

EE Lunch (Oct 28, 2024)

Outline

- 5 minutes about my relationship with EE
- 10 minutes about an idea

Brian A. Wandell
Psychology Department

EE, GSE, Ophthalmology (by courtesy)
Wu Tsai Neurosciences Institute
Stanford Center for Cognitive and Neurobiological Imaging
Stanford Center for Image Systems Engineering

QUANTITATIVE MEASUREMENTS

∞

COMPUTATIONAL MODELS

∞

CHECK AND SHARE

In the 1980s

Through the 1980s I studied human visual perception, particularly color vision; a number of EE faculty mentored me

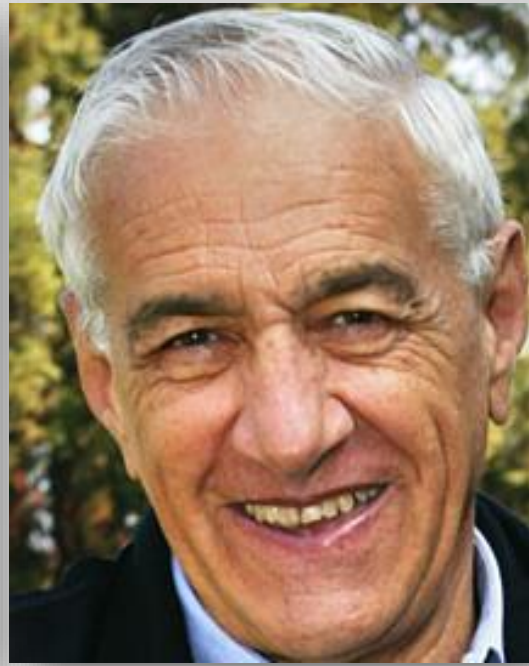


Image Systems Engineering at Stanford
Goodman and Wandell (1996) International
Conference on Image Processing (ICIP).

Image Systems Engineering at Stanford

Joseph W. Goodman & Brian A. Wandell
Center for Image Systems Engineering
McCullough 150, Stanford University
Stanford, CA 94305 USA

Abstract

A new Image Systems Engineering Program (ISEP) has recently been launched at Stanford University. The program includes more than a dozen faculty participants drawn from four departments. The planned stages of growth of the Program are described, with emphasis on the anticipated respective roles of the university and industry.

end-to-end design of an image system also requires an unusual interdisciplinarity, and thus a special program is needed to serve as a vehicle to integrate the training and research from faculty in different disciplines. Finally, there exists a large and still-growing collection of companies whose products are mainly concerned with the creation, manipulation, and delivery of images. This industry is international in character, but a substantial computer-related segment resides in Silicon Valley, physically near

Programmable digital camera project

In the late 1990s, Abbas and I cooperated on image systems



Stanford Report

April 26, 2001

Speedy camera-on-a-chip both captures and processes images
BY DAWN LEVY

Faster than a speeding bullet. Able to leap photographic obstacles with a single computer chip. It's a camera. It's a chip. It's a camera-on-a-chip.

Thanks to the efforts of electrical engineering Professor Abbas El Gamal, psychology and electrical engineering Professor Brian Wandell and their students, it's getting harder to take a bad picture.

- Trisha Lian – Meta
- Henryk Blasinski - Apple
- Haomiao Jiang - Roblox
- Andy Lin - Apple
- Steven Lansel - Meta
- Peter Catrysse - Stanford
- Feng Xiao - Fengyun Vision
- Jeff DiCarlo – Intuitive Surgical
- Zheng Lyu – Gyges lab
- Zhenyi Liu – Apple
- Manu Parmar – Pyxd
- Xuemei Zhang - Apple

Expansion to an industrial affiliates program

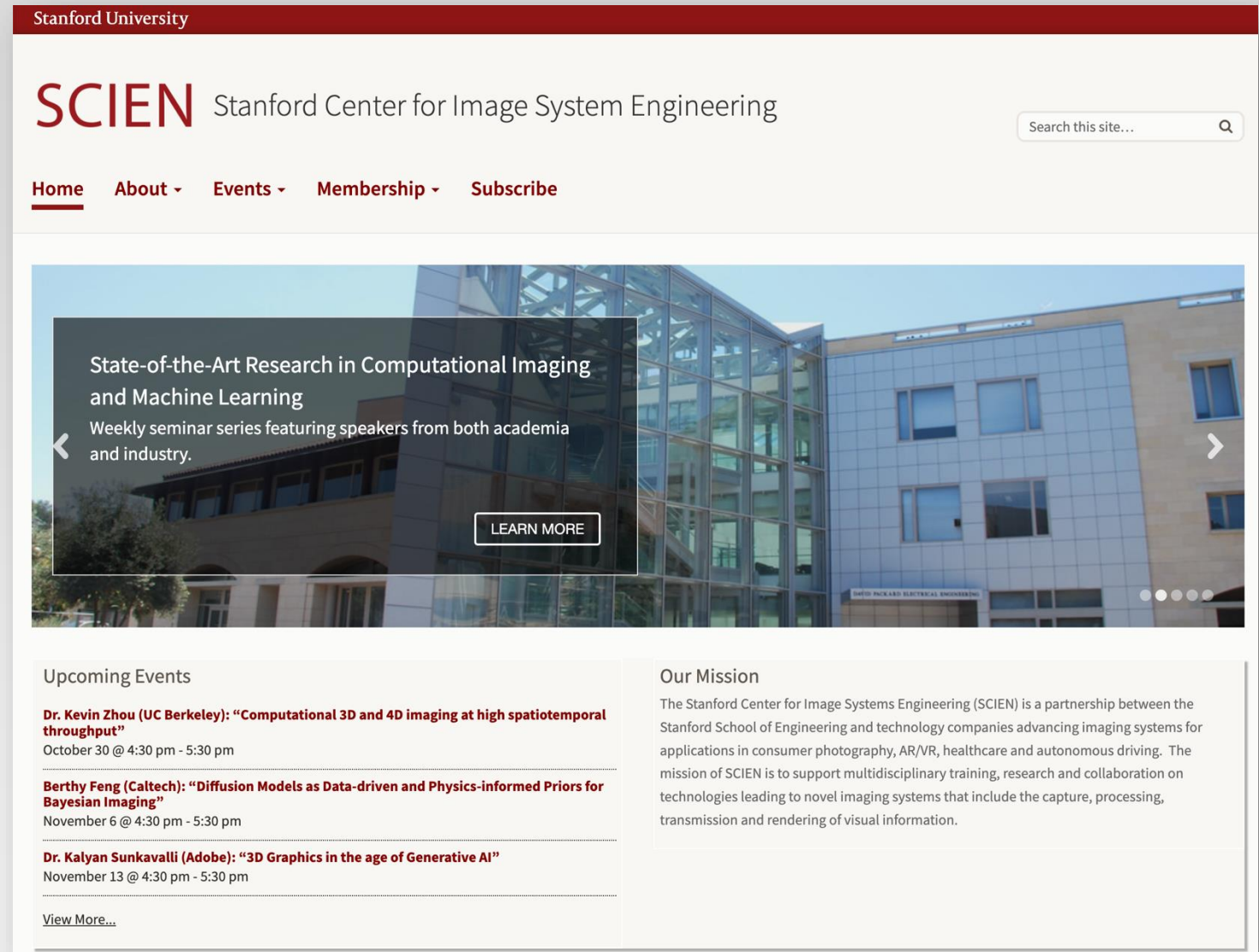
Joyce Farrell
Executive
director
(2002-present)



Bernd Girod
Faculty director
(2000-2024)



Gordon Wetzstein
Faculty director
(2023-present)







The screenshot shows the homepage of the Stanford Center for Image System Engineering (SCIEEN). At the top, it says "Stanford University" and "SCIEEN Stanford Center for Image System Engineering". There is a search bar on the right. Below the header is a navigation menu with "Home", "About", "Events", "Membership", and "Subscribe". The main content area features a large banner image of a modern building with a glass facade. Overlaid on the banner is text: "State-of-the-Art Research in Computational Imaging and Machine Learning" and "Weekly seminar series featuring speakers from both academia and industry." There is a "LEARN MORE" button. Below the banner is a section titled "Upcoming Events" with three entries: "Dr. Kevin Zhou (UC Berkeley): 'Computational 3D and 4D imaging at high spatiotemporal throughput'" (October 30 @ 4:30 pm - 5:30 pm), "Berthy Feng (Caltech): 'Diffusion Models as Data-driven and Physics-informed Priors for Bayesian Imaging'" (November 6 @ 4:30 pm - 5:30 pm), and "Dr. Kalyan Sunkavalli (Adobe): '3D Graphics in the age of Generative AI'" (November 13 @ 4:30 pm - 5:30 pm). There is a "View More..." link. To the right of the events is a section titled "Our Mission" with text describing the center's partnership with the Stanford School of Engineering and technology companies, and its mission to support multidisciplinary training, research, and collaboration on imaging technologies.


SCPD/CGOE Certificate and Psych 221 (former EE 362)

Home » Programs » Visual Computing Graduate Certificate


Visual Computing Graduate Certificate
Stanford School of Engineering

 [Graduate Certificate](#)  Online, instructor-led

 \$19,682 - \$25,738  [View Courses](#)

 [Academic Calendar](#)

[GET STARTED](#)



OVERVIEW

Visual computing is an emerging discipline that combines computer graphics and computer vision to advance technologies for the capture, processing, display and perception of visual information. The courses in this certificate program teach fundamentals of image capture, computer vision, computer graphics and human vision. Several of the courses offer hands-on experience prototyping imaging systems for augmented and virtual reality, robotics, autonomous vehicles and medical imaging. You'll gain skills that will allow you to play a critical role in your organization – whether developing cutting-edge technologies, pioneering new products, developing fresh research capabilities, or influencing strategic decisions.

Stanford University

F24-PSYCH-22... » Pages » Image systems engineering

Fall 2024

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Image systems engineering

Instructors: [Brian Wandell](#), [Joyce Farrell](#) and [David Cardinal](#)

Psych 221 is an introduction to the School of Engineering's [visual computing specialization](#). This course explains key concepts in image formation, image capture, and image processing. The course also introduces students to properties of the human visual system that are essential for understanding the design of image systems.



A key aspect of the course is the use of software for image systems simulation ([ISETCam](#)) and the associated homework problems ([psych221](#)). The software implements many of the principles we teach in the class, including specifying the scene radiance, optics, sensor capture and image processing. This software enables experimentation with the image system components (lens, sensor, post-processing). Through these experiments students learn to evaluate how image system components work together to produce image data for consumer photography, virtual and augmented reality, biomedical applications, autonomous driving, and convolutional neural networks.

