Color… part 1

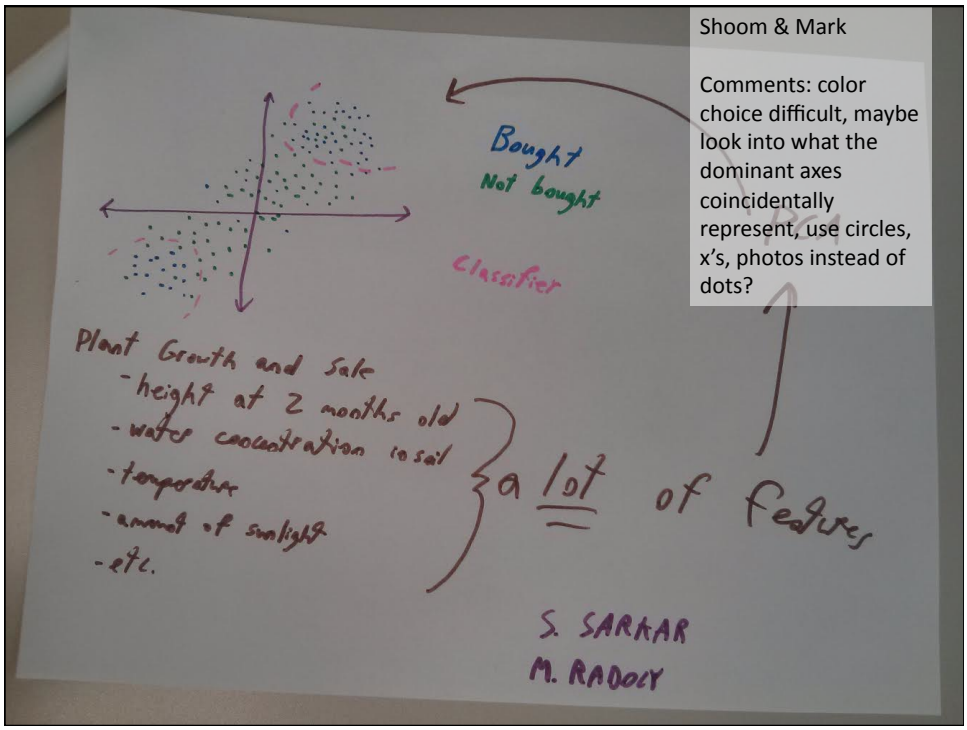
(some slides from Fredo Durand)

Today's Class

- Discussion of Friday's Crayon Exercise
- What is Color?
  - Human Perception
  - Color Blindness & Metamerism
- Color Spaces
  - LMS, RGB, XYZ, HSV, L*a*b*, ….
- Reading Choice for Friday
- Color & Projection in Spatially Augmented Reality

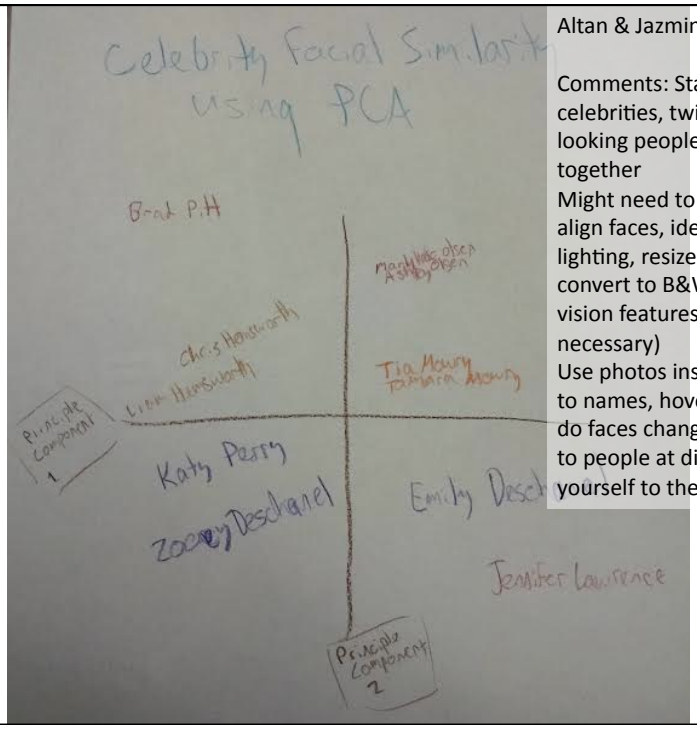
Friday's Crayon Exercise

- Brainstorm a big, high-dimensional dataset with which you are familiar
  - Either have had your hands on the data and/or think you intuitively know what patterns lurk in the data
  - It's ok if obtaining this data is not feasible… ☺
- Come up with a hypothesis about the data that can be proved (or disproven) using visualization
- Mock-up a visualization of the data as:
  - a parallel coordinates plot – OR –
  - a radar plot – OR –
  - a 2D scatter plot after automatic PCA dimensionality reduction
- Think about axes ordering, labels, color, data density, etc.



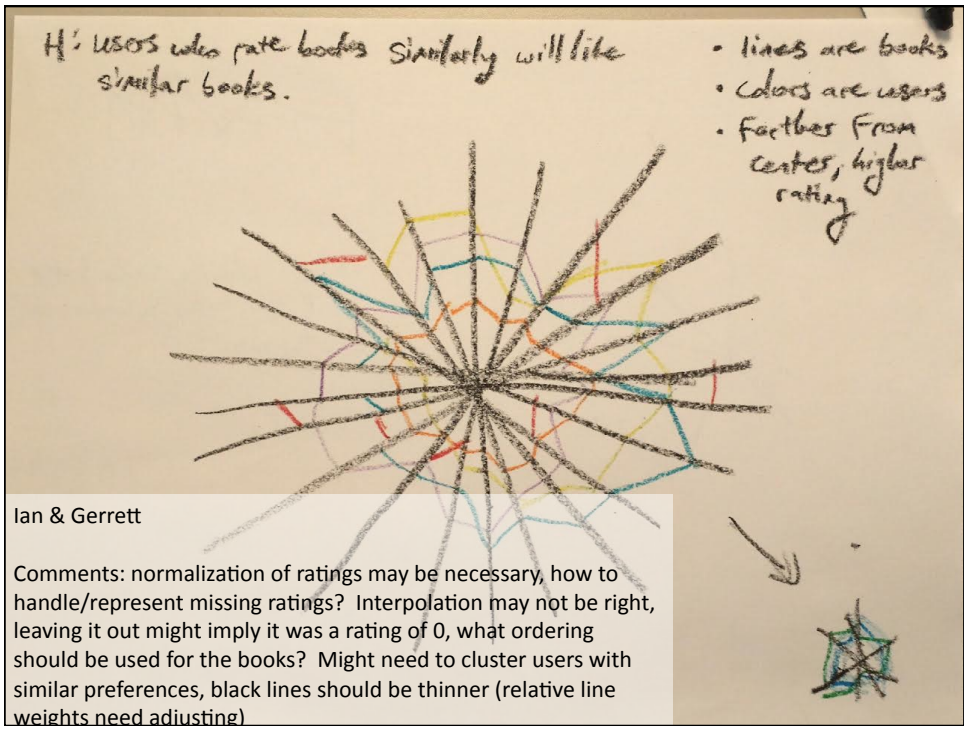
Shoom & Mark

Comments: color choice difficult, maybe look into what the dominant axes coincidentally represent, use circles, x's, photos instead of dots?



