AIC Capstone

Colour: The Intersection of Art and Science

John J. McCann
http://mccannimaging.com
LED Lighting
Museum Lighting
Color and Food
Color and Wellbeing
Color and Ergonomics
Colour in Art
Colour Aesthetics
Fashion
Architectural Colour
Colour Technology
Sustainable Coloration
Colour Imaging
MCS2013
Product Design and Branding
The Colour of Culture
Colour Difference
Colorimetry
Interdisciplinary Colour
Environmental Colour
Colour Printing
Colour Vision
From the Retina to the Cortex
Interior Design and Lighting
Colour Harmony
Colour and Music
AIC word cloud of Sessions

aesthetics architectural art branding coloration colour colourimetry cortex culture design difference environmental ergonomics fashion food harmony imaging interdisciplinary interior led lighting mcs2013 museum music printing product retina sustainable technology vision wellbeing
AIC word cloud of paper titles

aesthetic analysis application architecture art assessing brand change chromatic content cultural design development difference digital dyes effect emotion environment evaluation fabric fashion green harmony human illumination image impact influence interior led life light material measurement methods model naming natural object painting perception preference printing quality reflectance rendering skin sources space spectral surface symposium textile texture theory urban visual white
Trichromacy at a Pixel responds to Cone Quanta Catch

X, Y, Z

X', Y', Z'
The homogenial Light and Rays which appear red, or rather make Objects appear so, I call Rubrific or Red-making;..
Photography & Color

Three receptors describe color at a pixel

Thomas Wedgwood & Sir Humphrey Davy
Royal Institution, London

Scholium: Since, for the reason here assigned by NEWTON, it is probable that the motion of the retina is rather of a vibratory than of an undulatory nature, the frequency of the vibrations must be dependent on the constitution of this substance. Now, as it is almost impossible to conceive each sensitive point of the retina to contain an infinite number of particles, each capable of vibrating in perfect unison with every possible undulation, it then becomes necessary to suppose the number limited, for instance, to the three principal colours, red, yellow, and blue, of which the undulations are related in magnitude nearly as the numbers 8, 7, and 6; and that each of the particles is capable of being put in motion less or more forcibly, by undulations differing less or more from a perfect unison; for instance, the undulations of green light being nearly in the ratio of 6 1/2, will affect equally the particles in unison with yellow and blue, and produce the same effect as a light composed of those two species: and each sensitive filament of the nerve may consist of three portions, one for each principal colour.
ROYAL INSTITUTION OF GREAT BRITAIN.
May 1, 1802.

PATRON.
The King.

PRESIDENT.
The Earl of Winchelsea and Nottingham, F. A. S.

MANAGERS.
For One Year. (Elected 1800.)
The Earl of Morton, K. T. V. P. R. S. The Earl of Aylesford, F. R. S. Henry Cavendish, Esq. F. R. S.

For Two Years. (Elected 1801.)

For Three Years. (Elected 1802.)

VISITORS.
For One Year. (Elected 1800.)

For Two Years. (Elected 1801.)

For Three Years. (Elected 1802.)

J. P. Auriol, Esq. Secretary.
Charles Butler, Esq. Counsel.
Claudius Stephen Hunter, Esq. Solicitor.

Thomas Young, M. D. F. R. S. Professor of Natural Philosophy, and Superintendent of the House, and Humphry Davy, Professor of Chemistry, and Director of the Chemical Laboratory, joint Editors of the Journals.
Frederick Accum, Assistant Chemical Operator.
William Savage, Clerk, and Printer.
Kenneth Mc'Culloch, Mathematical Instrument Maker.
Charles Royce, Superintendent of the Workshops.
Thomas Young, M. D. F. R. S. Professor of Natural Philosophy, 
and Superintendent of the House, and 
Humphry Davy, Professor of Chemistry, and Director of the 
Chemical Laboratory, joint Editors of the Journals. 
Frederick Accum, Assistant Chemical Operator. 
William Savage, Clerk, and Printer. 
Charles Royce, Superintendent of the Workshops.
Wedgwood, Davy, Young on Photography