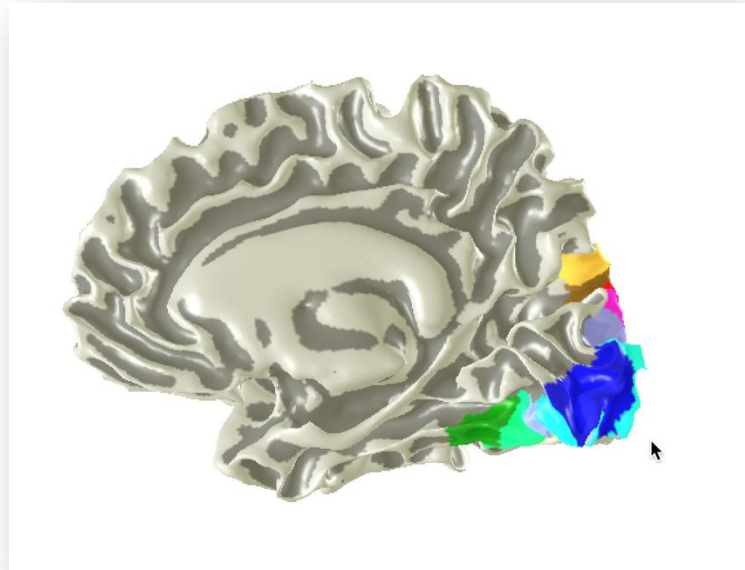
Magnetic resonance imaging

MRI instrumentation can be used in many ways to learn about brain tissue, structure, and activity





Visual field map reviews



- Maps tile the occipital lobe
- Extend into IPS and VOT
- Response properties differ
- Identification from gross anatomy

Cell
PRESS

366 Neuron 56, October 25, 2007

Neuron
Review

Visual Field Maps in Human Cortex

Brian A. Wandell,^{1,*} Serge O. Dumoulin,¹ and Alyssa A. Brewer²

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²Department of Cognitive Sciences, University of California, Irvine, Irvine, CA 92697, USA

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DOI 10.1016/j.neuron.2007.10.012

Much of the visual cortex is organized into visual field maps: nearby neurons have receptive fields at nearby locations in the image. Mammalian species generally have multiple visual field maps with each species having similar, but not identical, maps. The introduction of functional magnetic resonance imaging made it possible to identify visual field maps in human cortex, including several near (1) medial occipital (V1, V2, V3), (2) lateral occipital (LO-1, LO-2, hMT+), (3) ventral occipital (hV4, VO-1, VO-2), (4) dorsal occipital (V3A, V3B), and (5) posterior parietal cortex (IPS-0 to IPS-4). Evidence is accumulating for additional maps, including some in the frontal lobe. Cortical maps are arranged into clusters in which several maps have parallel eccentricity representations, while the angular representations within a cluster alternate in visual field sign. Visual field maps have been linked to functional and perceptual properties of the visual system at various spatial scales, ranging from the level of individual maps to map clusters to dorsal-ventral streams. We survey recent measurements of human visual field maps, describe hypotheses about the function and relationships between maps, and consider methods to improve map measurements and characterize the response properties of neurons comprising these maps.

Vision Research 51 (2011) 718-737



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Contents lists available at ScienceDirect

Vision Research

journal homepage: www.elsevier.com/locate/visres



Review

Imaging retinotopic maps in the human brain

Brian A. Wandell*, Jonathan Winawer

Psychology Department, Stanford University, Stanford, CA 94305, United States

ARTICLE INFO

Article history:

Received 5 April 2010

Received in revised form 2 August 2010

Available online 6 August 2010

ABSTRACT

A quarter-century ago visual neuroscientists had little information about the number and organization of retinotopic maps in human visual cortex. The advent of functional magnetic resonance imaging (fMRI), a non-invasive, spatially-resolved technique for measuring brain activity, provided a wealth of data about human retinotopic maps. Just as there are differences amongst non-human primate maps, the human maps have their own unique properties. Many human maps can be measured reliably in individual sub-

Stanford's Center for Cognitive and Neurobiological Imaging (CNI)



Co-directors
Adam Kerr
Kawin Setsompop

Introductory class with a focus on magnetic resonance imaging (Psych 204A)

- Account
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Winter 2024

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- Discussions

Human Neuroimaging Methods

An introduction to human neuroimaging using magnetic resonance

PSYCH 204A | 3 units | UG Reqs: None | Class # 12129 | Section 01 | Grading: Letter or Credit/No Credit |

SEM | Session: 2023-2024 Winter 1 | In Person

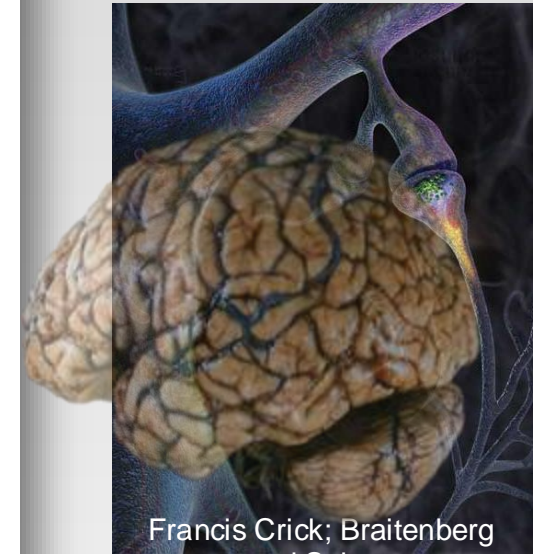
01/08/2024 - 03/15/2024

Tue, Thu 1:30 PM - 2:50 PM

[Sequoia Hall 200](#)

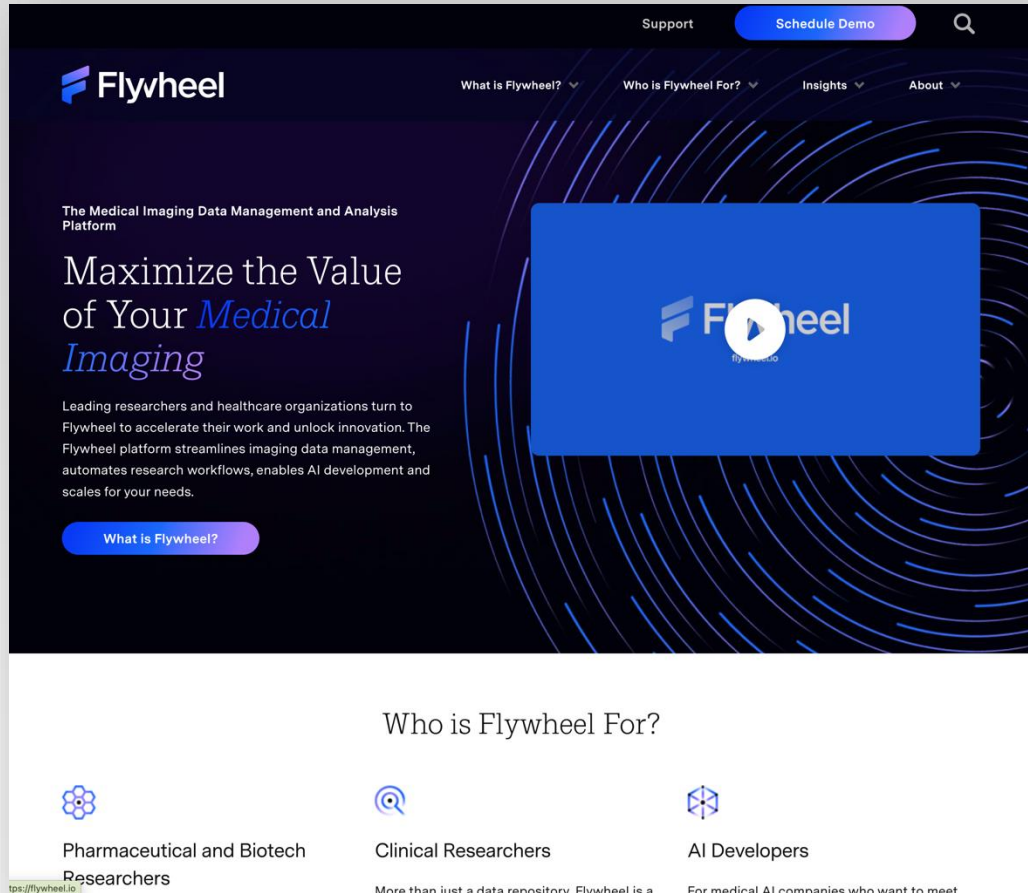
Instructors: Wandell, B. (PI); Yan, R. (TA)

Magnetic resonance imaging (MRI) has become an important scientific tool for measuring living human brain structure and function. This course is for students who would like to learn the physical basis of MRI and how the method is used to make anatomical images of brain structures (sMRI and dMRI), measure quantitative tissue properties (qMRI), and assess brain activity (fMRI).



Francis Crick; Braitenberg
and Schutz
Synapse image from Grahm
Johnson

Founded Flywheel.io for Reproducible Science and Medicine



The screenshot shows the Flywheel.io homepage. At the top, there is a navigation bar with the Flywheel logo, a search icon, and links for 'Support', 'Schedule Demo', 'What is Flywheel?', 'Who is Flywheel For?', 'Insights', and 'About'. The main content area features a dark blue background with a circular pattern of lines. The text reads: 'The Medical Imaging Data Management and Analysis Platform', 'Maximize the Value of Your *Medical Imaging*', and 'Leading researchers and healthcare organizations turn to Flywheel to accelerate their work and unlock innovation. The Flywheel platform streamlines imaging data management, automates research workflows, enables AI development and scales for your needs.' A blue play button icon is overlaid on the Flywheel logo. At the bottom, there is a section titled 'Who is Flywheel For?' with three icons representing 'Pharmaceutical and Biotech Researchers', 'Clinical Researchers', and 'AI Developers'.

Support Schedule Demo

Flywheel

What is Flywheel? Who is Flywheel For? Insights About

The Medical Imaging Data Management and Analysis Platform

Maximize the Value of Your *Medical Imaging*

Leading researchers and healthcare organizations turn to Flywheel to accelerate their work and unlock innovation. The Flywheel platform streamlines imaging data management, automates research workflows, enables AI development and scales for your needs.

What is Flywheel?

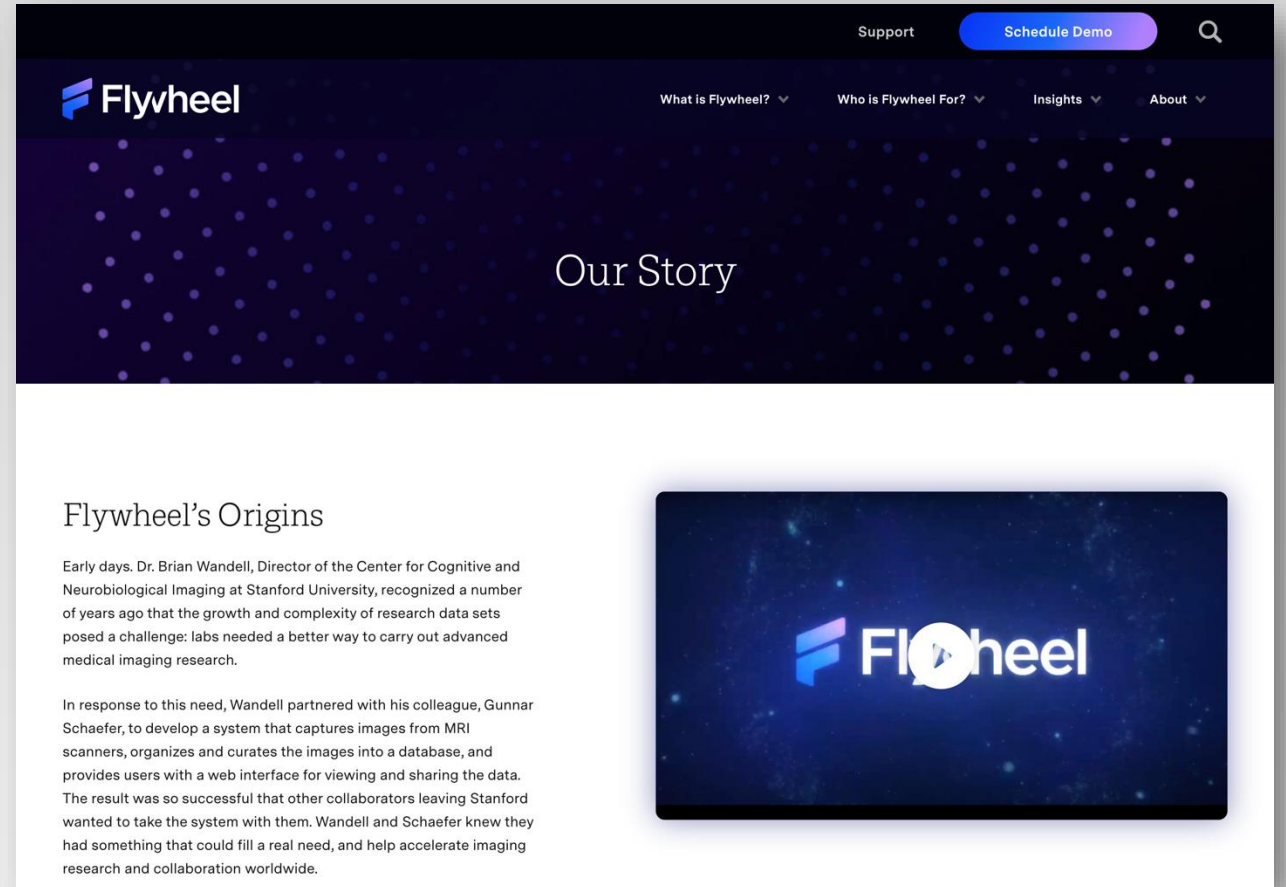
Who is Flywheel For?

