap has not always been apparent. Particularly in the scientific tradition of the Western world there has been - and probably still is - a basic conception that the beauty of the divine is always the beauty of simplicity. This divine simplicity is disturbed by the inquisitive search for knowledge: Adam and Eve had to leave Paradise. But when the search for knowledge finally achieves its goal - when, for example, Newton understands why the apple falls - then one finds that truth has divine beauty- This is what is meant when it is stated that the laws of nature can always finally be formulated in simple and beautiful formulae like, for example, the Law of Gravity. If accurate empirical observations cannot be systematized into a simple mathematical function, then you can bet your life that you are not on the trail of a natural law. This divine discipline has overshadowed many empirical data so that it agreed with the divine simplicity, symmetry and beauty they wished to behold. In this way, thousands of years of astronomical observations could be distored - or censored - by the Christian scientific tradition, in order to fit into the ever-changing, false but always divinely beautiful and simplistic models of the universe. If Kepler´s Law had not been imbued with even greater simplicity (and thereby beauty), he would surely have had to wait even longer in his grave before he was believed.

It may be worth noting that several of our new "natural laws" could be formulated just because their empirical measurements did not fit the beautiful, classical laws of nature. When they could no longer be disregarded as measurement errors, we were forced to look deeper into the workings of materia. The concepts of quantum and relativity were introduced, as well as the stochastic approach which has enabled us to interpret the empirical studies of the boundary state of materia.

However, I do not want to deal with the aesthetics of science because I know too little about it - although I do have my suspicions about the pressure it exerts on the objectivity of the researcher. Nor will I go deeper into aesthetics as a science, but just touch upon it.

Many building research bodies include in their programmes the study of Man's perception of the built environment, in physiological and ergonomic terms as well as in terms of the five senses, as perception, interspersed with values that we refer to as hedonistic or aesthetic.

The example from our world of colour can serve as an illustration. The classical theory of colour, founded on a physical basis, presupposed three primary colours - red, yellow and blue - which through varying admixture could produce all colours - as in a colour photograph. The world of colour was often described as a triangle.

By applying the rule of the "simplicity and beauty of truth" it was also taken for granted that a complementary colour would be found directly opposite in the triangle - opposite red would be green, halfway between yellow and blue. This classical conception of the structure of colours has found many different expressions - a manifest example of this is the puristic streak in art that never accepted green as a a pure colour; which is why Piet Mondrian's paintings. depicting cross-sections of the universe, never contain the colour green.

But for those of us who are a bit more down to earth, green does exist and it can, in both practical and experimental terms be differentiated as a "distinct" colour, that is lacking any tinge of blue or yellow. And it has a complementary colour (its retention) that is by no means a clear red. Thus the laws of physics and perception are incongruent. To the senses, the world of colour is a circular continuum with four distinct poles. The stages between what appear visually to be "equally large" variations on colour, are of varying dimensions when measured in the physical term of wavelength. The eye and the sense of sight thus operate as erratically as the ear and the sense of hearing, for which pitch and volume co-vary in a way that from physical viewpoint is disconcertingly irregular and ungainly (- you surely know the shapes of the phon-curves).

Research into the aesthetics of the environment can, in its applied form, provide answers about people's reactions on a semantic scale of

"beautiful and ugly"
"safe and frightening"
"harmonious and chaotic"

and thereby substantiate simple interview and questionnaire findings and well-correlated physiological observations of eye movement, perspiration, muscular tension and palpitations. Nevertheless, the uncertainty we still experience when faced with the findings of such research, has to do with its prognostic value. If the design of a building is based on positive reactions to something existing (or experimentally arranged), can we still be sure that the result will create the same positive reactions? How long do these continue to remain positive? How quickly do they wear off? How much more positively would something else, either new or different be assessed? Would motives and images, that are far removed from what are functionally and technically determined in a building, contribute positive values to the environment? We are at a stage in the history of architectual design where attempts are being made to make us believe this - although the aesthetic and scientific foundation for such argument is fragile.