- Wedgwood worked on AgX photography in 1790s
- Wedgwood and Young were from Quaker families.
- Wedgwood and Young traveled in Italy & Harz Mts. 1795

- Davy RI paper on Wedgwood’s work, 1802
  “Nothing but the method of preventing the unshaded parts of the delineation from being coloured by exposure to the day, is wanting to render the process as useful as it is elegant.” J. Roy. Inst, 1, 1802.

- Young & Davy co-editors of RI Journal

Reproduction

- LeBlon ‘Colorito’ 1702
- Wedgwood & Davy 1802
- Schultze silver salts 1732
- Daguerre/Fox Talbot 1837
- Maxwell 1861
- Joly Lumiere Dufay 1900
- Echtachrome Mees, Mannes & Godovski 1937
- T. Young 1802
- Hypo [Vogol]
Maxwell’s Contributions

- Maxwell 1860s
- Electromagnetic fields
- Color matching experiments
- Human spectral sensitivity function
- Color photography
- Maxwell’s Ribbon
Pixel Colour

- Pixel theories and algorithms
  - Colorimetry -
  - Color film photography
  - CIEXYZ, CIEL*a*b*, CIEL*u*v*
  - CIECAM -
  - sRGB and Gamma [ICC]
  - ICC Profiles -
  - Tone scale processing [HDR to LDR]
  - Displays Gamut Mapping
  - Printing
  - Multi-Spectral Color

All follow the AgX model
Colour Theory = Colour Photography?

Pixel

Mike Pointer - EK
Bob Hunt - EK
Jim Bartelson - EK
Ed Breneman - EK
Jameson & Hurvich - EK
Ralph Evans - EK
Dave McAdam - EK
LA Jones - EK
CEK Mees - EK RI
Hurter & Driffield
Frederick Ives - halftone
JC Maxwell - RI
Sir H Davy - RI
T Wedgwood - RI
Thomas Young - RI?

Spatial

EH Land - Polaroid, RI
Ansel Adams - Zone
Spatial Comparisons

Color Contrast
Color Shadows
Color Reproduction
Color Afterimages
Color Constancy
Color Assimilation
Edge Ratios
Red&White Photography
Color Mondrians
Rod/Lone Color

DaVinci 1500
von Guericke 1670
LeBlon 1700
Goethe 1810
Hering 1872
Gelb 1930
Wallach 1939
Land 1959
Film: a pixels quanta catch = all information

Human Vision

Film

Light in the World

AgX Film

Unique

Pixel value = 128

Max

Min

White

Black

Variable

Vision: a pixels quanta catch = almost no information
In 1872 Hering wrote: “The approximate constancy of the colors of seen objects, in spite of large quantitative or qualitative changes of the general illumination of the visual field, is one of the most noteworthy and most important facts in the field of physiological optics. Without this approximate constancy, a piece of chalk on a cloudy day would manifest the same color as a piece of coal does on a sunny day, and in the course of a single day it would have to assume all possible colors that lie between black and white.” (Hering, 1872/1905)
Color = \( f(pixel) \)

Color = \( f(pixel, \text{all other pixels}) \)
Prometheus was bound by AgX (pixel) thinking

Prometheus Bound by Thomas Cole (1801−1848)
Chains = Pixel Algorithms

Color = \( f(pixel) \)

Color = \( f(pixel, all\_other\_pixels) \)

Accounts for Constancy & HDR
Reflectances

Long = 21
Middle = 62
Short = 8

Long = 85
Middle = 48
Short = 67
Illuminations

Long = 85
Middle = 48
Short = 67

Long = 21
Middle = 62
Short = 8
Mondrians

Long = 53
Middle = 55
Short = 38
Mondrians

Long = 53
Middle = 55
Short = 38

Color Constancy in complex images
Pixel Theory Spatial

Match pixel = \( f \) (Radiance)
Appearance \( \neq f \) (Radiance)