Pharmaceutical and Biotech Researchers

Clinical Researchers

AI Developers

https://flywheel.io



The screenshot shows the 'Our Story' page on Flywheel.io. The top navigation bar is identical to the homepage. The main content area has a dark blue background with a starry pattern. The text reads: 'Our Story', 'Flywheel's Origins', and 'Early days. Dr. Brian Wandell, Director of the Center for Cognitive and Neurobiological Imaging at Stanford University, recognized a number of years ago that the growth and complexity of research data sets posed a challenge: labs needed a better way to carry out advanced medical imaging research.' A blue play button icon is overlaid on the Flywheel logo. Below the text, there is a section titled 'In response to this need, Wandell partnered with his colleague, Gunnar Schaefer, to develop a system that captures images from MRI scanners, organizes and curates the images into a database, and provides users with a web interface for viewing and sharing the data. The result was so successful that other collaborators leaving Stanford wanted to take the system with them. Wandell and Schaefer knew they had something that could fill a real need, and help accelerate imaging research and collaboration worldwide.' A blue play button icon is overlaid on the Flywheel logo.

Support Schedule Demo

Flywheel

What is Flywheel? Who is Flywheel For? Insights About

Our Story

Flywheel's Origins

Early days. Dr. Brian Wandell, Director of the Center for Cognitive and Neurobiological Imaging at Stanford University, recognized a number of years ago that the growth and complexity of research data sets posed a challenge: labs needed a better way to carry out advanced medical imaging research.

In response to this need, Wandell partnered with his colleague, Gunnar Schaefer, to develop a system that captures images from MRI scanners, organizes and curates the images into a database, and provides users with a web interface for viewing and sharing the data. The result was so successful that other collaborators leaving Stanford wanted to take the system with them. Wandell and Schaefer knew they had something that could fill a real need, and help accelerate imaging research and collaboration worldwide.

The main work now: Image systems simulation

Measuring system performance using **quantified** (units) throughout

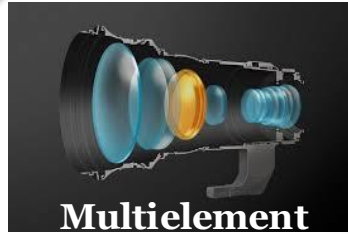
Scenes

Ray traced spectral scene simulations

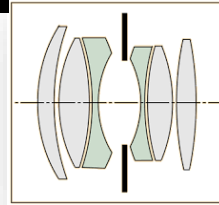


PBRT, ISET3D

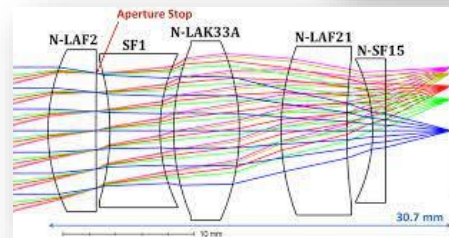
Optics



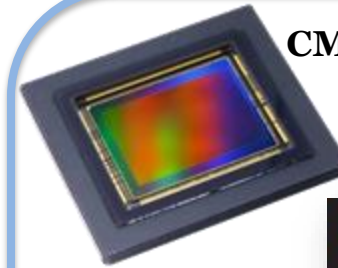
Spherics



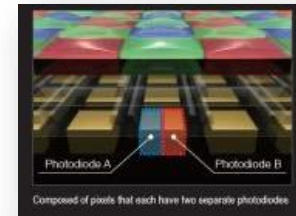
Aspherics



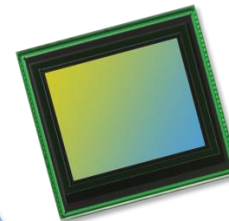
Sensors



Microlens

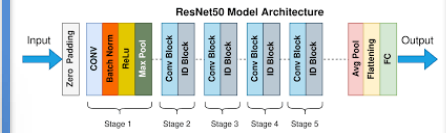


Dual or multipixel autofocus



Processing

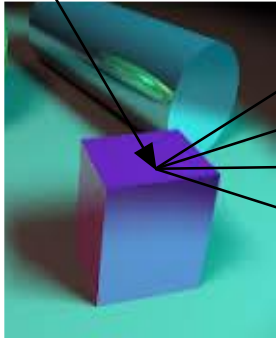
Deep networks



 **PyTorch**



Image systems simulation for biology



Scene spectral radiance



Physiological optics

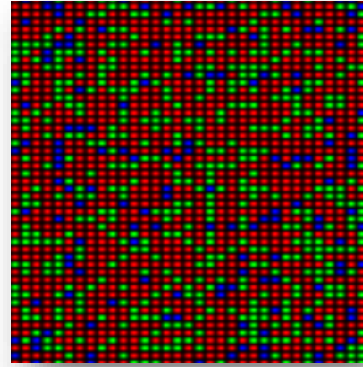
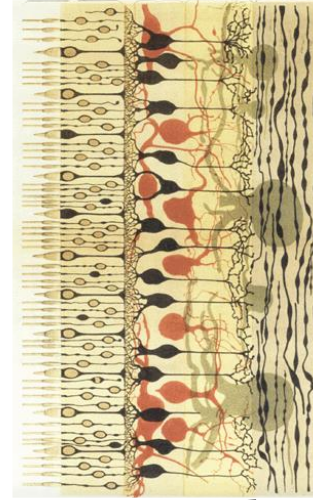
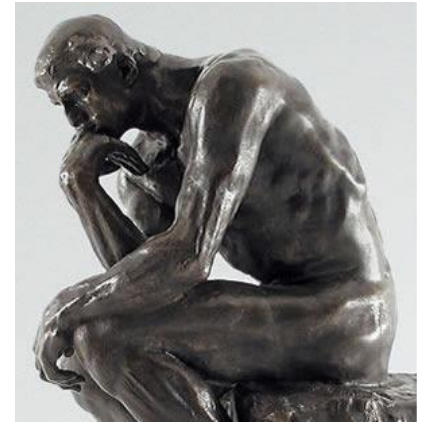


Photo transduction



Retinal processing



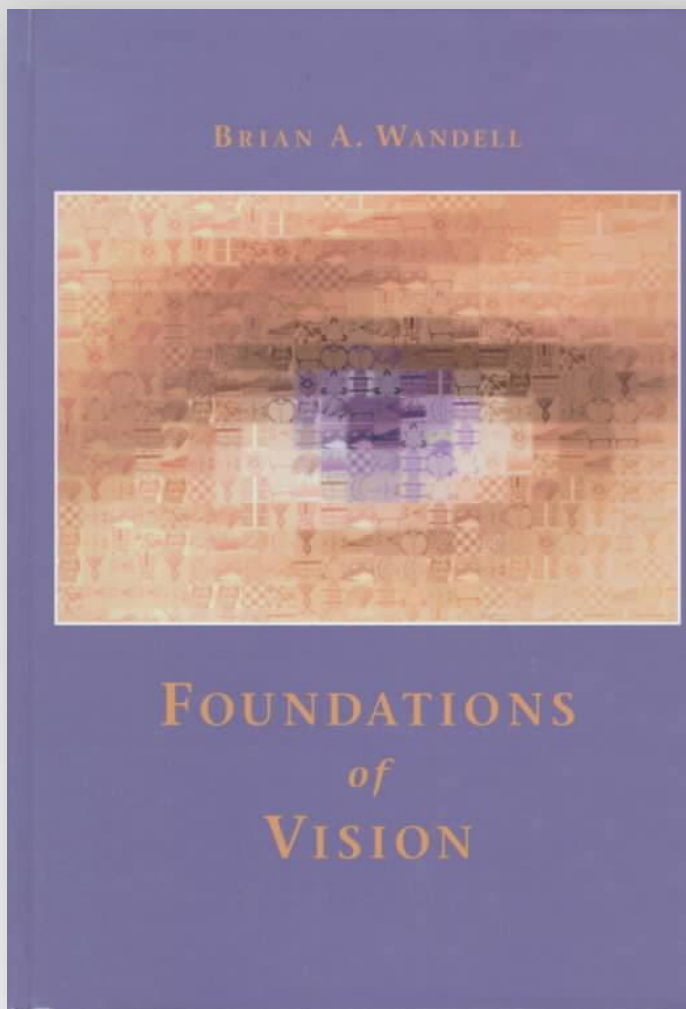
Inference



Book writing

New edition of my vision book

- I am working on web-first versions of these two books
- Using Quarto from POSIT; let me know if you are interested in this approach and want to share tips and ideas



New book based on Psych 221

Foundations of Image Systems Engineering

Preface

- 1 Light fields
 - 2 Optics
 - 3 Sensors
 - 4 Human visual system
 - 5 Displays
 - 6 Summary
- References
- Appendices
- A Wavebands
 - B Optics diffraction
 - C Multi-element lens calculations

Foundations of Image Systems Engineering

AUTHOR
Brian A. Wandell and Friends

PUBLISHED
October 20, 2024

Preface

The rapid development image systems technology over the last few decades has impacted many parts of society. For engineers who understand imaging principles, keeping up with these rapid advances is exhilarating and challenging. The main purpose of this book is to explain the fundamental principles of image systems to people who are entering the field, or to people who are simply curious about how image systems work.

Image systems comprise many parts that work together. This book introduces the reader to tools that simulate and characterize the performance of the whole image system. Any image system will have multiple components, and to understand the system we must understand the original signal (scene) as well as the components - optics, sensors, image processing, display - and properties of the human visual system. It is impossible for me to keep up with every new advance in the component technologies. On the other hand, even as technology advances, each component implements certain principles that persist across generations of technology. This book aims to describe principles that remain invariant, even as technology evolves. Hence, the title is: **Foundations of Image Systems Engineering.**



An idea to illustrate my current work

- How to estimate the cone spectral sensitivities in the living human eye from behavioral measurements
- Builds on two ideas from Thomas Young (1802) and James Clerk Maxwell (1860)
- Uses linear algebraic methods that are common in engineering
- Application – let me know of other contexts where you have seen the idea

PROCEEDINGS B

royalsocietypublishing.org/journal/rspb



Research



Cite this article: Wandell BA, Goossens T, Brainard DH. 2024 Deriving the cone fundamentals: a subspace intersection method. *Proc. R. Soc. B* **291**: 20240347. <https://doi.org/10.1098/rspb.2024.0347>

Received: 12 February 2024
Accepted: 11 July 2024

Subject Category:
Neuroscience and cognition

Subject Areas:
neuroscience, behaviour

Keywords:
colour, retina, perception

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Deriving the cone fundamentals: a subspace intersection method

Brian A. Wandell¹, Thomas Goossens¹ and David H. Brainard²

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Two ideas, proposed by Thomas Young and James Clerk Maxwell, form the foundations of colour science: (i) three types of retinal receptors encode light under daytime conditions, and (ii) colour matching experiments establish the critical spectral properties of this encoding. Experimental quantification of these ideas is used in international colour standards. However, for many years, the field did not reach consensus on the spectral properties of the biological substrate of colour matching: the spectral sensitivity of the cone fundamentals. By combining auxiliary data (thresholds, inert pigment analyses), complex calculations, and colour matching from genetically analysed dichromats, the human cone fundamentals have now been standardized. Here, we describe a new computational method to estimate the cone fundamentals using only colour matching from the three types of dichromatic observers. We show that it is not necessary to include data from trichromatic observers in the analysis or to know the primary lights used in the matching experiments. Remarkably, it is even possible to estimate the fundamentals by combining data from experiments using different, unknown primaries. We then suggest how the new method may be applied to colour management in modern image systems.