However, my task here is not to nag at either those concerned with the mysticism of number or the postmodernists. Instead, what I would like to discuss is how the serious design of buildings and development can make use of the findings of enviromental research, and what impacts these have on design.

The first requirement is a plausible theory about the design process, regarded more in terms of the "spiritual" process within the architect and engineer than in terms of negotiation and decision making between client and designer, Nobel prizewinner Herbert Simon, in his book entitled "The Sciences of the Artificial", speculated on the creative process and defined the designer´s problem as looking for, and discovering, a satisfying combination of a multitude of given elements:

"...he solves his problems by moving through a large combinatorial space in which he adds one element after another to his design - of course, sometimes revising or even deleting those that are already in it ...

... Notice that the problem space through which the designer searches is not a space of designs, but a space of design components and partially completed designs".

In contradition to Simon, Susanne Langer states that the creative process is not additive. "That which is created is something new" she states and "its elements, its whole and its internal relationships are something that did not exist previously". Then in that case it is not so completely new, replies Arthur Koestler, instead it is the result of a new selection of elements from various "matrices", that consist of rules, standards and models as well as new experiences and research findings. Creativity presupposes that the individual has an overview of the total of all possible selections.

It seems reasonable to describe normal design work as just such a process involving selection from different matrices. On the one hand, these obviously include explicit knowledge of the laws of nature, of legislation and regulations, of economic optimisation, etc., and, on the other hand of the "silent knowledge" that Wittgenstein calls the "professionalism" that we have internalized through learning and training, but about which we are largely inarticulate (rather like our knowledge about how to swim or ride a bicycle). Seen in this light, the design process is not a simple game of combinations, an unequivocal solution of problems that starts afresh for each new task. Instead it comprises a multitude of "concealed" preconditions in the designer´s mind - his private conceptions, his sense of form, his adherence to formal stylistic ideals and aesthetic doctrines. Sometimes I think one could go as far as to state that it is not the architect who has solved a design problem but rather that the problem has found the right architect, one who has the "spiritual preparedness", the self-evident design solution for that very problem.

This internalized knowledge ("silent knowledge"), the hidden preconditions within an individual, are not always positive, they also act as a filter for new knowledge and perceptions of reality. Here is an example.

At the California Institute of Technology, experiments were made on people´s ability to see and draw (in order to study, among other things, how the two halves of the brain react and can be trained). In the experiments, quite ordinary people, men and women, were put into two groups and asked to demonstrate how they would draw a person. This is how one member of the group drew a human being. Then he was asked to copy Picasso´s well-known portrait of Stravinsky. This was the result, a stereotyped image, symbolizing a human being and characterised by the same structure as the first one.

In the other group, people drew human beings in the same way, for example like this. But for this group. Picasso´s portrait was turned upside down. What people then copied was a pattern of lines, not a form that released individual preconceptions. What was demanded now was observation, to be able to see without having any previous knowledge. This was the result. If we then turn the copy the right way up, we see that we have an interesting, richly detailed and faithful copy, not a symbol.

One should be careful of drawing analogies, but I think that the observations at CIT say something about how difficult it is to penetrate, influence and resolve established conceptions and designs. In fact there are some, for example, Jung and Spengler, who would go as far as to state that design consists of constitutional, archetypal hereditary factors. And reputable experiments today would seem to support this argument. In his book "The Child in the City", Colin Ward describes a psychoanalytical study of 450 models of towns made by 150 prepubescent children. It was found that boys concentrated on streets, towers and frontages where girls started off with interiors and people. Again, in a Swedish study of architectural preferences, Ann Westerman demonstrated that there might be distinct differences in the values of men and women.

Of course, these design constraints or internalized knowledge ("silent knowledge") should not solely be diagnosed as creative inhibitions. On the contrary, it is these or related phenomena that are regarded as the real essence of creativity.