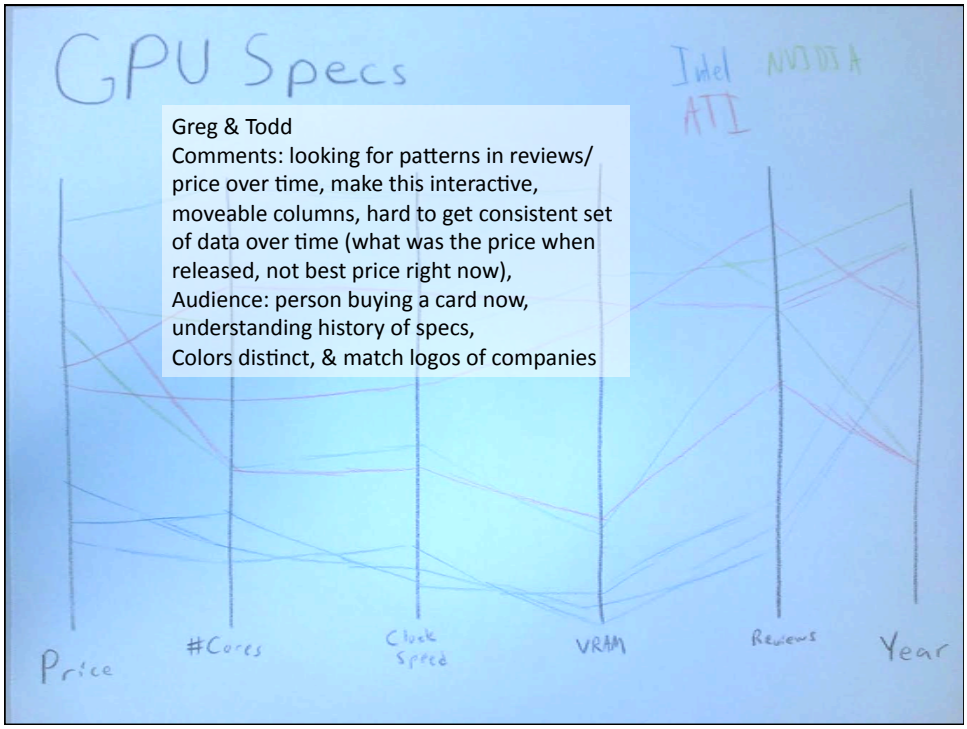
Altan & Jazmine

Comments: Start with photos of celebrities, twins and similar looking people would be close together
Might need to normalize data, align faces, ideally with similar lighting, resize to common size, convert to B&W, get computer vision features (may or may not be necessary)
Use photos instead of/in addition to names, hover to see photo, how do faces change over time, similar to people at different ages, add yourself to the celebrity collage

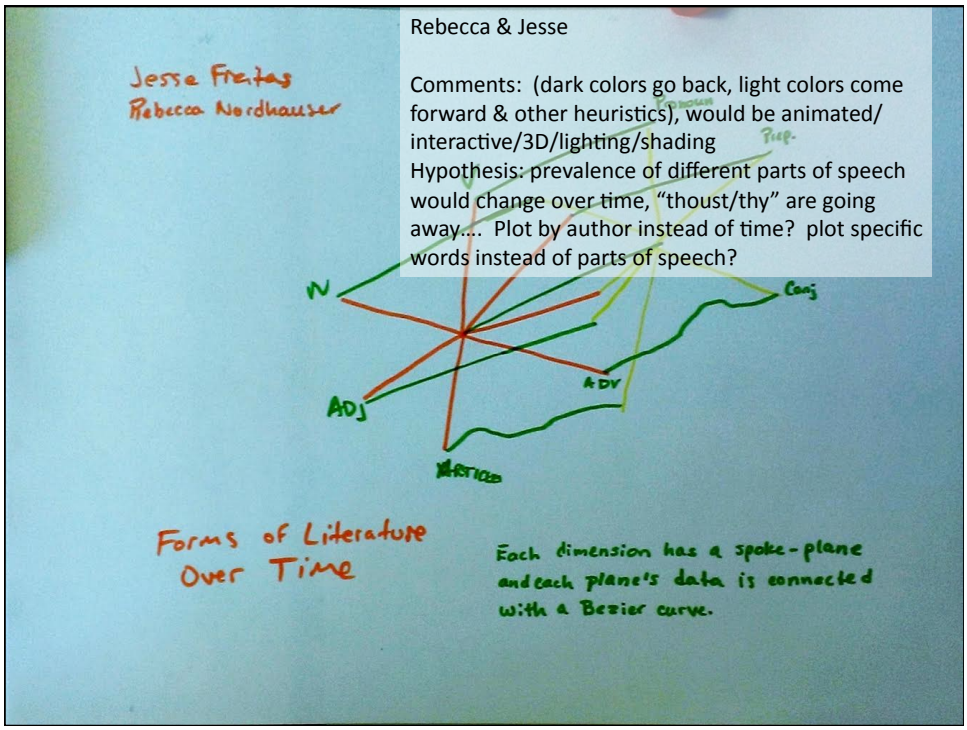


Ian & Gerrett

Comments: normalization of ratings may be necessary, how to handle/represent missing ratings? Interpolation may not be right, leaving it out might imply it was a rating of 0, what ordering should be used for the books? Might need to cluster users with similar preferences, black lines should be thinner (relative line weights need adjusting)

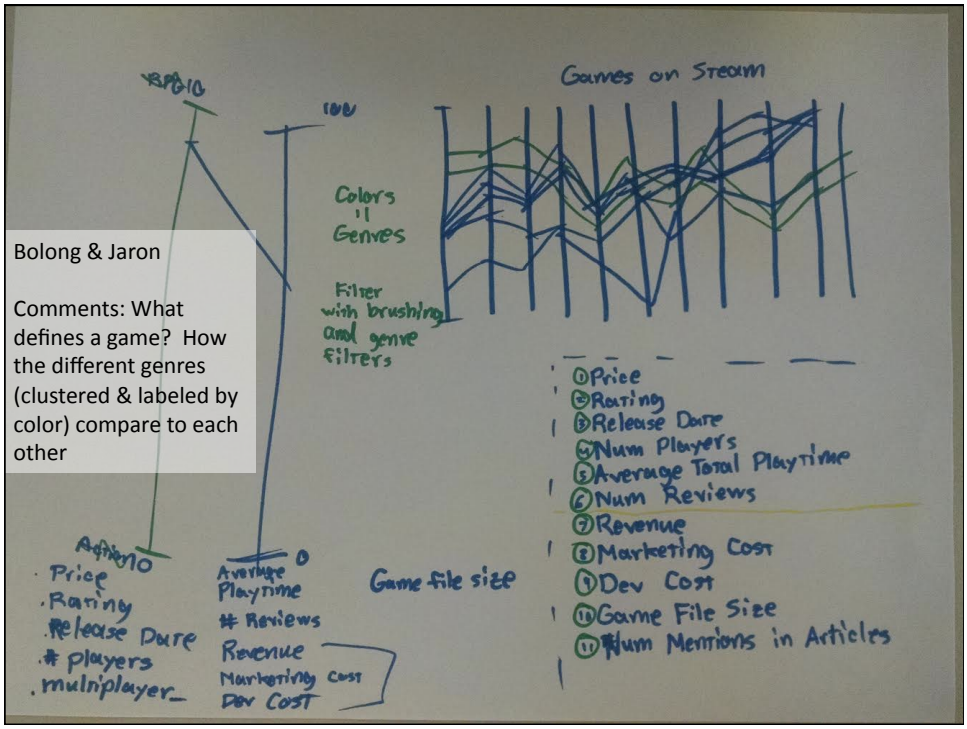


Greg & Todd
Comments: looking for patterns in reviews/ price over time, make this interactive, moveable columns, hard to get consistent set of data over time (what was the price when released, not best price right now),
Audience: person buying a card now, understanding history of specs,
Colors distinct, & match logos of companies



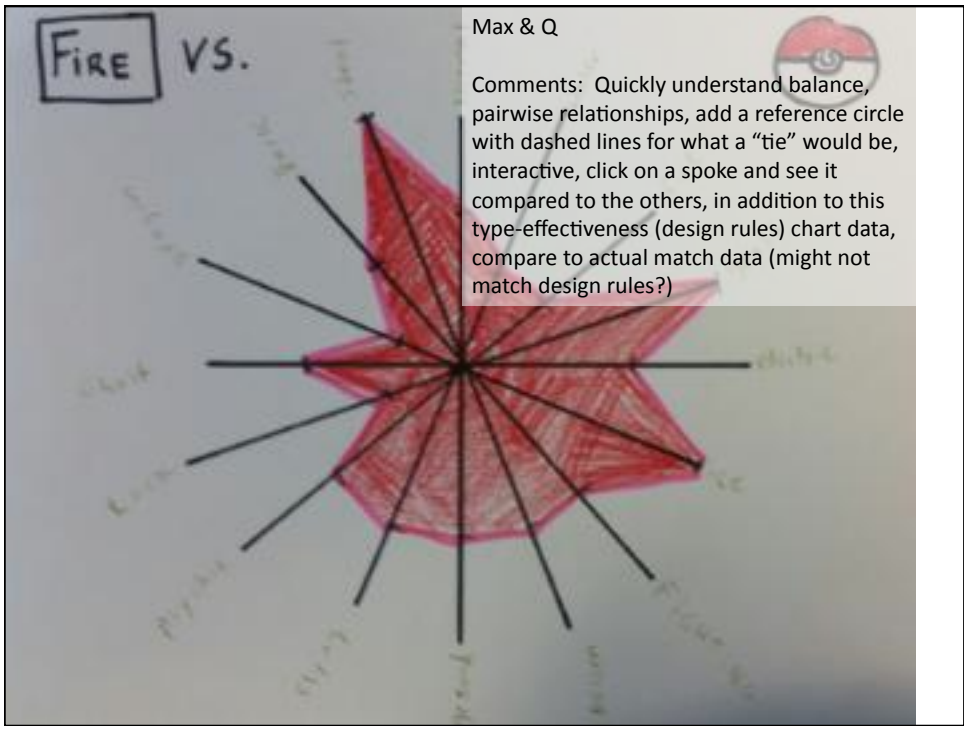
Rebecca & Jesse

Comments: (dark colors go back, light colors come forward & other heuristics), would be animated/ interactive/3D/lighting/shading
Hypothesis: prevalence of different parts of speech would change over time, "thoust/thy" are going away.... Plot by author instead of time? plot specific words instead of parts of speech?