No Glare

No Neural Contrast

At match - a single spot of light

Appearance \( \neq \) Radiance

A particular X, Y, Z can be any color
Pixel-based Colorimetry

Spatial comparison Retinex

XYZ -> pixel -> color

L-channel -> color
M-channel -> color
S-channel -> color
1960’s
All post-receptor processes are spatial

- Munsell spacing
- Veiling glare & Neural contrast - cancel
- Practical painting, printing, and HDR photography
- Future spatial topics to watch
  - Adaptive optics
  - Melanopsin
  - Neurophysiology
    - Spatial target
    - Double opponency
    - Microelectrode arrays
    - Brain Mapping
Measure distances in appearance

Measures the end of the process
WRIGHT’S COLOR MATCHES

CIE 1931

X, Y, Z space
Work backwards:
- Start with Munsell chips
- Reflectance * Illumination = Radiance
- Radiance * CMF = X, Y, Z = Y, x, y [analogous to H, L, C]
- Plot retinal color space that appears equally spaced

Illustrates Vision’s color transformation
Both Munsell and Yxy plots are scaled so the white chip and black chip superimpose.

NOTE: $L$ axis plots CIE $Y$; $a$ plots $x$ chromaticity axis; $b$ plots $y$ chromaticity axis.

http://mccannimaging.com/Site_4/Ch_2-Color_Spaces.html
Two Spatial Processes

- LMS Retinal Cones
- Glare

Opponent Color

- Munsell Spacing

7 x Stretch

Stiehl, W. A. et al., JOSA (1983)
D’Andrade and Rooney, PNAS 100, 6281-86. (2003)
Two scene-dependent spatial mechanisms: glare and contrast. Glare masks the strength of spatial contrast.
• A. HDR Targets with varying glare - Vary Surround (88% area)

Scene Dynamic Ranges at Cornea

<table>
<thead>
<tr>
<th>Scene Dynamic Range</th>
<th>Log Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>200,000:1</td>
<td>5.3</td>
</tr>
<tr>
<td>250,000:1</td>
<td>5.4</td>
</tr>
<tr>
<td>630,000:1</td>
<td>5.8</td>
</tr>
</tbody>
</table>
• B. Calculate retinal luminances:

Scene content controls range on the retina.
Compare scene vs. retinal image

Effect of Veiling Glare

Retinal Optical Density

Scene Optical Density

- Retinal Contrast 0%W
- Retinal Contrast 100%W
- Retinal Contrast 50%W
Scene Dependent Contrast

Appearance = m \times \log(\text{retinal luminance})
Retinal Optical Density

Lightness (MagEst)

10,000:1

No amplification

Retinal Range = 4 log units

White

Black
30:1

Retinal Range = 1.5 log units

Strong amplification
Range of response varies with scene content

L* - Stevens Power Law - Weber’s Law - Single Psychometric functions
Scene Dependent Lower Contrast

Spatial Glare

Scene Dependent Higher Contrast variable amplification

Spatial Contrast
Lascaux Cave, Vézère River, France (14,000 BC)

- 140 centuries
Children Playing on a Winter Day, Sung dynasty scroll (960-1297)

Render in uniform illumination on uniform background

- 10 centuries

Pre-Chiaroscuro
“Lady with an Ermine”
Leonardo da Vinci,
c. 1483-1490

Render a high-dynamic range scene in a low-dynamic range reflectance image.
- 5.2 centuries
Newton’s birth - 3.7 centuries

Rembrandt, “Night Watch”, 1642
Practice vs. Theory

- LeBlon 1704
  - three primitives
  - mezzotint tool
  - trial and error

- Young 1802
  - limited to three principal colors
Presenting a Facsimile Edition of