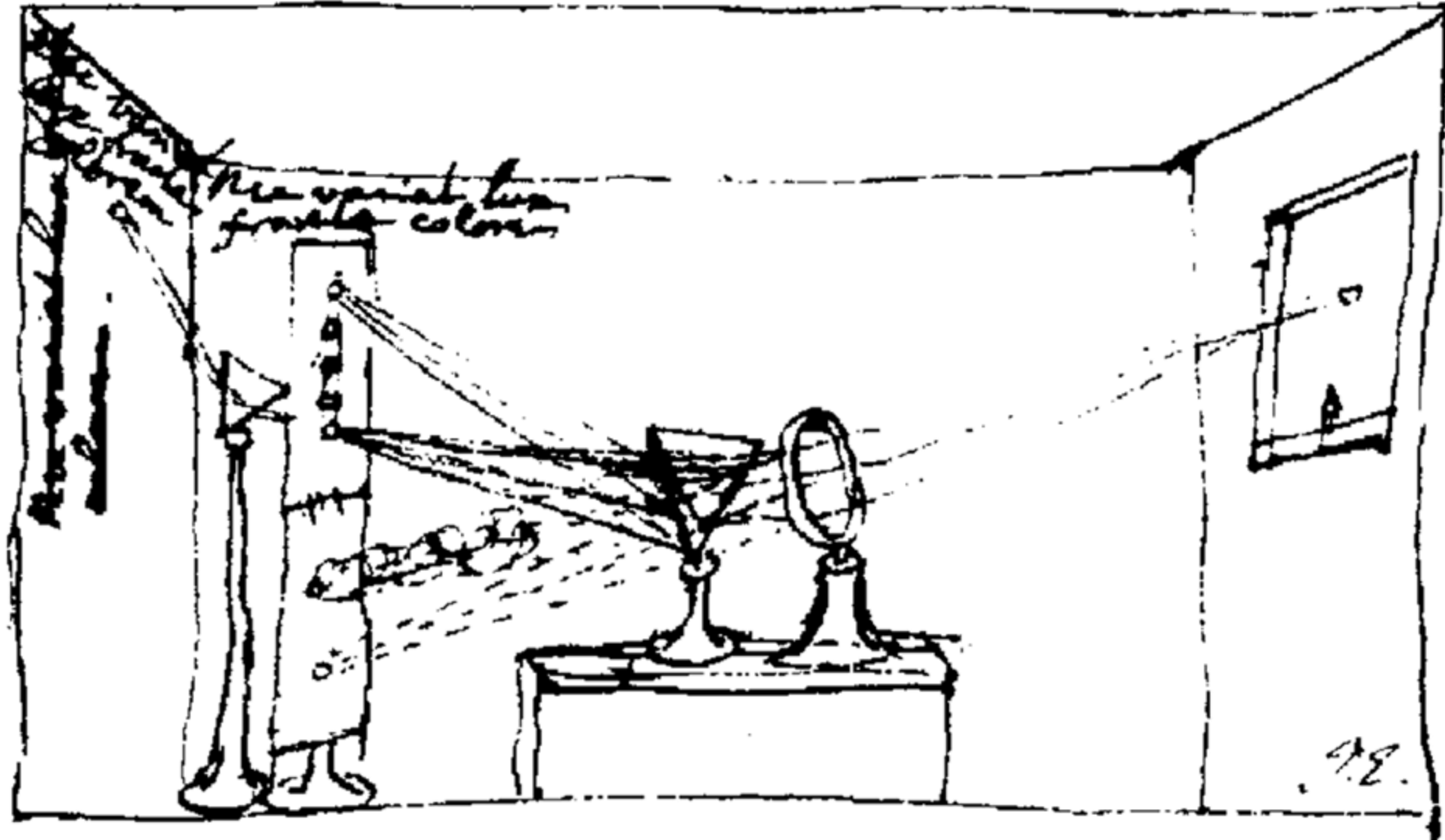
1. Introduction

It appears therefore that the result of any mixture of colours, however complicated, may be defined by its relation to a certain small number of well-known colours. Having selected our standard colours, and determined the relations of a given colour to these, we have defined that colour completely as to its appearance. Any colour which has the same relation to the standard colours, will be identical in appearance, though its optical constitution, as revealed by the prism, may be very different. (James Clerk Maxwell) [1]

The fundamental components of light



Isaac Newton

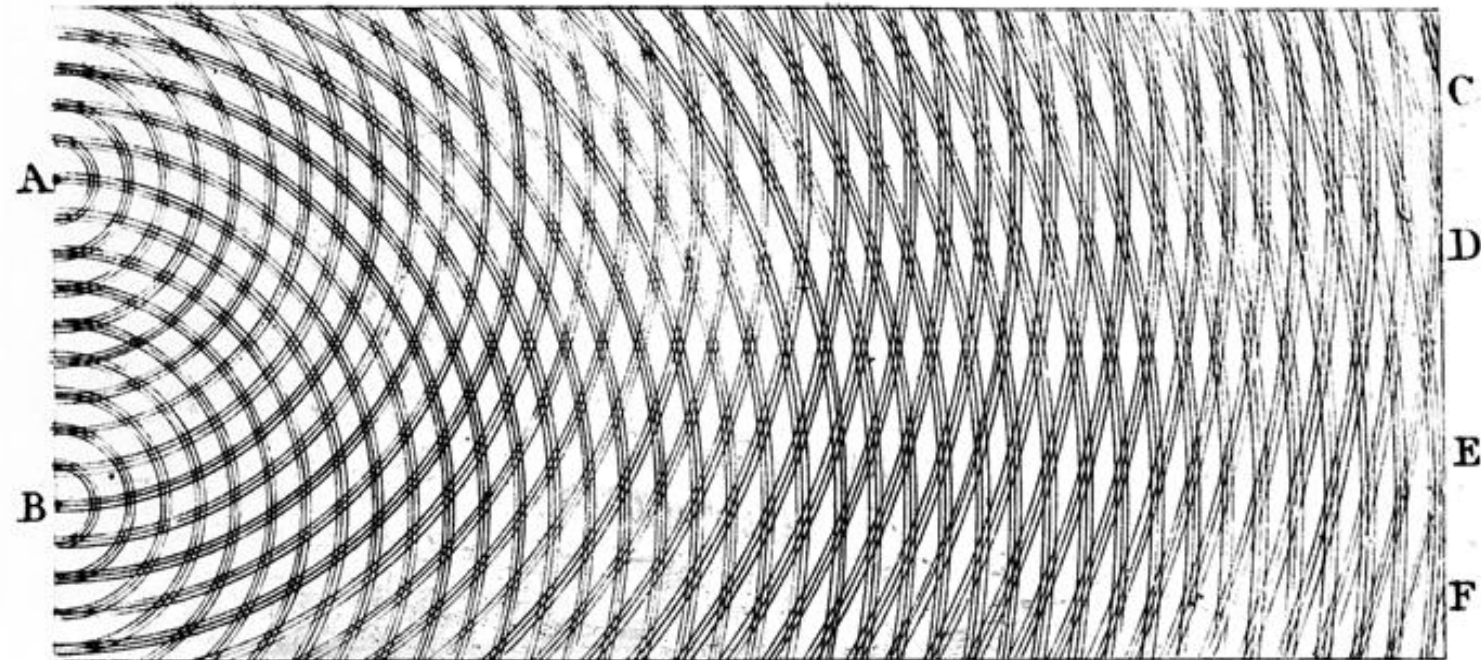


Thomas Young – Double slit experiment and diffraction



Thomas Young's sketch supporting the wave theory of light
presented to the Royal Society, 1803

<http://en.wikipedia.org/wiki/Diffraction>



Thomas Young (1802)
On the theory of lights
and colours.
Philosophical
Transactions of the
Royal Society 92, 12-
48.

Thomas Young – Trichromacy from his Royal Society presentation



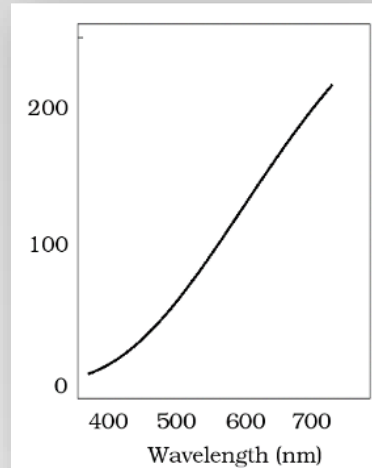
Thomas Young “II. The Bakerian Lecture. On the theory of light and colours”
presented to the Royal Society Nov. 12, 1801

“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 units with every possible undulation, it becomes necessary to suppose the number limited for instance to the three principal colours ...”

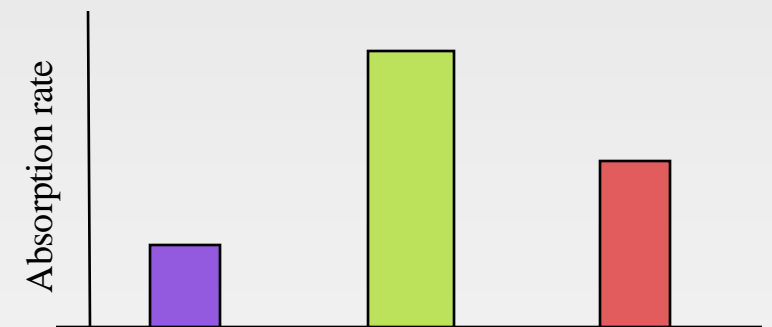
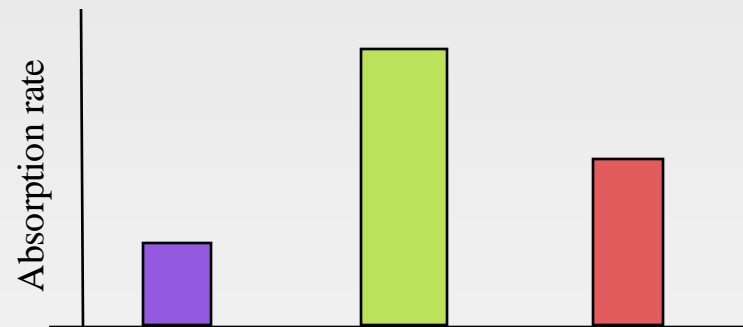
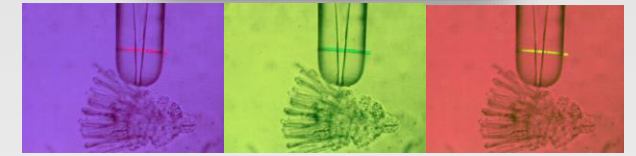
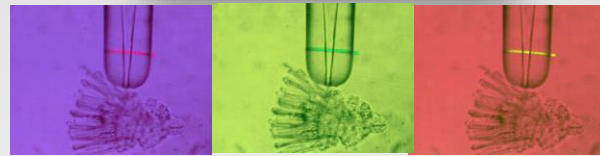
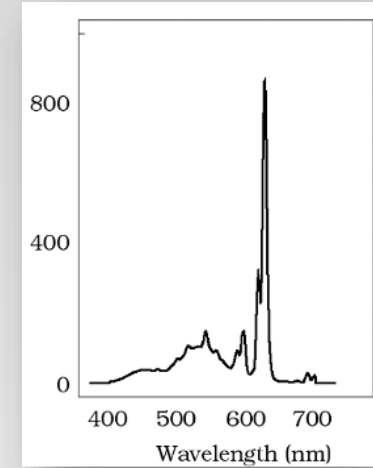
Thomas Young (1802)
On the theory of lights
and colours.
Philosophical
Transactions of the
Royal Society 92, 12-
48.

- Brewster didn't buy it – he thought color was a property of light
- Helmholtz mis-estimated the number of cone types
- Maxwell got it right in a series of remarkable papers

Thomas Young – Trichromacy

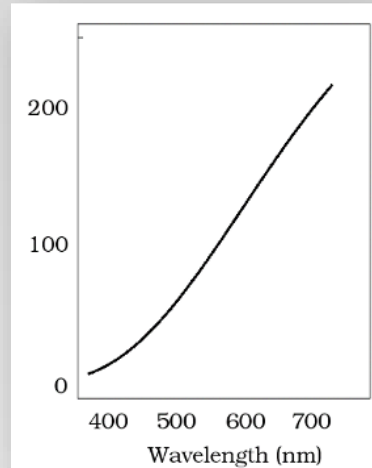


Two lights that differ physically but appear identical (metamers)

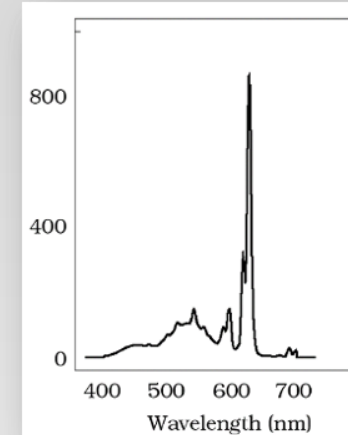


Thomas Young (1802)
On the theory of lights
and colours.
Philosophical
Transactions of the
Royal Society 92, 12-
48.