In the cultural debate, design is often referred to as the "artistic whole" and thereby inviolate, as the artist´s spiritual gift to Man. The aesthetic and technical demands for uncompromising consistency between "the whole" and its "parts" then leads to the primary artistic conception determining the rules that form and construction are to follow - and where the architect becomes, at least partially, a medium for a higher logic.

In a rigid model of this type, space for a new knowledge is limited - and if there is room for it, it is because it just happened to fit in and not because of its inherent authority.

It is indeed remarkable that this subjective and authoritarian method of working, for which the creative individual has determined how much space should be devoted to the influence of opinion and knowledge, is referred to as humanistic. As counter forces to this humanism, one finds not only demands for participation but also, and more importantly, attempts to systematize people´s habits, values and requirements as design standards. "Kitchen Taylorism" is the somewhat contemptuous name given to the enormous efforts to re-introduce everyday experience into design work as a result of housing research in many countries.

I must admit that this extremely artistic attitude to knowledge and to the world around us has been pushed into the background during the post-war democratisation of planning and building. But the threat is always there. Postmodernism readily appears under the banners of humanism - and its penchant for Palladian Classic is a consistent signal of its authoritarian ambitions.

Of course, not everyone is a post-modernist genius. In most design offices people are keenly attentive to public opinion and to the findings of social and technical research. Nevertheless, one still meets, even from the most ambitious, a conditional aesthetic attitude. People make statements such as

"I get inspiration from some research reports - particularly those that contain theoretical arguments".

I have always thought that that was the case - which is why I think the report was good and why I shall make use of it" and

"The report has provided me with arguments for a non-conventional design"

From the research side we should, of course, express our gratitude for such positive attitudes. Yes we would appreciate even more unconditional points of view. If we accept Koestler´s concept of "matrices of rules, models, experience and research findings which make up the designer´s "box of bricks", our efforts should involve trying to fill that box with clear and reliable information as well as ridding it of delusions and formalistic con::raints. And we should warn the designer from turning up with ready-made concepts which act as a filter for what he wishes to accept.

Perhaps computer aided design will provide us with greater freedom to use research findings? Will the logical construction of such design systems involve the rejection of design solutions that are in conflict with programmed demands and routines? Will improvements in the formulation of research findings in programming terms mean that we can place greater reliance on their uncomprising use?

Well yes, if knowledge is of such an absolute and uncomprising nature. But it seldom is! And our intention is not to make knowledge a filter for creativity any more than we would accept creativity as a filter for knowledge. On the contrary, we would like knowledge - and new information - to release creativity, to open up new opportunities for artistic expression and forms that are pregnant with meaning.

But research findings do not always involve new opportunities. Instead they often require reflection, consideration and restraint. The energy crisis of the 1970s - the suspicion that within the near future we will have depleted the world's energy resources - gave us a useful push in the right direction- Research institutes around the world have taught us to respect the laws for the handling of energy in a building, and this knowledge has stressed many aesthetic forces. Many have used this new knowledge as a pretext for the violent overdramatization of exterior form, others have more quietly revised their aesthetic ideals and probably created buildings with considerably better climatic properties than before. Contacts between reseachers around the world have, perhaps most importantly, drawn attention to the variation of external parameters. Here in Sweden, for example, we are close neighbours with the North Pole - a fact which only the artist believes he can change.

Technical research findings which pose new problems or provide new opportunities are naturally welcome. Although often misinterpreted, they sometimes release creative forces and provide us with new perceptual values of greater authenticity than the pasted-on variety. However, the findings of the social scientists pose greater difficulties. Studies of ordinary people's reactions, habits and values seldom result in any revolutionary upheavals. On the contrary, they often take the form of the quintessence of good technical solutions, good organisation, etc. And they often point out defects and practical difficulties which have perhaps occurred as a result of dramatic design. It takes a lot of will-power on the part of the architect to act on the basis of such experience, which nearly always demonstrates that psychologically social problems cannot be solved by investments, by physical design. They demand an interaction between people and equipment thereby reducing the significance of articats. And that is a tough blow to aesthetic humanism!