COLORITTO

By J. C. LeBLON

1667 - 1741

Inventor and Developer of the
RED-YELLOW-BLUE Theory of
Color Printing (Ca 1720)

With an Introduction by
FABER BIRREN

Printed in a Limited Edition

VAN NOSTRAND REINHOLD COMPANY
New York, 1980
Louis XV
J. C. Le Blon
1739
hand made mezzotint color separations
1738

Cardenal de Fleury
J. C. Le Blon

hand made mezzotint color separations
Colorful Impressions

The Printmaking Revolution in Eighteenth-Century France

1700-1799

French color prints

National Gallery, Washington
1746

L’Ange anatomique
J. Dagoty

hand made
mezzotint
color separations
1769

*Tate de Flora*
Louis-Martin Bonner

after Francois Boucher

hand made mezzotint color separations
Plate 1 -(Blue green)  Plates 1 & 2 (white + carmine)  Plates 1 +2+3 (dark blue)  Plates 1-3 +4 (local R,Y,G)

Plates 1-4 + 5-(Contours )  Plates 1-5 +6 (carmine)  Plates 1-6 +7 (dark brown)  Plates 1-7 +8 (white)
1789

Queen
Marie-Antoinette
Pierre-Michel Alix

wash manner in blue, red, yellow and black inks
Fontenelle Meditant sur la pluralite des mondes
Antoine-Francois Sergent

wash manner in blue, red, yellow and black inks
Les Espiegle
Charles-Melchior Descourtis

wash manner in blue, red, yellow and black inks
May 1, 1807.
1850
Hand Painted Print
from a Daguerreotype
The HDR idea

1853 - Edward Baldus, “Cloisters of the Church of St. Trophime, Arles”

Multiple Exposure Technique

10 paper negatives - 1.6 centuries
1858 - H.P. Robinson “Fading Away”

professional photographic actors
5 exposures on glass plates
glued together in 1 negative to make print

All outdoor Scenes are HDR [controlled by illumination]

<table>
<thead>
<tr>
<th>Image</th>
<th>Location</th>
<th>White Paint</th>
<th>Black Paint</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Field</td>
<td>21,900 cd/m²</td>
<td>725 cd/m²</td>
<td>30:1</td>
<td>1.5 log units</td>
</tr>
<tr>
<td>Garage</td>
<td>16 cd/m²</td>
<td>1 cd/m²</td>
<td>1369:1</td>
<td>2.8 log units</td>
</tr>
<tr>
<td>Illumination range</td>
<td>1369:1</td>
<td>2.8 log units</td>
<td>21,900:1</td>
<td>4.3 log units</td>
</tr>
</tbody>
</table>
Ansel Adams Print

Print Range 114:1

Print Luminance (cd/m²)

Fit the world into the print? 114:1
In digits its Quantization
Rendering intent

- Scene specific (capture dynamic range)
  - exposure
  - development
  - paper
  - enlarger
- Render entire dynamic range
- *Tune receptor response for scene (prior-exposure)*
Beyond Tone Scale

- Tone scale
- Spatial - Dodging and Burning
- Beyond what a tone scale can do
Dodging & Burning

Changing the gradients while preserving the edges
Burning

Dodging
Clearing Winter Storm

24" lens
f/22
SELECTOL - SOFT 1:2 +
DEKTOL
100 cc to
500 cc S.S. stock
SEAGULL #2
Toned in Selenium

+2

+10

+10
WITH HOLE

+3 +3 +3

+4 +2

-2

-2

-2
Adams, Zone System 1939

HDR IMAGING

Pixel Tone Scale

Spatial with dodging & burning
Luminance Plot
Take home points

Artists and Retinex use spatial relationships to render HDR scenes

• render relationships
• preserve edges
Separate illumination from reflectance?
Spatial Comparisons