Thomas Young – Trichromacy



Two lights that differ physically but appear identical (metamers)



????

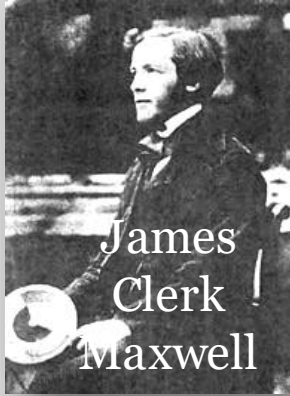
What is the biological basis of this equivalence

???

Thomas Young (1802)
On the theory of lights
and colours.
Philosophical
Transactions of the
Royal Society 92, 12-
48.

Maxwell JC. 1860

On the theory of compound colours, and the relations of the colours of the spectrum.
Phil. Trans. R. Soc. Lond. 150, 57–84. (doi:10.1098/rstl.1860.0005)



IV. *On the Theory of Compound Colours, and the Relations of the Colours of the Spectrum.* By J. CLERK MAXWELL, M.A., Professor of Natural Philosophy in *Medical College and University of Aberdeen*. Communicated by Professor STOKES

It appears therefore that the result of any mixture of colours, however complicated, may be defined by its relation to a certain small number of well-known colours. Having selected our standard colours, and determined the relations of a given colour to these, we have defined that colour completely as to its appearance. Any colour which has the same relation to the standard colours, will be identical in appearance, though its optical constitution, as revealed by the prism, may be very different. (James Clerk Maxwell)

light.

NEWTON has also shown† how to combine the different rays of the spectrum so as to form a single beam of light, and how to alter the proportions of the different colours so as to exhibit the result of combining them in any arbitrary manner.

The number of different kinds of homogeneous light being infinite, and the proportion in which each may be combined being also variable indefinitely, the results of such combinations could not be appreciated by the eye, unless the chromatic effect of every

Maxwell's color-matching apparatus

- Color-mixing with spectral lights (1860)
- Channel C provides a constant daylight, channels XYZ provide three spectral lights

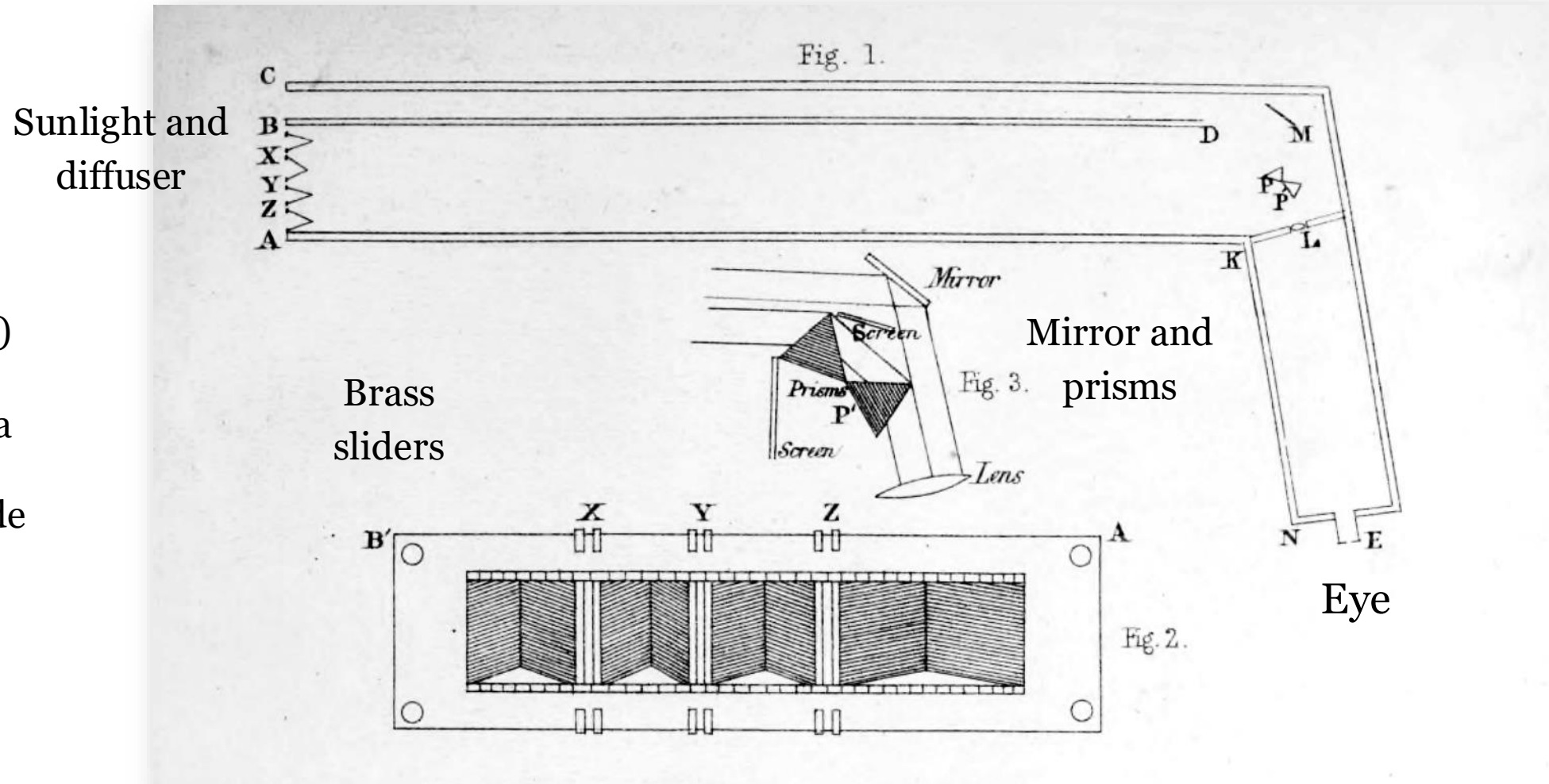


Fig. 1, Plate I. represents the instrument for making the observations. It consists of two tubes, or long boxes, of deal, of rectangular section, joined together at an angle of about 100° . The part AK is about 5 feet long ...

Data and analyses are included in the 1860 paper

TABLE VI.

Observer (K.).	(24.)	(44.)	(68.)
44.3(20)=	18.6	+ 0.4	+ 2.8
16.1(28)=	18.6	+ 5.8	- 0.1
22.0(32)=	18.6	+19.3	- 0.1
25.2(36)=	12.2	+31.4	- 0.8
26.0(40)=	3.3	+31.4	- 0.2
35.0(46)=	- 1.2	+31.4	+ 0.3
41.4(48)=	- 2.6	+31.4	+ 3.5
62.0(52)=	- 3.4	+31.4	+17.5
61.7(56)=	- 3.1	+21.0	+30.5
40.5(60)=	- 1.9	+ 7.7	+30.5
33.7(64)=	- 1.1	+ 1.1	+30.5
32.3(72)=	+ 0.6	+ 0.2	+30.5
44.0(76)=	+ 1.1	+ 0.7	+30.5
63.7(80)=	+ 0.3	- 1.8	+30.5

TABLE IX.

Observations by J., October 1859.

	(24.)	(44.)	(68.)
44.3(20)=	18.1	- 2.5	+ 2.3
16.0(28)=	18.1	+ 6.2	- 0.7
21.5(32)=	18.1	+25.2	- 0.7
19.3(36)=	8.1	+27.5	- 0.3
20.7(40)=	2.1	+27.5	- 0.5
52.3(48)=	- 1.4	+27.5	+10.7
95.0(52)=	- 2.4	+27.5	+37.0
51.7(56)=	- 2.2	+ 4.8	+37.0
37.2(60)=	- 1.2	+ 0.8	+37.0
36.7(64)=	- 0.2	+ 0.8	+37.0
35.0(72)=	+ 0.6	- 0.2	+37.0
40.0(76)=	+ 0.9	+ 0.5	+37.0
51.0(80)=	+ 1.1	+ 0.5	+37.0

may be considered complete, and the operator must measure the breadth of each slit by means of the wedge, as before described, and write down the result as a colour-equation, thus—

$$\text{Oct. 18, J.} \quad 18\cdot5(24) + 27(44) + 37(68) = W^* \quad \dots \dots \dots (13.)$$

This equation means that on the 18th of October the observer J. (myself) made an observation in which the breadth of the slit X was 18·5, as measured by the wedge, while its centre was at the division (24) of the scale; that the breadths of Y and Z were 27 and 37, and their positions (44) and (68); and that the illumination produced by these slits was exactly equal, in my estimation as an observer, to the constant white W.

The position of the slit X was then shifted from (24) to (28), and when the proper adjustments were made, I found a second colour-equation of this form—

$$\text{Oct. 18, J.} \quad 16(28) + 21(44) + 37(68) = W. \quad \dots \dots \dots (14.)$$