For those of us working in environmental research, it can be disheartening to see the arbitrary way in which our colleagues, among architects and design engineers, utilize the information we provide. We would willingly work together with them if better rules were available for the query of aesthetic attitudes (in the widest sense) and were included in the exchange of old and new. But we would like to do this with the inherent authority of objective argument - not with the aid of regulations and the pressure of external forces.

One way of approaching these rules would be to carry out research on the transmission of knowledge. How can we describe the creative process from the first sketches of the architect to the completed work in everyday use? How can we best describe the "matrice" from which the designer selects his means, that peculiar collection of cultural archtetypes, personal design ambitions and respect for empirical data which can become, in the best cases, a complete orchestra, and at worst a scrap-heap. I believe that we could learn a great deal about how we define problems and how we present their solutions, by carefully following the work process of the building designer. We could study how the creative idea is confronted with practical demands and technical and economic opportunies, how the give and take between idea and reality occurs, how ideals fall and are replaced by new ones, and also how robust ideas can create new solutions - or require new research efforts.

Those of us who have believed in the rationality and objectivity as architectural ideas, and have attempted to contribute to the fund of knowledge on the art of building, have generally been able to see the practical results of our efforts. At the same time we cannot avoid noticing the changes in attitude that are now taking place. The "image" of a building has once again become the main feature, and its functional and technical aspects have to comply with the building's function as a set-piece in the streetscape. The amount of space for the testing of knowledge will thereby be reduced - and it will not be those designers who are thirsting for knowledge who will receive this type of scenographic brief!

We should therefore be needful of aesthetic attitudes to research - they change like fashions in clothes. But while such changes have generally involved a trend towards greater freedom - from Victorian severity to Swinging London - they are unreliable. Over and again they involve nostalgic digressions into the past instead of the discarding of the last vestigates of constraint. Constraint is the sign of the apprehension which always confronts the ignorant. Knowledge gives space and freedom for imagination and creative power.

FAREWELL ADDRESS
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Closing Session

Åke S:son Stenius

Mesdames et Messieurs
Meine sehr geehrte Damen und Herren
Ladies and Gentlemen

As an outsider in the field of colour order systems, I have not been able to prevent my thoughts from strolling along unorthodox paths during the last few days. Bridges rather than colours have been their theme; bridges in time and bridges in thought.

There has been a Scandinavian bridge in time with one pier established more than three centuries ago by the Helsinforsian, Sigfrid Forsius, who stated already at that early stage that three dimensions were needed for the proper ordering of colours in a meaningful system.. Another pier was established barely three decades ago by another Helsingforsian, Gunnar Svaetichin, who, by his discovery of the S-potentials, provided physiological confirmation that the figure four of the opponent colour theory was a reality and thus superior for the ordering of perceptive colours.

However, for colour ordering, coarse structures based on figures like 3 or 4 are not sufficient. For the fine structure we need concepts, notations and terms, each characterized by unequivocal definitions. I have noticed that colorimetrists have their physical terminology based on ambiguous concepts, just the science that gives us the final answer to the question of what a colour really looks like, governed by laws of perception, still wrestles with difficulties partly due to ambiguous terminology.

I have therefore welcomed a meeting like this which we have enjoyed here during the last days, where both psychologists and physicists have met around their common interest: colour. Difficulties in mutual understanding have forced us to construct bridges that I should like to characterize as non-mathematical psycho-physical relations for unifying our diversified concepts.

However, we have not only dealt with differences in concepts. The semantic questions that have been considered during the last days have also made it clear that we are in need of linguistic bridges for an improved international understanding of colour.

I consider all these bridges as rays from a convex lens that converge towards a common goal: colour order systems that due to their common use, are considered suitable for inclusion in a synthesis by International Standardization. This would be a great step forward towards a universal colour language. In my opinion, our conference has been a great move in that direction. Simultaneously, I know that the lens has hardly any curvature. The focal point of the converging rays lies far away in the future; on the other hand our conference has been a first step to increase the curvature of this lens.