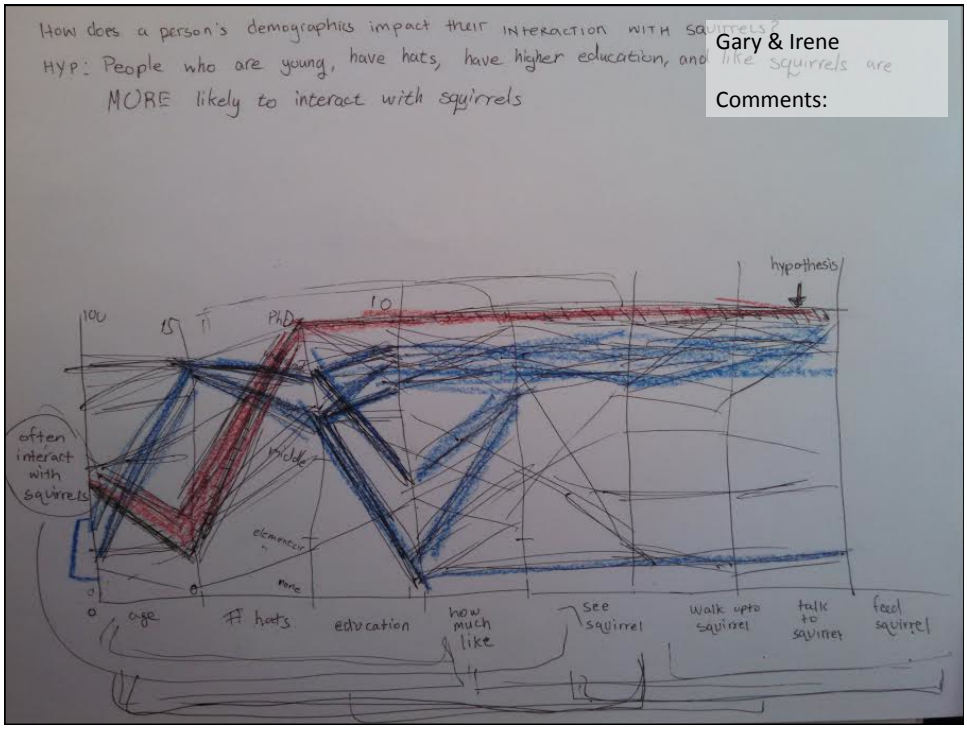
Bolong & Jaron

Comments: What defines a game? How the different genres (clustered & labeled by color) compare to each other



Max & Q

Comments: Quickly understand balance, pairwise relationships, add a reference circle with dashed lines for what a "tie" would be, interactive, click on a spoke and see it compared to the others, in addition to this type-effectiveness (design rules) chart data, compare to actual match data (might not match design rules?)