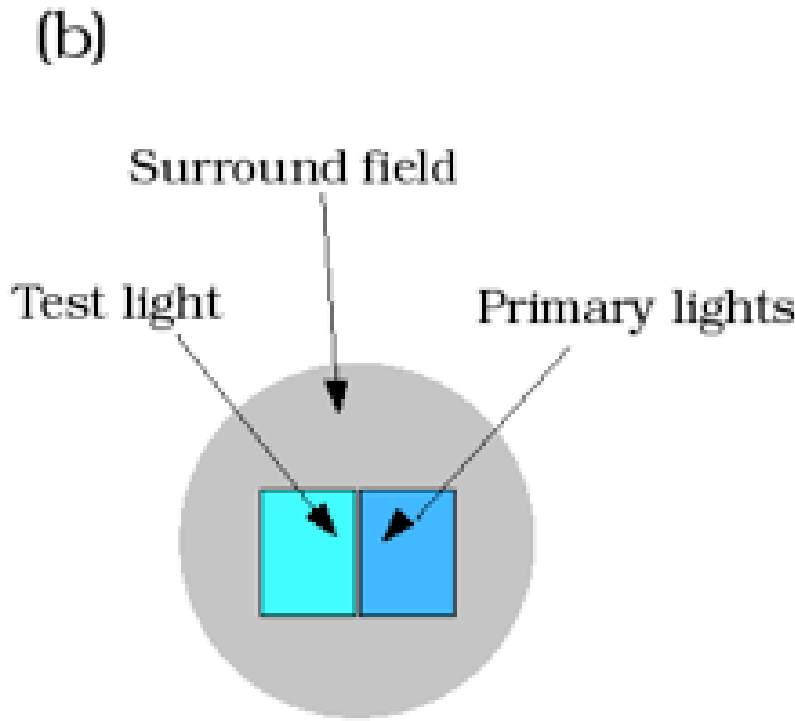
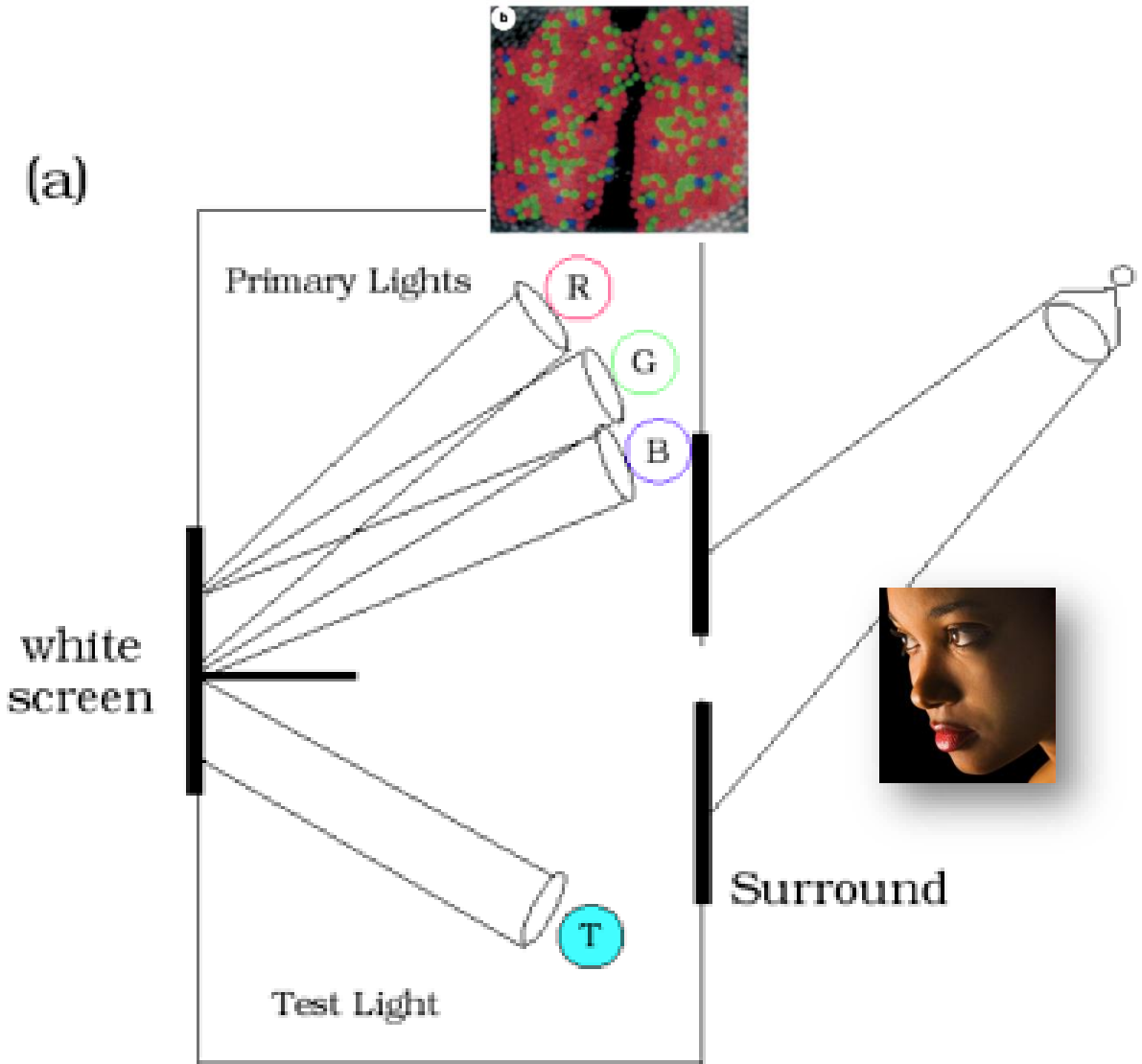
Subtracting one equation from the other and remembering that the figures in brackets are merely symbols of position, not of magnitude, we find

$$16(28) = 18\cdot5(24) + 6(44), \quad \dots \dots \dots (15.)$$

showing that (28) can be made up of (24) and (44), in the proportion of 18·5 to 6.

In this way, by combining each colour with two standard colours, we may produce a white equal to the constant white. The red and yellow colours from (20) to (32) must be combined with green and blue, the greens from (36) to (52) with red and blue, and the blues from (56) to (80) with red and green.

Cone color matching experiment (cone vision)



Color matching equations: Origins of linear algebra



[Grassmann](#)
(history)

- From his experiments and calculations, Maxwell derived and plotted the rows of this matrix, which we now call the color matching functions
- With Sutton, he went on to use this to produce the first color photograph

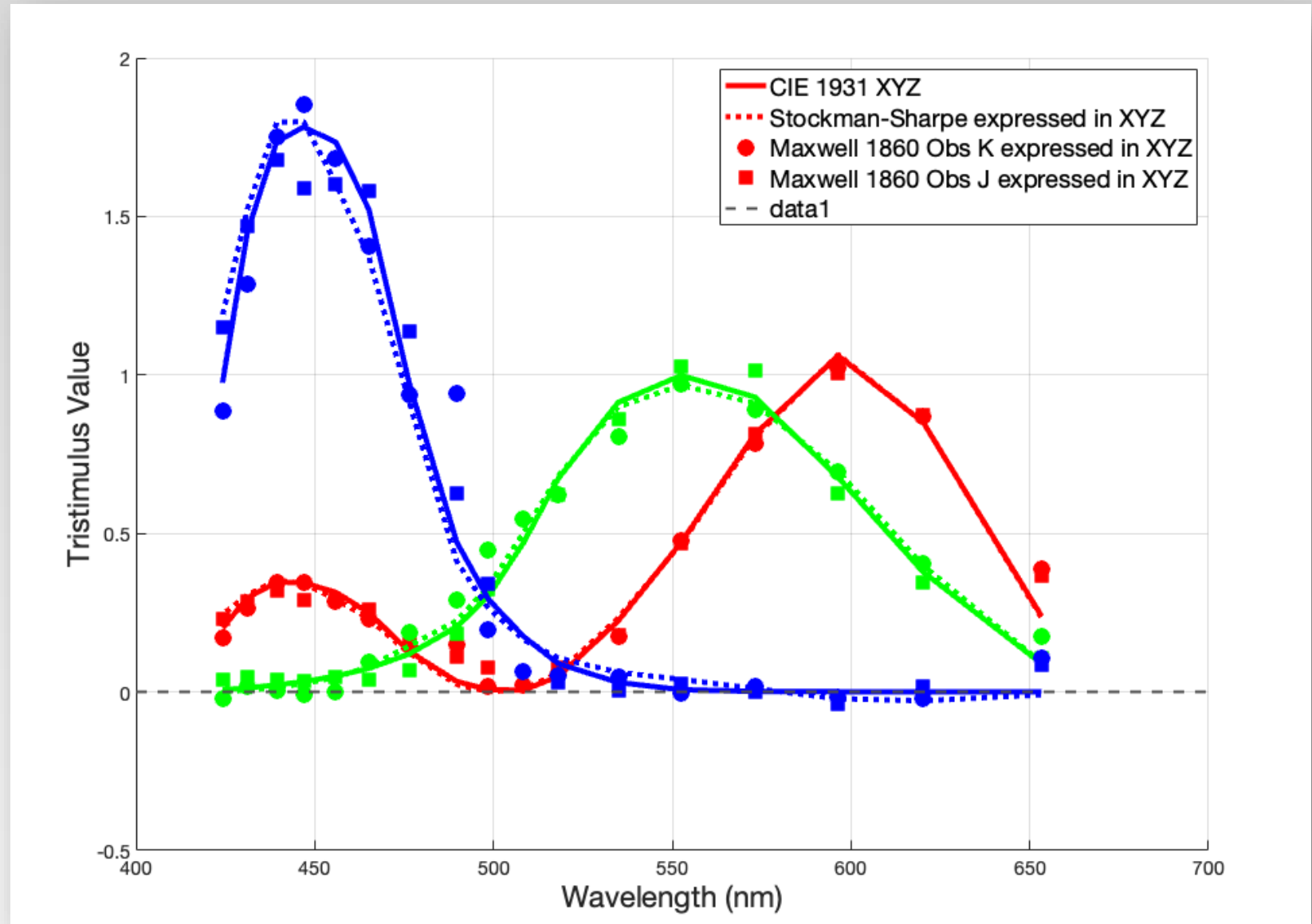


Primaries

$$\begin{pmatrix} R \\ G \\ B \end{pmatrix} = \begin{pmatrix} \text{Red} \\ \text{Green} \\ \text{Blue} \end{pmatrix} \begin{pmatrix} \text{Any light SPD} \end{pmatrix}$$

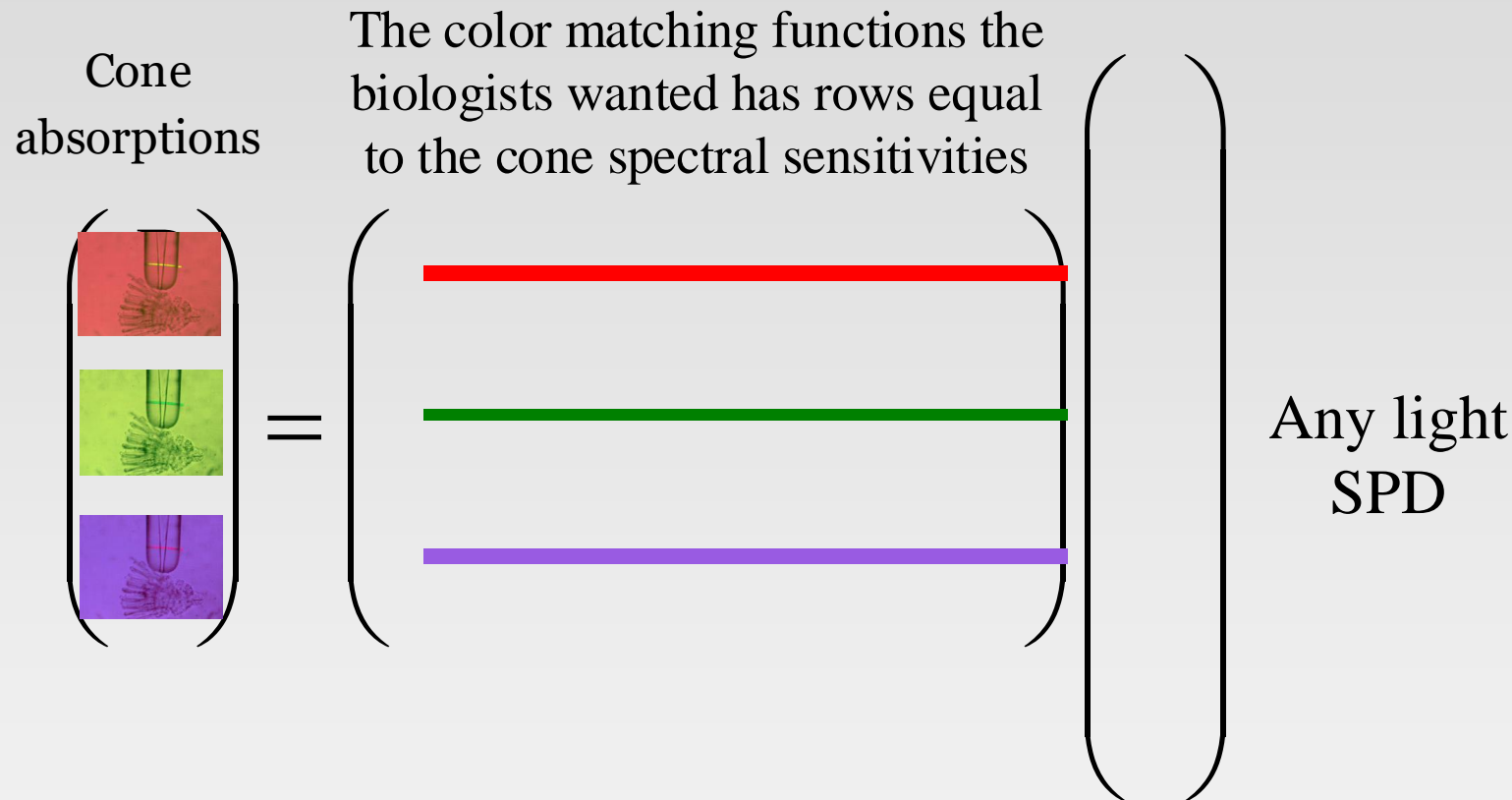
Maxwell – in 1860 – and the CIE today

- We compared Maxwell's data with modern standards
- We had to make only one small adjustment to Maxwell's wavelength estimates, via Judd (10 nm)