Today the symposium ended with a discussion on Color Order Systems and Environment Design. And now I am really skating on thin ice. I am not only an outsider, I am a layman and an amateur as well.

In the first days we discussed how colours should be ordered in the colour space so that neighbouring colours would be at such distances from one another that they suited the plan of some network. The opinions of how these networks should be constructed were varying, everyone had her or his opinion on that.

Today, all these concepts were turned upside down. It was not the question of relations between neighbouring colours; on the contrary, the main role today was played by colours very far away from one another in the present colour order systems. What were their interrelations? What were their interactions? Can we create colour spaces that can be turned over into colour order systems for designers, i.e., systems that have aesthetic relations between highly differing colours built into their network? This is certainly a challenge to the new AIC Study Group.

Ladies and Gentlemen

On behalf of all the organizations and institutions that have organized this meeting, I wish to extend my sincere thanks to all participants who, by their ideas and their contributions to the discussions, so clearly have shown their capacity in one branch of civil engineering: the construction of bridges, the bridges that we all are in such need of.

With these words of sincere thanks to you, all included though not named, I hereby declare the Forsius Symposium on Colour Order Systems and Environmental Design closed.

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Figure captions for colour picture prints representing the colour slides shown in Prof. Spillman's lecture
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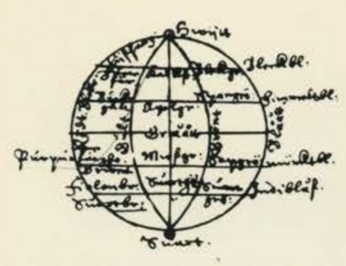
Colour print	Picture	Text to illustration
PAGE I	No I:1	Colour order scheme by Aron Forsius (1610).
	I:2	Double cone of NCS, Natural Colour System by Anders Hård.
	I:3	The Natural System of Colours and their harmonious connections, by Moses Harris.
	I:4	Colour Circle by Moses Harris.
	I:5	Colour Circle by Isaac Newton.
	I:6	Colour Circle by Johann Wolfgang Goethe.
	I:7	Munsell Colour Tree.
	I:8	Ostwald's double cone, illustrated by Harald Kuppers.
	I:9	Colour Harmony Manual according to Wilhelm Ostwald's Color Order System.
	I:10	Ring-star by Ostwald.
	I:11	Schemes of whiteness/blackness-equalities according to Ostwald.
	I:12	Whiteness/blackness-equalities, Ostwald.
	I:13	Colour triangle, Swiss Colour atlas by Aemilius Muller.
	I:14	Colour combination (constant hue) by Aemilius Muller.
	I:15	Colour combination (hue deviation) by Aemilius Muller.
	I:16	Colour Circle, Swiss Colour Atlas by Aemilius Muller.
	I:17	Colour combinations: constant hue (middle), symmetric hue deviation (left and right).
	I:18	Colour combinations: constant hue (middle), symmetric hue deviation (left and right).
	I:19	Colour sequence by Werner Spillman.
	I:20	Colour sequence by Werner Spillman.

Colour print	Picture	Text to illustration
PAGE II	No II:1	Red house with white frames in Sweden.
	II:2	Sainte Chapelle in Paris.
	II:3	Red-orange stairs.
	II:4	Blue cupola.
	II:5	Hunter in vegetation-green landscape.
	II:6	Analysis of the degree of chromaticness of a green leaf.
	II:7	Reddish shine of the setting sun.
	II:8	Flowers in a garden.
	II:9	Wangen Castle (Switzerland).
	II:10	School building (France).
	II:11	Muralla Roja (Spain).
	II:12	Aerial view of Florence (Italy).
	II:13	Blue building (England).
	II:14	Town (Marocco).
	II:15	Farmer's village (Switzerland).
	II:16	Villa Carlotta (Italy).
	II:17	Santorini (Greece).
	II:18	Supermarket (Switzerland).
	II:19	Home for aged people (Switzerland).
	II:20	School building (Switzerland).