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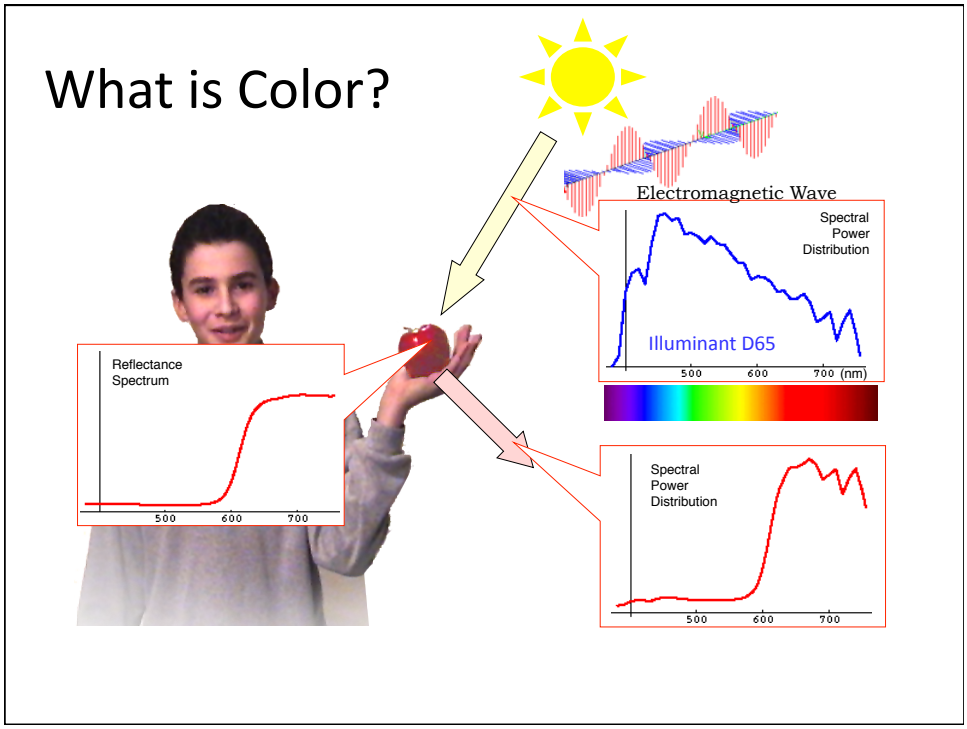
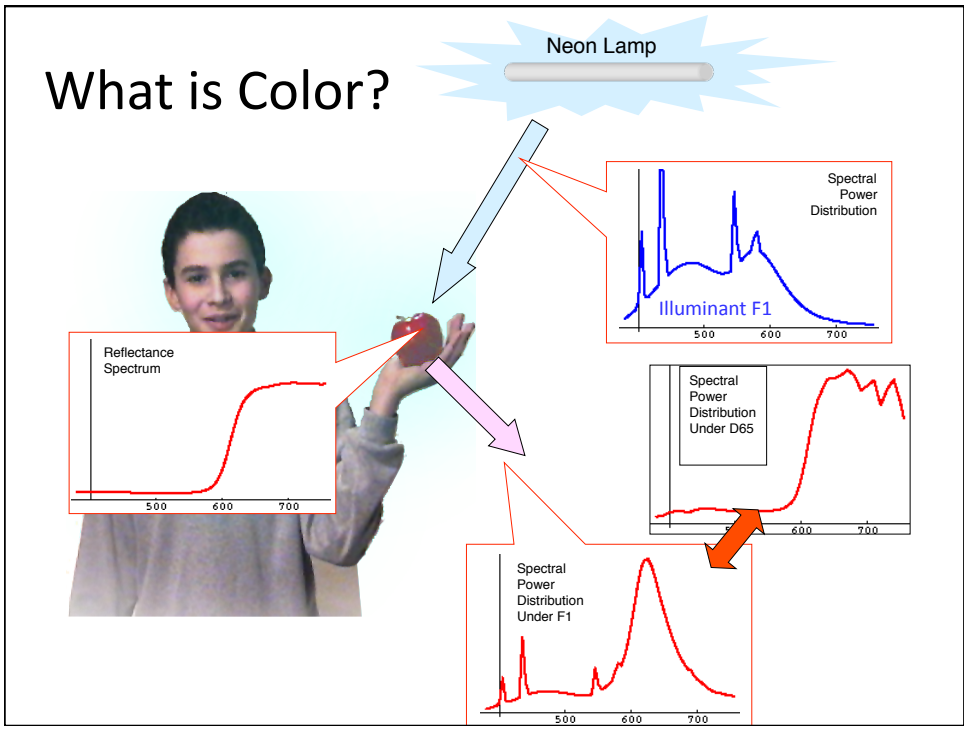
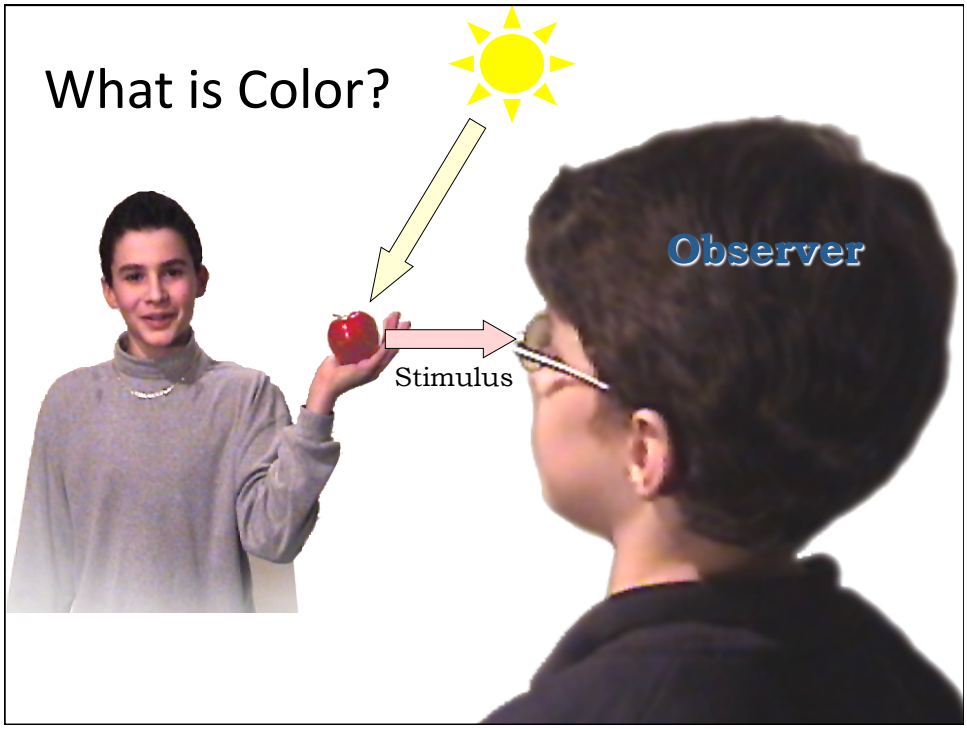
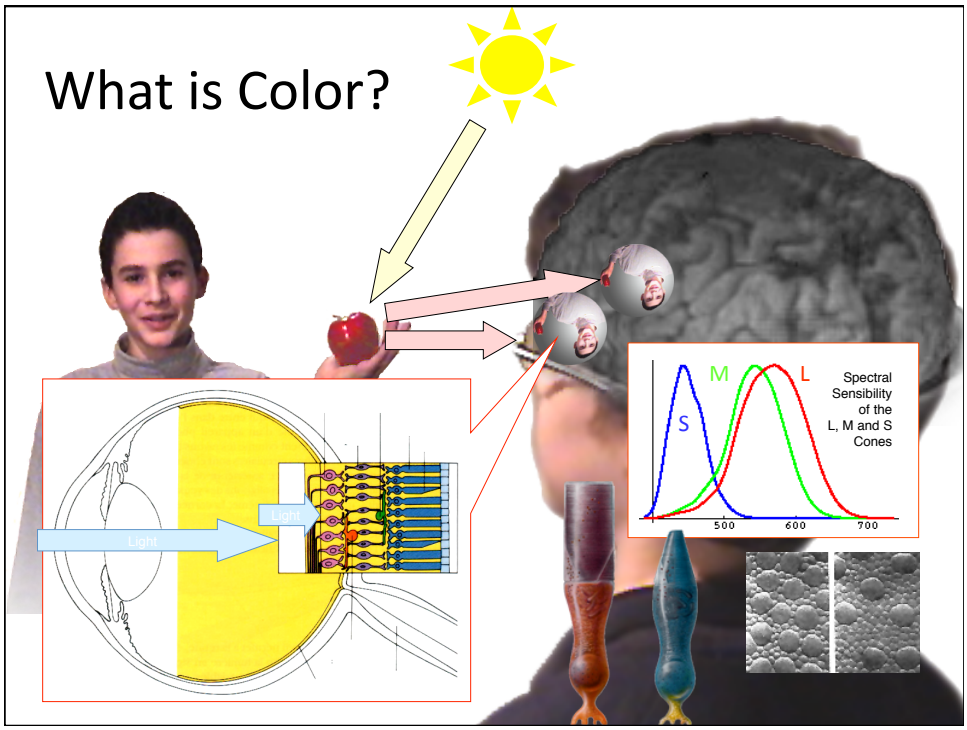
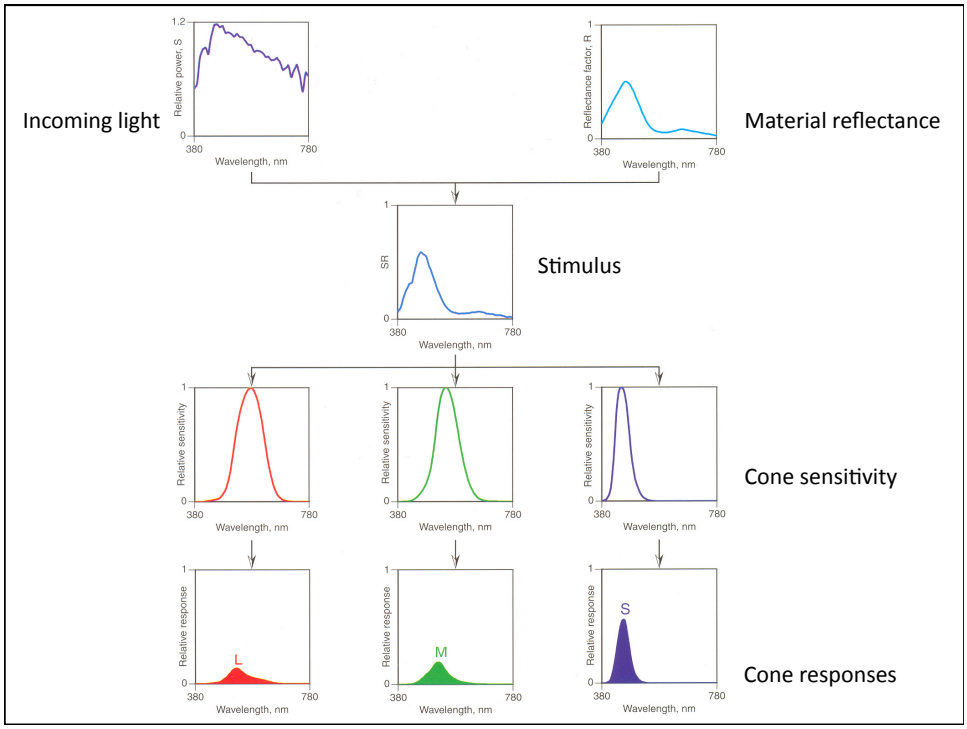

What is Color?
Electromagnetic Wave
Spectral
Power
Distribution
Illuminant D65
500
600
700 (nm)
Reflectance
Spectrum
500
600
700
Spectral
Power
Distribution
500
600
700


What is Color?
Neon Lamp
Spectral
Power
Distribution
Illuminant F1
500
600
700
Reflectance
Spectrum
500
600
700
Spectral
Power
Distribution
Under D65
600
700
Spectral
Power
Distribution
Under F1
500
600
700

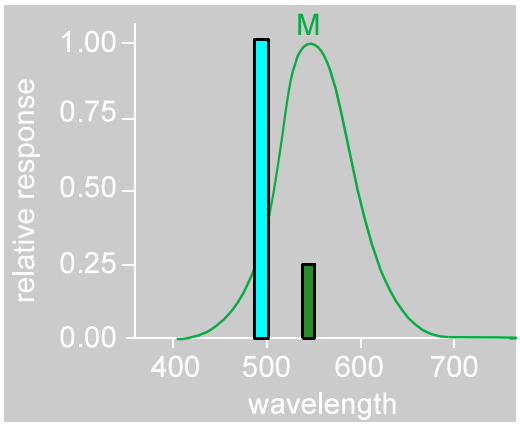

What is Color?
Observer
Stimulus


What is Color?
Light
Lens
M
L
S
Spectral Sensibility of the L, M and S Cones
500
600
700