Ratio
Product
Reset
Average

Retinex Process
Fox Talbot’s First Negative

C. E. K. Mees’s Tone Scale

Bob Sobol’s Retinex
Future Colour

• Future as the extension of the past
  • HDR - The General Solution
  • Naming
  • Color Rendering Index [LED & OLED]
  • Neurophysiology -
Figure 4. False color images showing the arrangement of L (red), M (green), and S (blue) cones in the retinas of different human subjects. All images are shown to the same scale.
Edward J. Steichen, 
*Portrait of Alfred Steiglitz*, 1907
The Museum of Modern Art, NY

1903/1907
Lumiere
Autochrome

Edward J. Steichen, 
*Portrait of Alfred Steiglitz*, 1907
The Museum of Modern Art, NY
AgX film

Autochrome
Autochrome

Human vision

Rayleigh matches
Future Colour

• Future as the extension of the past
  • Neurophysiology -
    • Optics - population of LMS cones
    • Melanopsin - Locality Influence
      • discovered in 1998
      • circadian rhythms
      • pupil size
      • dynamic range ???

Two AIC Posters:

Rod, cone and iprgc interactions in color perception.
Sei-Ichi Tsujimura, Naoshi Hamazono, Yusuke Saito and Katsunori Okajima

Spectral opponency in human circadian phototransduction:
Implications for lighting practice.
Mariana Figueiro and Mark Rea
Melanopsin

• Retina’s 5th photopigments
  • Retinene + opsin [480 nm peak]
  • Not in receptors
  • Gives form vision without rods & cone
Future Colour

- Future as the extension of the past
  - Neurophysiology -
  - Optics - population of LMS cones
  - Melanopsin - Locality Influence
  - Progress from spots to images
    - Zeki - Colour Mondrians
    - Daw and Conway - double opponent
    - Greg Field’s - array of electrodes
  - Brain mapping
No Glare

No Neural Contrast

Semir Zeki
Daw / Conway
double opponent cells
Arrays of electrodes

Functional connectivity in the retina at the resolution of photoreceptors
The Brain Activity Map Project and the Challenge of Functional Connectomics

A. Paul Alivisatos,¹  Miyoung Chun,²  George M. Church,²  Ralph J. Greenspan,³  Michael L. Roukes,⁵  and Rafael Yuste⁶,*
¹Materials Science Division, Lawrence Berkeley National Lab and Department of Chemistry, University of California, Berkeley, Berkeley, CA 94720, USA
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*Correspondence: rafaelyuste@columbia.edu
DOI 10.1016/j.neuron.2012.06.006

The function of neural circuits is an emergent property that arises from the coordinated activity of large numbers of neurons. To capture this, we propose launching a large-scale, international public effort, the Brain Activity Map Project, aimed at reconstructing the full record of neural activity across complete neural circuits. This technological challenge could prove to be an invaluable step toward understanding fundamental and pathological brain processes.

http://www.brain-connect.eu
Scientists - take an artist to lunch. Artists - take a scientist to your studio.

Don’t wait until 2017!

We need each others’ help to understand vision.

Vision is spatial
How do we capture the output of vision?

Carinna Parraman’s Measurements of LDR & HDR appearances by painting with watercolors
Appearance = Reflectance?

Planar

LDR

HDR

Uniform illumination

Almost uniform illumination

Non-uniform illumination
Carinna Parraman’s Watercolor Painting
Appearance = Reflectance?

<table>
<thead>
<tr>
<th>Planar</th>
<th>LDR</th>
<th>HDR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes</td>
<td>Mostly</td>
<td>Rarely</td>
</tr>
<tr>
<td>Spatial, Cone</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

McCann JJ, McKee, SP., & Taylor, T.

Parraman C.E. et al.,
“Artist's colour rendering of HDR scenes in 3D Mondrian colour-constancy experiments”,
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Don’t wait until 2017!
We need each others help to understand spatial vision.
Thank You

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See you in 2017

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http://web.mac.com/mccanns/McCannImaging/Home.html