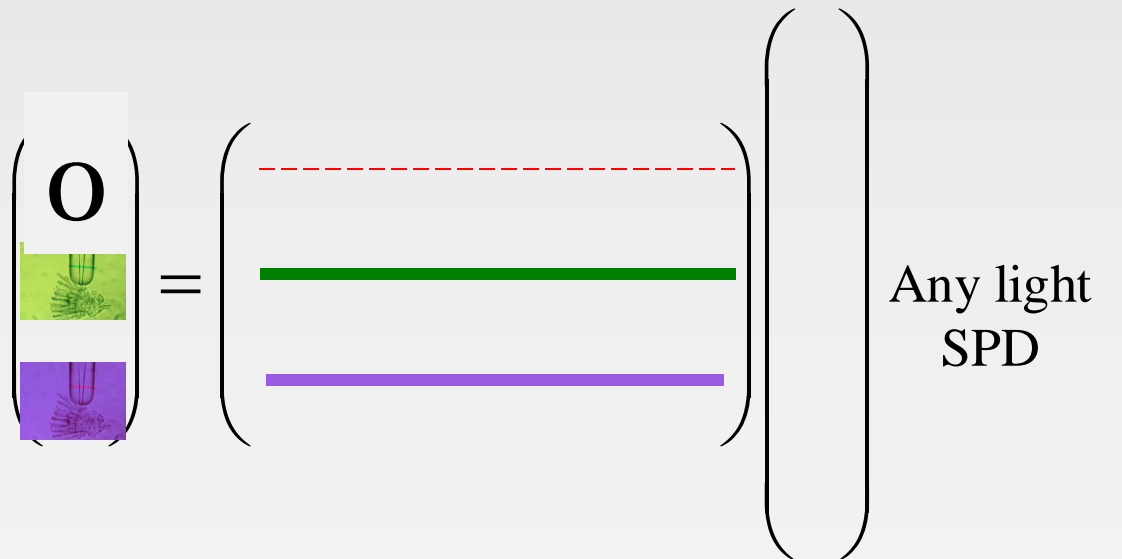
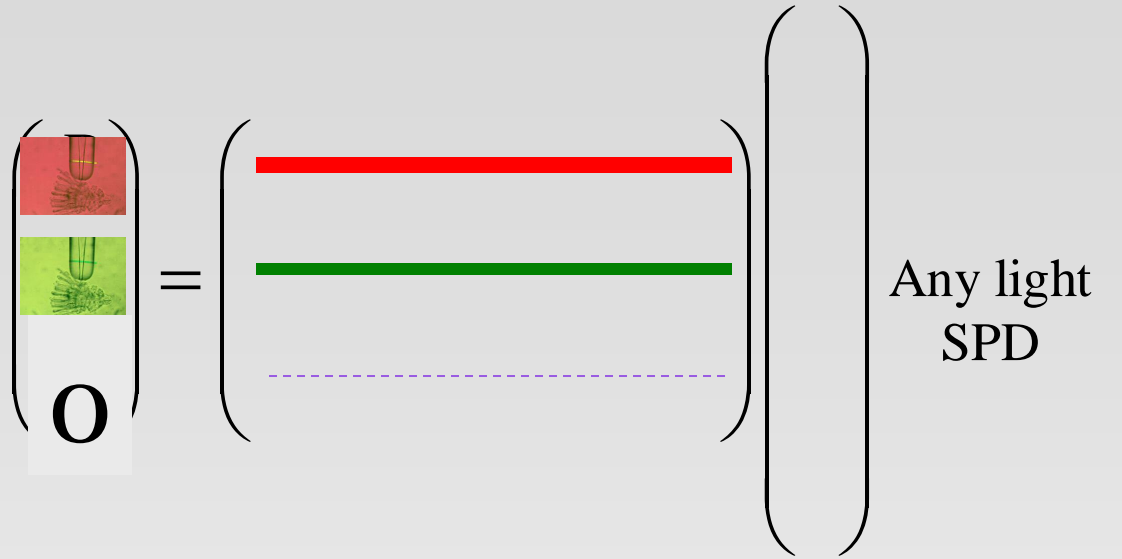
Color matching equations: Cone fundamentals

- The color matching functions the biologists wanted has rows equal to the cone spectral sensitivities
- Over the years, these were estimated using a wide variety of auxiliary experimental methods
- A standard was established in the year 2000 by the CIE based on Stockman



Color matching equations: Dichromats

- There are people who have only two of the three types of cone fundamentals
- Reduction dichromats
- Genetically detectable



Here is the idea we understood and implemented in the paper



1935

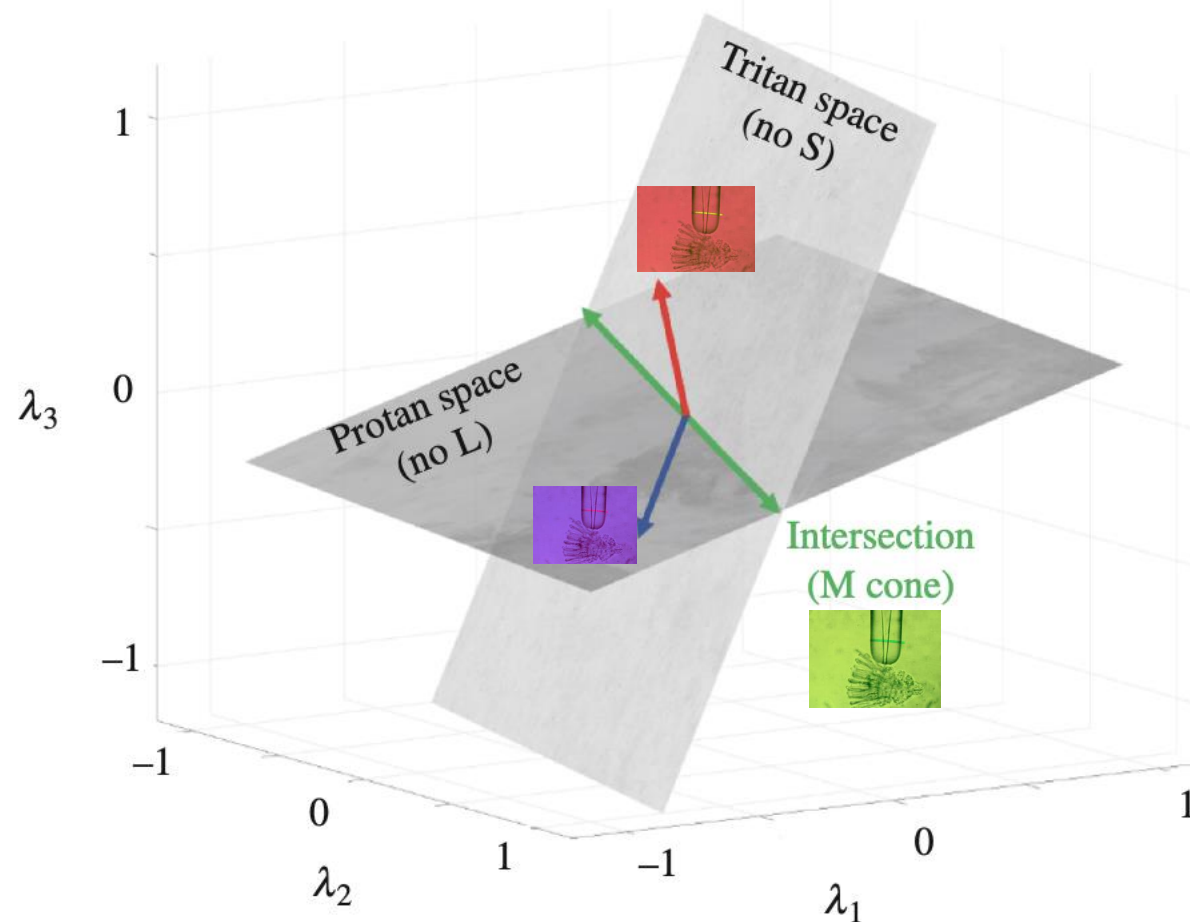
Dichromatic color matching functions have two rows, not 3

$$\mathbf{C}_p = \begin{bmatrix} \mathbf{c}_1^p & \mathbf{c}_2^p \end{bmatrix} = [\mathbf{m} \ \mathbf{s}] \mathbf{A}_p,$$

$$\mathbf{C}_d = \begin{bmatrix} \mathbf{c}_1^d & \mathbf{c}_2^d \end{bmatrix} = [\mathbf{1} \ \mathbf{s}] \mathbf{A}_d,$$

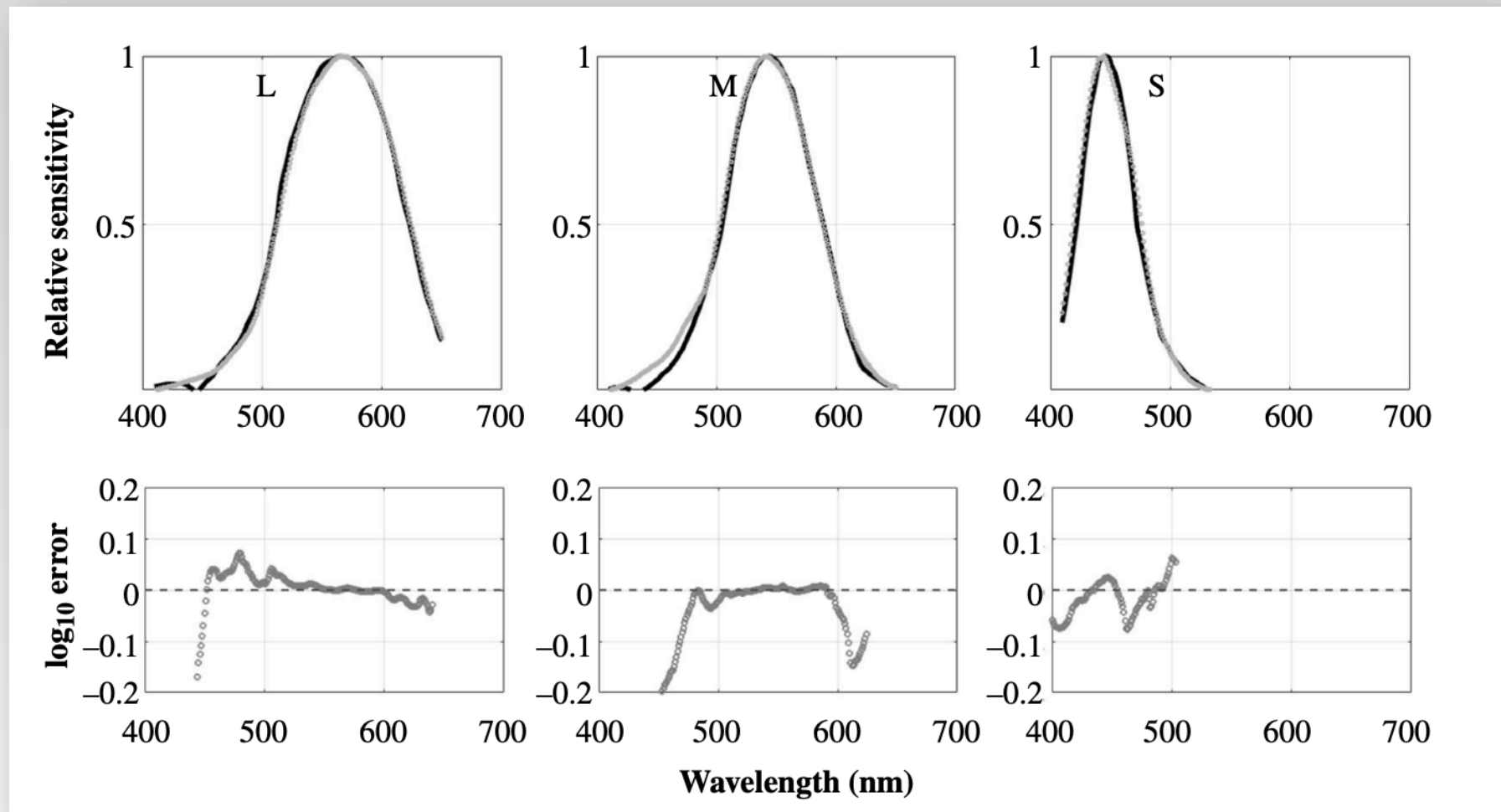
$$\mathbf{C}_t = \begin{bmatrix} \mathbf{c}_1^t & \mathbf{c}_2^t \end{bmatrix} = [\mathbf{1} \ \mathbf{m}] \mathbf{A}_t.$$

Using only color matching functions from dichromats, we can solve for the three cone fundamentals



Comparison of CIE 2000 standard and our estimates from color-matching only

- This is how well the procedure did compared to the CIE 2007 standard (proposed by Stockman in 2000).
- The differences are within the variation in the human population



Methods and data are on GitHub and SDR, as usual

The screenshot shows the GitHub Wiki page for the repository 'isetbio / isetfundamentals'. The page title is 'Home' and it was last edited by Brian Wandell on August 23. The main heading is 'Deriving the cone fundamentals: a subspace intersection method'. The abstract discusses the foundations of color science, mentioning Thomas Young and James Clerk Maxwell. A sidebar on the right lists 'Pages' and 'Home' with sub-items like 'Computational', 'Conceptual', 'Computation notes', and 'Citations'.