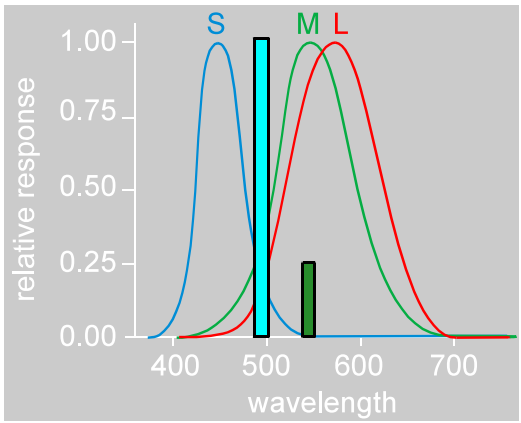
Cones do not "see" colors

- Different wavelength, different intensity
- Same response to a single cone



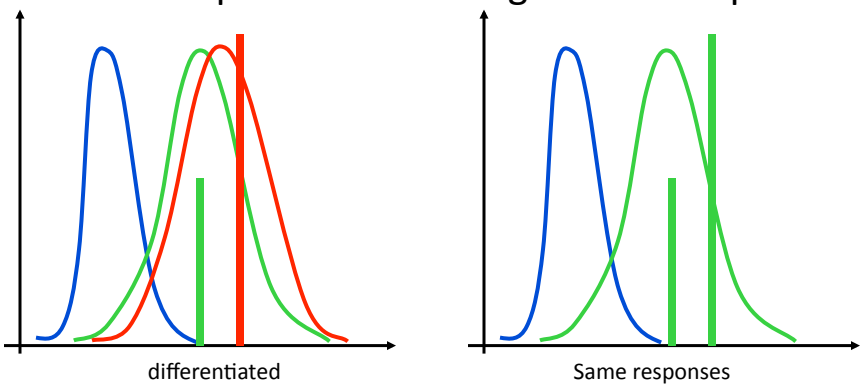
Response Comparison

- Different wavelength, different intensity
- But different response for different cones

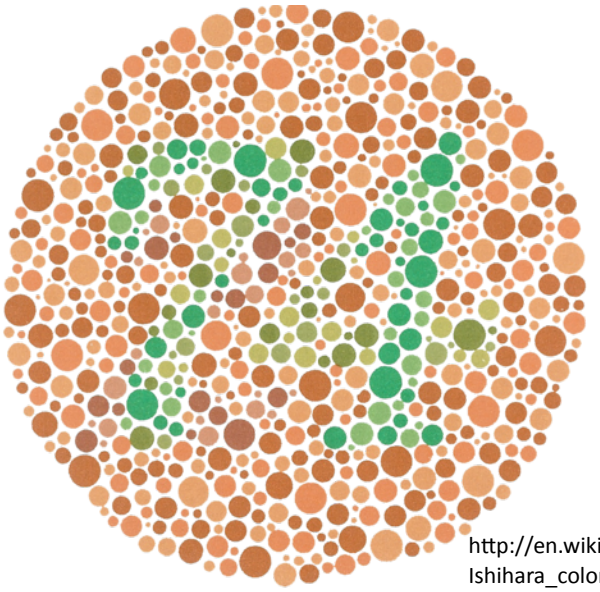


Color Blindness

- Classical case: 1 type of cone is missing (e.g. red)
- Now Project onto lower-dim space (2D)
- Makes it impossible to distinguish some spectra

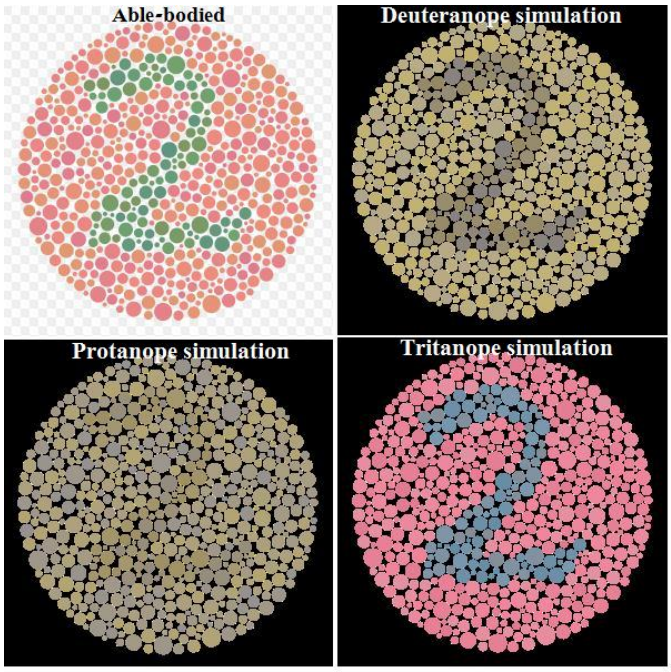


Ishihara Color Blindness Test



http://en.wikipedia.org/wiki/Ishihara_color_test

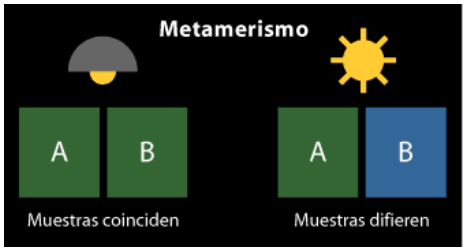
- Deuteranopia: missing green cone
- Protanopia: missing red cone
- Tritanopa: missing blue cone (rare)



http://en.wikipedia.org/wiki/File:Ishihara_compare_1.jpg

Metamerism: Apparent Matching

- When two materials look the same under one lighting condition (a coincidence), but look different under another:



http://gusgsm.com/metamerismo

- Remember that different spectral distribution of input light yield different visual stimuli
- We all experience some color blindness

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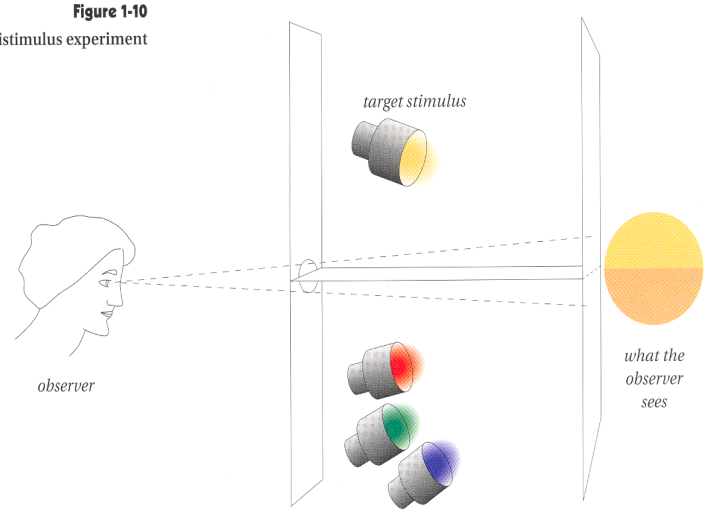
Standard Color Spaces

- Colorimetry: Science of color measurement
- Quantitative measurements of colors are crucial in many industries
  - Television, computers, print, paint, luminaires
- Naive digital work uses a vague notion of RGB
  - Unfortunately, RGB is not precisely defined, and depending on your monitor, you might get something different
- We need a principled color space…

CIE Color Matching Experiments

Figure 1-10
Tristimulus experiment



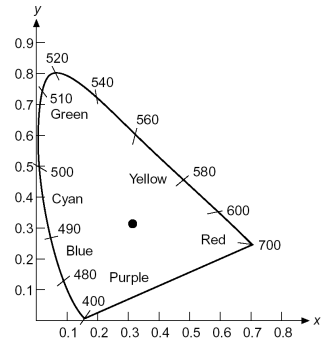
The observer adjusts the intensities of the red, green, and blue lamps until they match the target stimulus on the split screen.