Colour print	Picture	Text to illustration
PAGE III	III:1	Six levels of the universal colour language by Kelly.
	III:2	ISCC-NBS color-name block structure by Kelly and Judd.
	III:3-12	Colour conception and some real material and colour combinations for a home of aged people in Senzach/Winterthur (CH) by W. Spillman, Arch:V.Isler.
	III:13	NCS colour papers.
	III:14	Colour juxtaposition realized with NCS colour papers.
	III:15	Colour correction for a floor covering material with a difference less than 10 NCS units.
	III:16	Part of a material and colour sample collection for a school building.
	III:17	Railway station near Zurich Airport by S. Mengolli and W. Spillman.
	III:18	Investment office in Princeton by Michael Graves.
	III:19	Home for aged people in Frauenfeld by P. Widmer and W. Spillman.
	III:20	Home for aged people in Senzach/Winterthur by V. Isler and W. Spillman.

COLOUR ORDER SYSTEMS AND ENVIRONMENTAL COLOUR DESIGN
: Werner Spillman



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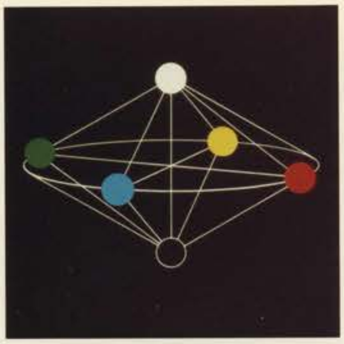

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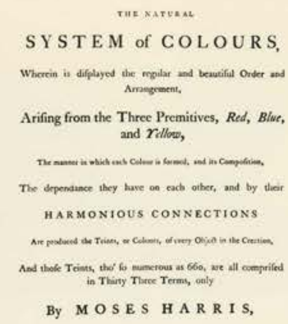

THE NATURAL

SYSTEM of COLOURS,

Wherein is difplayed the regular and beautiful Order and Arrangement,

Arifing from the Three Premitives, *Red*, *Blue*, and *Yellow*,

The manner in which each Colour is formed, and its Compofition,

The dependance they have on each other, and by their

HARMONIOUS CONNECTIONS

Are produced the Teints, or Colours, of every Object in the Creation,

And thofe Teints, tho' fo numerous as 660, are all comprifed in Thirty Three Terms, only

By MOSES HARRIS,

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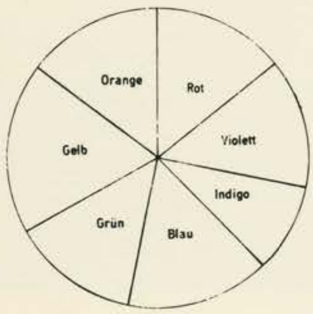

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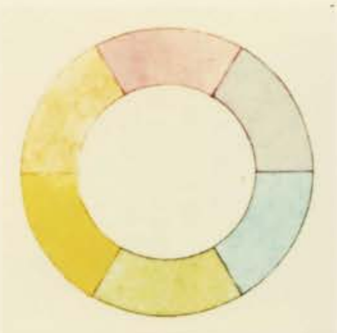

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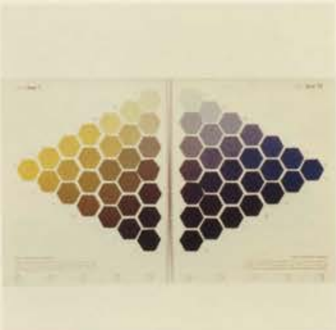

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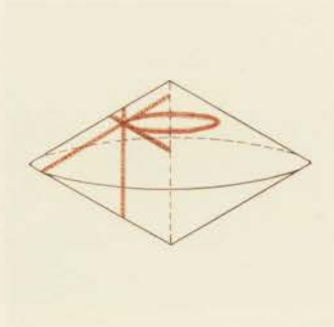