Home

Brian Wandell edited this page on Aug 23 · 31 revisions

Deriving the cone fundamentals: a subspace intersection method

Abstract Two ideas, proposed by Thomas Young and James Clerk Maxwell, form the foundations of color science: (1) Three types of retinal receptors encode light under daytime conditions, and (2) color matching experiments establish the critical spectral properties of this encoding. Experimental quantification of these ideas are used in international color standards. But, for many years the field did not reach consensus on the spectral properties of the biological substrate of color matching: the sensitivity of the in situ cones (cone fundamentals). By combining auxiliary data (thresholds, inert pigment analyses), complex calculations, and color matching from genetically analyzed dichromats, the human cone fundamentals have now been standardized.

Here we describe a new computational method to estimate the cone fundamentals using only color matching from dichromatic observers. We show that it is not necessary to include data from

- Pages 1
 - Find a page...
- Home
 - Deriving the cone fundamentals: a subspace intersection method
 - Koh Terai web site about the Maxwell color matching experiments
 - Figures
 - Computational
 - Conceptual
 - Computation notes
 - Citations

The screenshot shows the GitHub repository page for 'isetbio / isetfundamentals'. The repository is public and has 13 watchers, 0 forks, and 0 stars. The main content is a list of files and folders, including 'configuration', 'data', 'development', 'estimators', 'fig01Maxwell', 'fig02IntersectingPlanes', 'fig03WDWDichromats', 'fig04ConeEstimates', 'fig05VirtualChannel', 'optimization', 'tutorials', '.gitignore', and 'LICENSE'. The 'About' section on the right provides information about the repository, including a list of scripts related to the paper on estimating cone fundamentals, a list of releases, and a list of contributors.

isetfundamentals

Public

main 3 Branches Tags

Go to file

Code

wandell Update README.md ab3a47e · last month 156 Commits

configuration	Eliminate dependencies on BrainardLabT...	last year
data	Inserted citation	4 months ago
development	Delete cmfFovea.mat	4 months ago
estimators	added optimizer estimators	10 months ago
fig01Maxwell	Many tests, comments, and some re-org...	4 months ago
fig02IntersectingPlanes	Revert "Fixing errors in the code due to ...	4 months ago
fig03WDWDichromats	Many tests, comments, and some re-org...	4 months ago
fig04ConeEstimates	Many tests, comments, and some re-org...	4 months ago
fig05VirtualChannel	Many tests, comments, and some re-org...	4 months ago
optimization	Estimator using optimization with equalit...	10 months ago
tutorials	Revert "Fixing errors in the code due to ...	4 months ago
.gitignore	Estimator and figures using meanoftwo i...	10 months ago
LICENSE	Initial commit	last year

About

Scripts related to the paper on estimating cone fundamentals

- Readme
- MIT license
- Activity
- Custom properties
- 0 stars
- 13 watching
- 0 forks

Report repository

Releases

No releases published

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Packages

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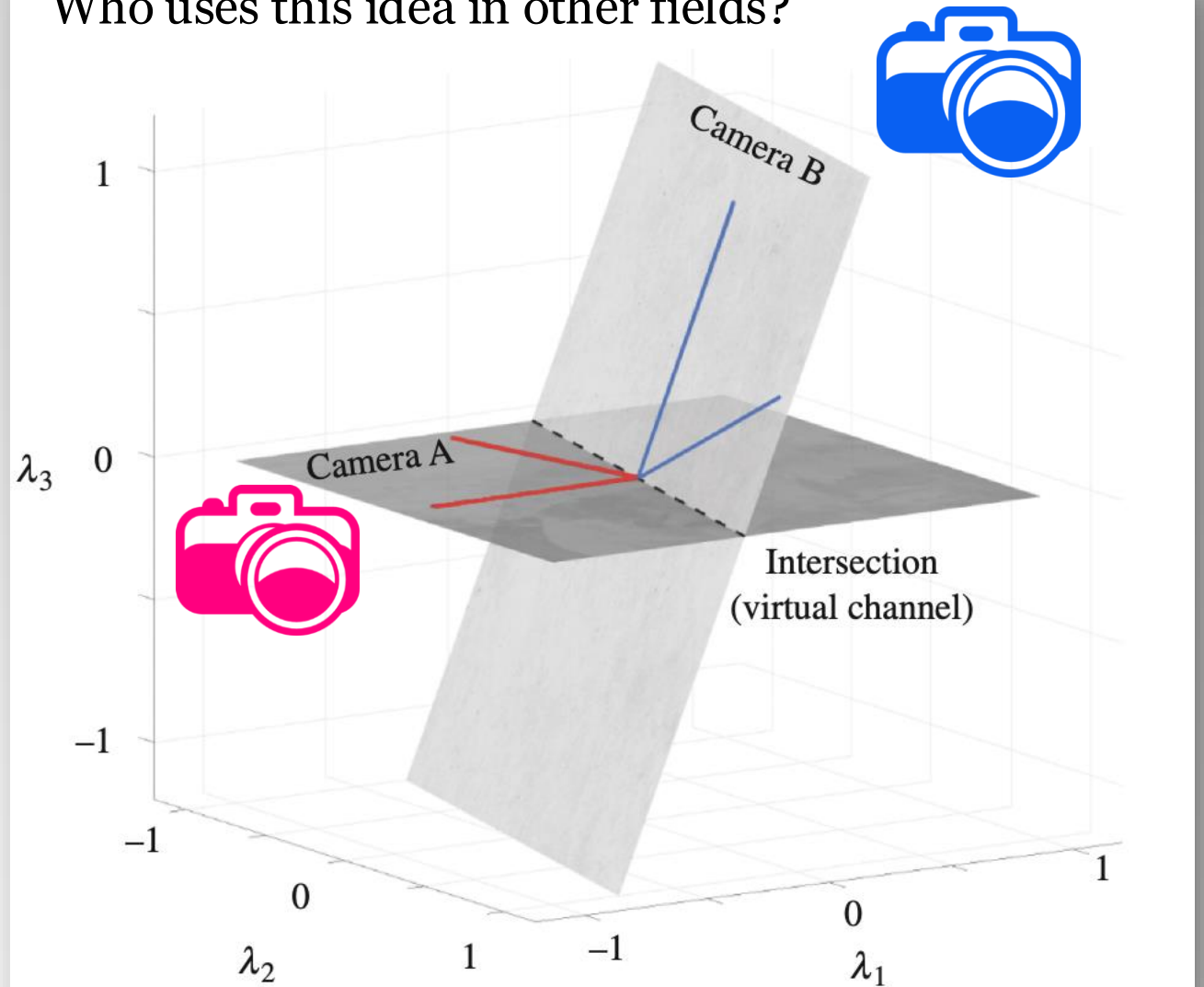
Contributors 4

- wandell Brian Wandell

The engineering application: between device comparison

- Suppose we have two cameras from different vendors
- Their color channels typically have different spectral responsivities
- Hundreds of papers try to fit each of the channels in, say, A from the channels in B
- In this example, a good fit is hopeless

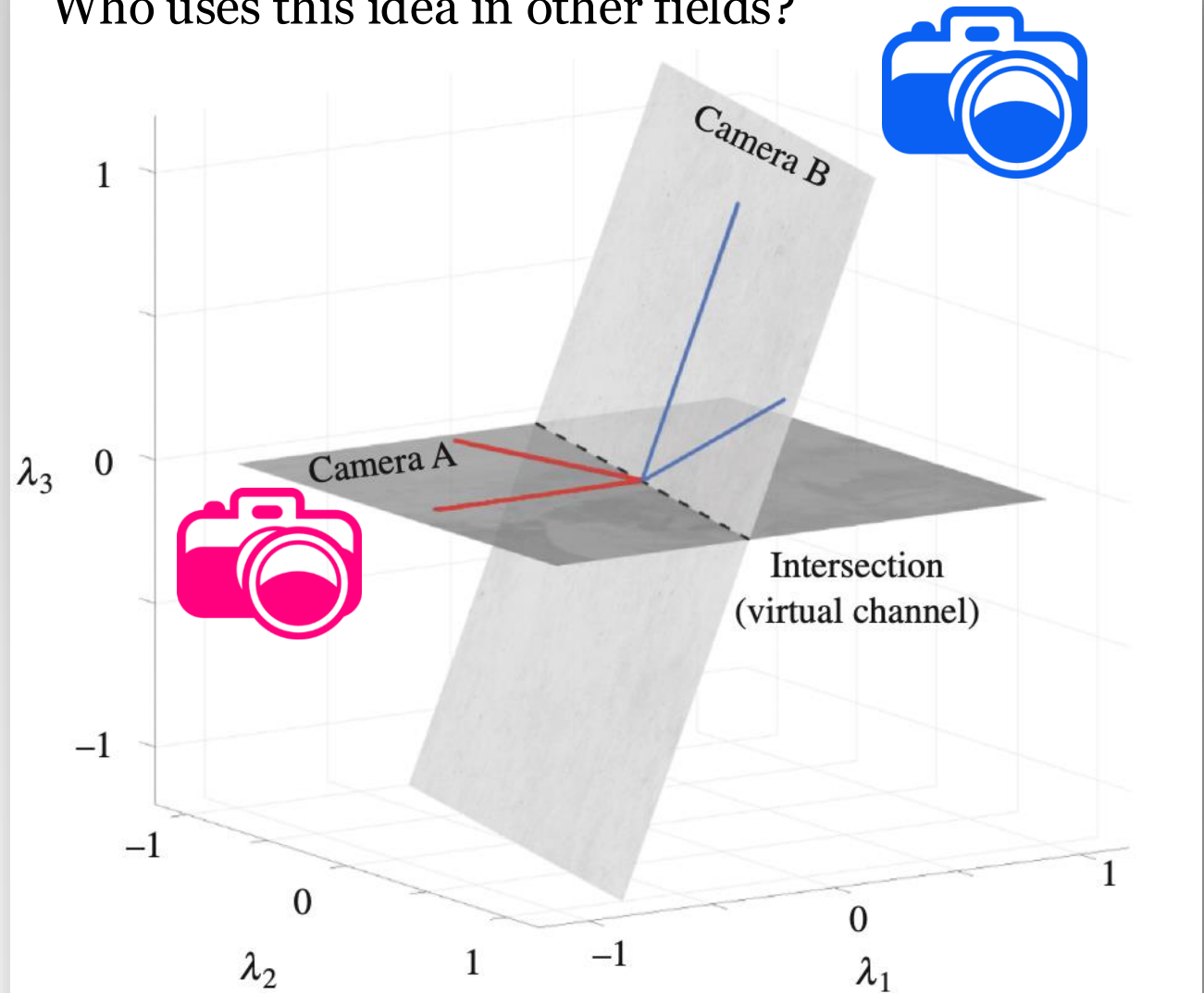
Who uses this idea in other fields?



The engineering application: between device comparison

- What is possible, however, is to find common ground between the two systems
- We can find the intersection of the spaces spanned by the two cameras (virtual channels)
- Neither camera has this channel, but both can render their data as if they did
- This will let us have the two systems check whether they are seeing the same object
- If they agree, we can combine the measurements to learn more about the object

Who uses this idea in other fields?



Thanks for the lunches and the years of collegiality

Koh Terai

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Psychology Department

EE, GSE, Ophthalmology (by courtesy)
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Stanford Center for Image Systems Engineering