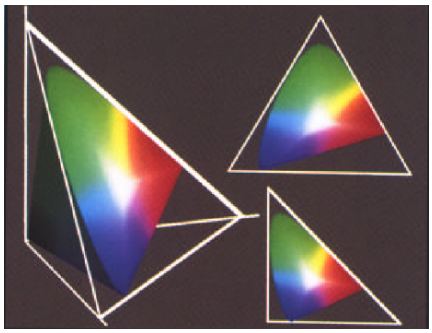
CIE XYZ Color Space

- Can think of X, Y , Z as coordinates
- Linear transform from typical LMS or RGB
- Note that many points in XYZ do not correspond to visible colors!

$$\begin{pmatrix} R \\ G \\ B \end{pmatrix} = \begin{pmatrix} 3.24 & -1.54 & -0.50 \\ -0.97 & 1.88 & 0.04 \\ 0.06 & -0.20 & 1.06 \end{pmatrix} \begin{pmatrix} X \\ Y \\ Z \end{pmatrix}$$

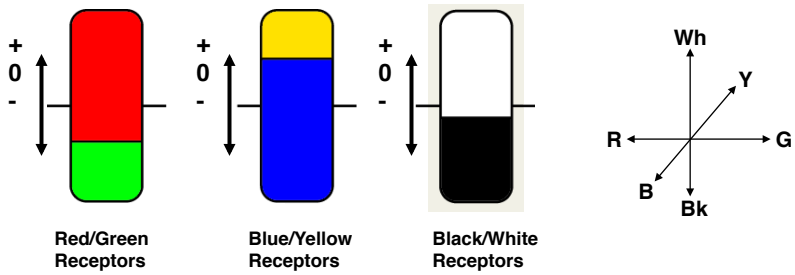
$$\begin{pmatrix} X \\ Y \\ Z \end{pmatrix} = \begin{pmatrix} 0.41 & 0.36 & 0.18 \\ 0.21 & 0.72 & 0.07 \\ 0.02 & 0.12 & 0.95 \end{pmatrix} \begin{pmatrix} R \\ G \\ B \end{pmatrix}$$





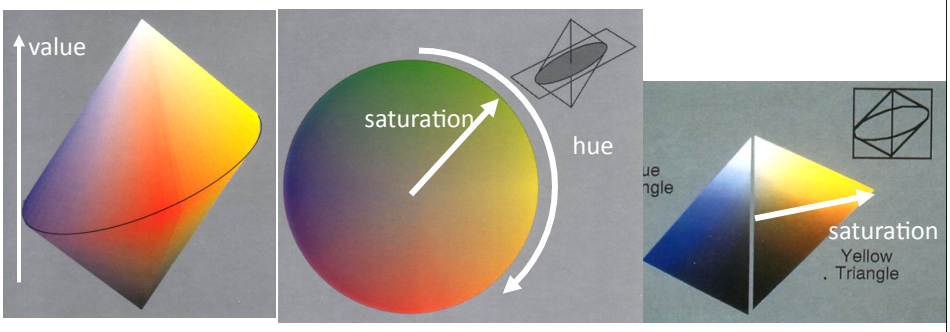
Hering 1874: Opponent Colors

- Hypothesis of 3 types of receptors: Red/Green, Blue/Yellow, Black/White
- Explains well several visual phenomena



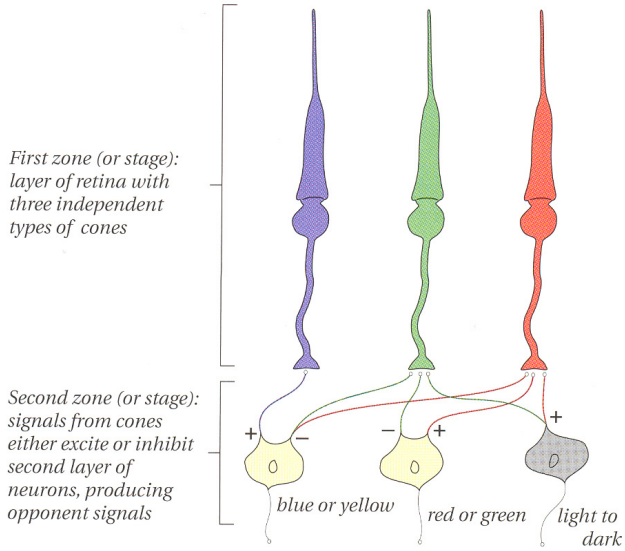
Hue Saturation Value (HSV)

- Value: from black to white
- Hue: dominant color (red, orange, etc)
- Saturation: from gray to vivid color



Color Opponents "Wiring"

- Sums for brightness
- Differences for color opponents
- It's just a 3x3 matrix to convert HSV from/to LMS, RGB, or XYZ



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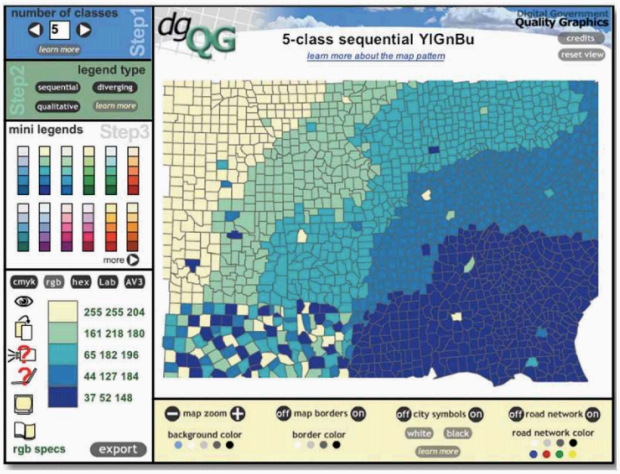
- Reading Choice for Friday
  - & 3-5 volunteers for mini-presentations
  - Jesse, Greg, Courtney, Q, Jorel
- Color & Projection in Spatially Augmented Reality

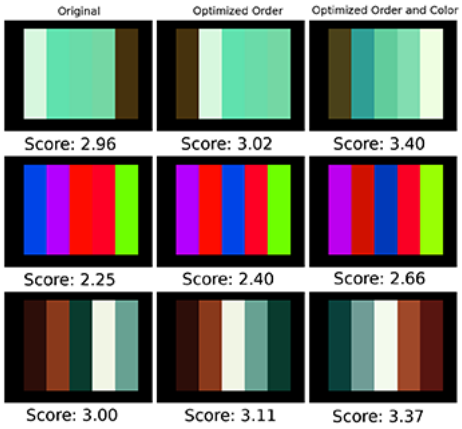
Reading for Friday: *choose one*

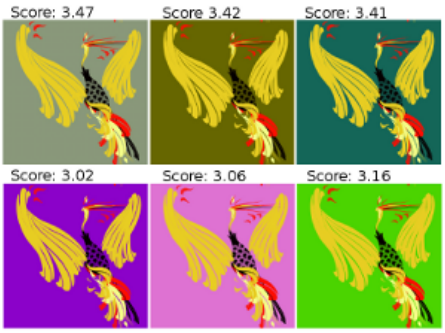
- "ColorBrewer.org: An Online Tool for Selecting Colour Schemes for Maps", Harrower & Brewer, The Cartographic Journal



Reading for Friday: *choose one*

- "Color Compatibility From Large Datasets", O'Donovan, Agarwala, & Hertzmann, SIGGRAPH





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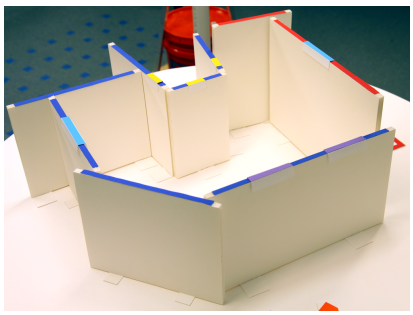
Spatially Augmented Reality (SAR) Projection

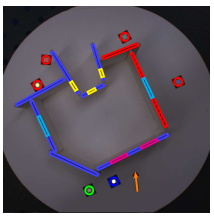
Tangible Interface for Architectural Design



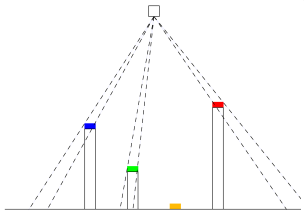
Exterior & interior walls

Tokens for:

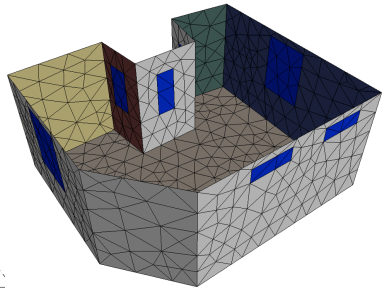
- *Windows*
- *Wall/floor colors*
- *North arrow*



Overhead camera

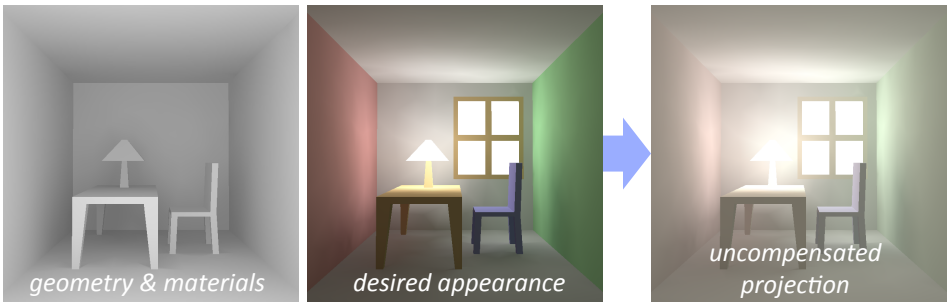


Projection geometry



Inferred design

Motivation:



Can we do a better job reproducing the desired appearance?