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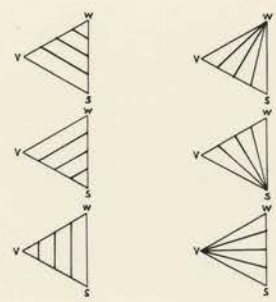

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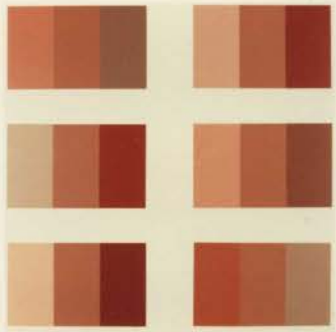

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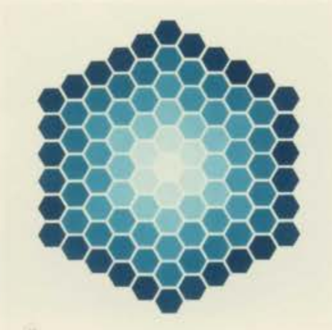

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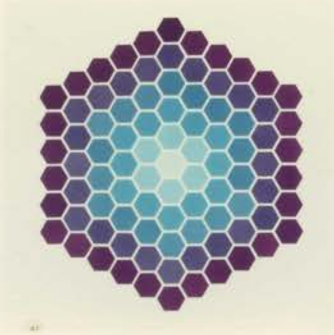

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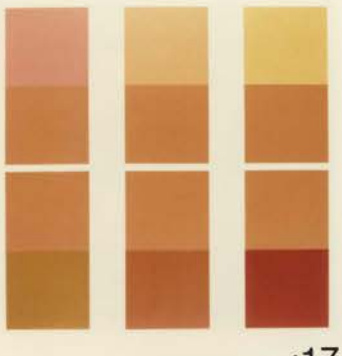

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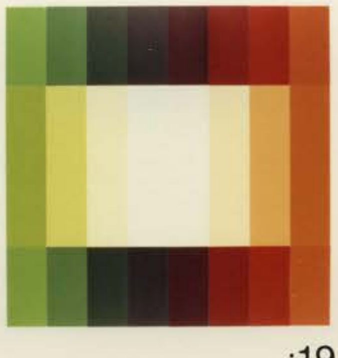

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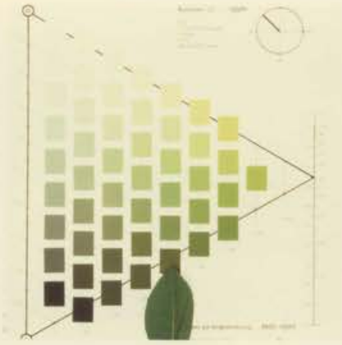

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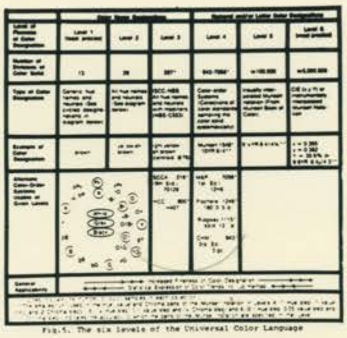

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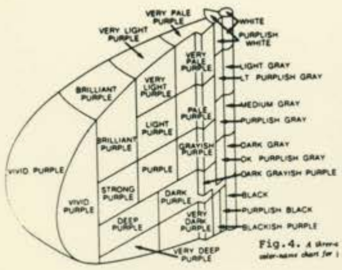

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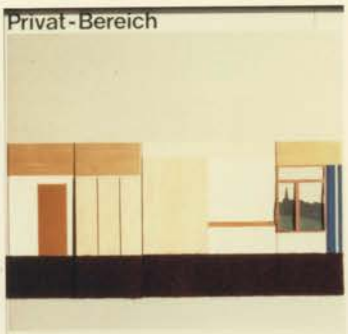

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