Related Work: Radiometric Compensation

- Minimize artifacts caused by light modulation with local surface [Bimber et al. 2005; Nayar et al. 2003; Grundhöffer & Bimber 2008]
- Does not consider global light inter-reflection

Grundhöffer & Bimber 2008

Our Problem Statement

- Known scene geometry
- Known surface reflectances, *all ideal diffuse*
- Fixed, calibrated projectors
- Given:

  Desired target surface appearance (texture) for each physical surface
- Solve for:

  Projection texture for each physical surface that most faithfully reproduces the desired appearance

Related Work: Reverse Radiosity

- Forward lighting with radiosity

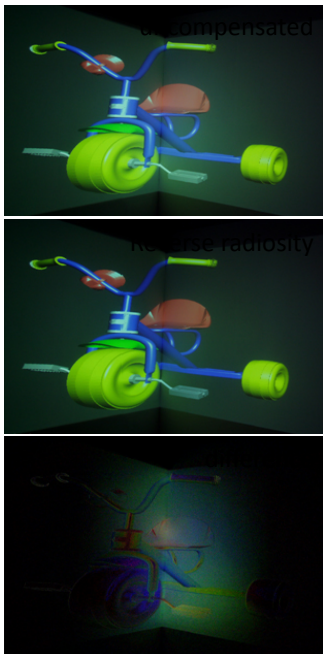
$$B = (I - F)^{-1} E$$

values for rendering — *form factor matrix* — *direct light*

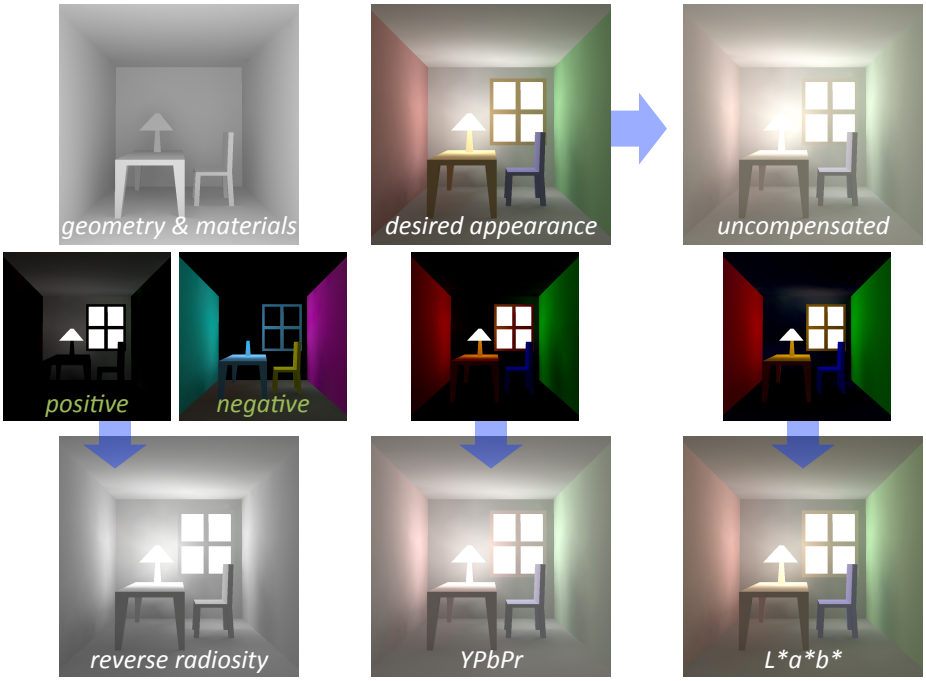
- Inverse lighting with radiosity: Reverse Radiosity (RR)
  - [Bimber et al. 2006]

$$E = (I - F) B$$

projection values — *desired appearance*



Bimber et al. 2006

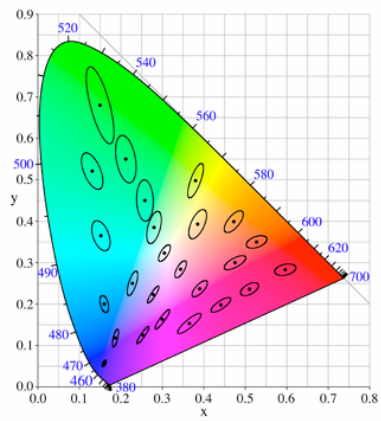


Sheng et al. 2010 — *Our new method*

Linear Color Spaces: RGB/XYZ/YPbPr

- Equal steps in linear color spaces do not correspond to equal differences for human perception
- MacAdam ellipses visualize the lack of perceptual uniformity [MacAdam 1942]

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} 0.4124 & 0.3576 & 0.1805 \\ 0.2126 & 0.7152 & 0.0722 \\ 0.0193 & 0.1192 & 0.9505 \end{bmatrix} \begin{bmatrix} R_{\text{linear}} \\ G_{\text{linear}} \\ B_{\text{linear}} \end{bmatrix}$$



http://en.wikipedia.org/wiki/File:CIExy1931_MacAdam.png

L*a*b*: a perceptual color space

Designed to match human color perception data

$$\begin{array}{r} \textit{intensity} \\ \textit{red-green} \\ \textit{yellow-blue} \end{array} \begin{bmatrix} L \\ a \\ b \end{bmatrix} = \begin{bmatrix} 116h(\frac{Y}{Y_n}) - 16 \\ 500\left(h(\frac{X}{X_n}) - h(\frac{Y}{Y_n})\right) \\ 200\left(h(\frac{Y}{Y_n}) - h(\frac{Z}{Z_n})\right) \end{bmatrix}$$

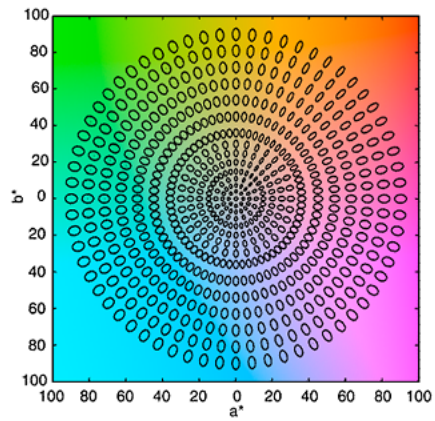
$$h(t) = \begin{cases} t^{\frac{1}{3}} & t > (6/29)^3 \\ \frac{1}{3}(\frac{29}{6})^2 t + \frac{4}{29} & \text{Otherwise} \end{cases}$$

L*a*b* is nonlinear, a challenge for optimization

Quantitative Perceptual Comparison

- $\Delta E = \sqrt{(L_1 - L_2)^2 + (a_1 - a_2)^2 + (b_1 - b_2)^2}$

- Where 2.3 ΔE = JND (just noticeable difference)
- The MacAdams ellipses are more equal size circles in L*a*b*



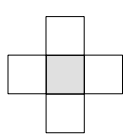
http://w3.kcua.ac.jp/~fujiwara/infosci/ellipses_lab.png

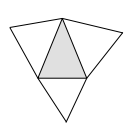
Our Optimization Formulation

desired appearance *projection result*

Absolute Error: $$\phi_{abs} = \frac{\sum_i A_i[(L_i - L_i')^2 + (a_i - a_i')^2 + (b_i - b_i')^2]}{A_{avg}}$$

Spatial Error: $$\phi_{spt} = \sum_{(i,j)\in nbd} [(L_i - L_j) - (L_i' - L_j')]^2 + [(a_i - a_j) - (a_i' - a_j')]^2 + [(b_i - b_j) - (b_i' - b_j')]^2$$





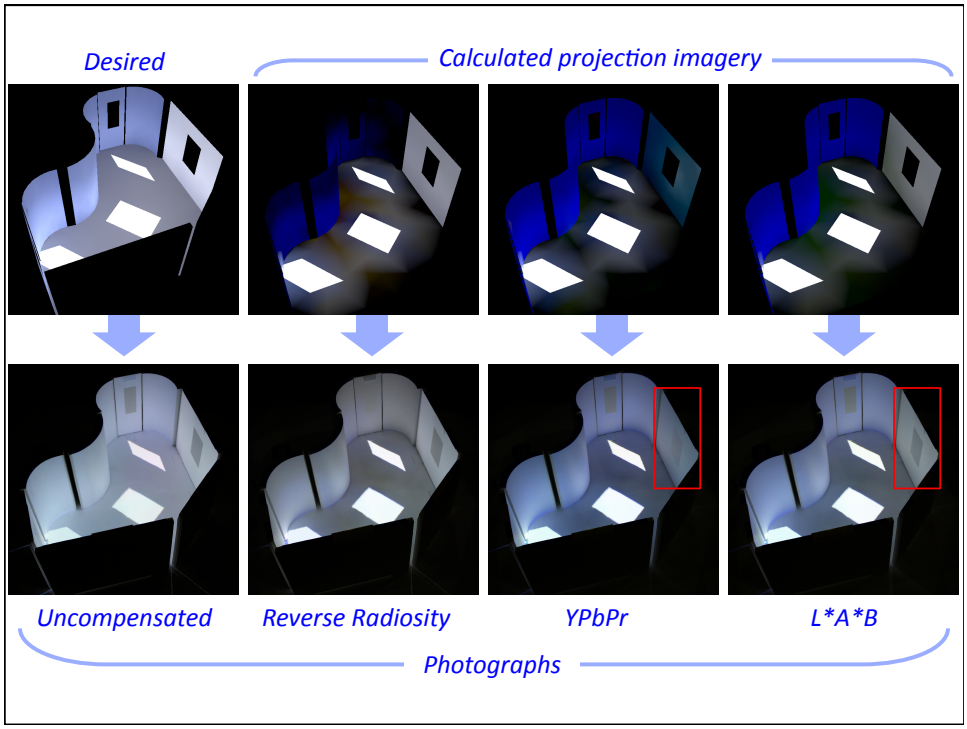
gradient in desired appearance *gradient in projection result*

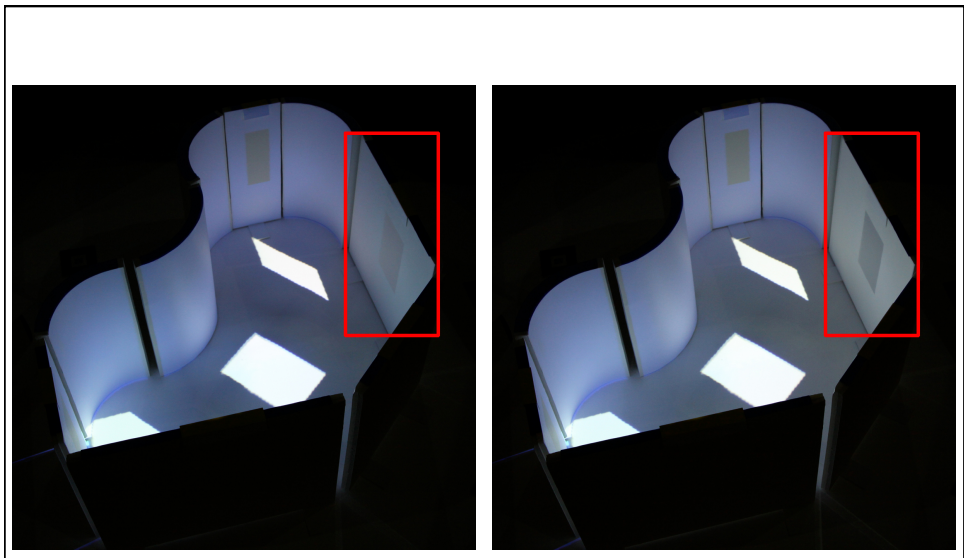
Complete Objective Function: $\phi = \alpha\phi_{abs} + (1-\alpha)\phi_{spt}$

We use α = 0.9

Box constraints:

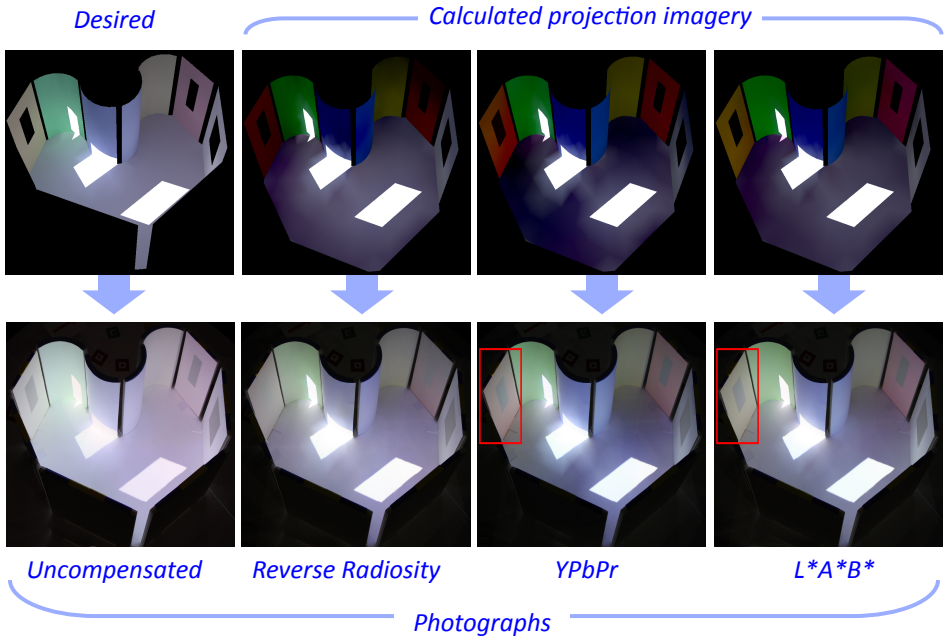
minimum & maximum brightness of projector system

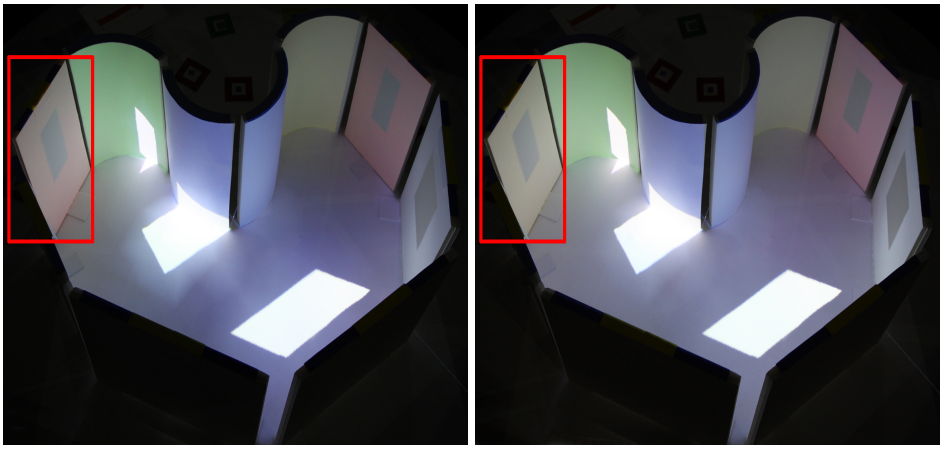




Sheng et al. 2010
Optimized in YPbPr space

New method
Optimized in L*A*B space





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New method
*Optimized in L*A*B space*

"Perceptual Global Illumination Cancellation in Complex Projection Environments"
Yu Sheng, Barbara Cutler, Chao Chen, and Joshua Nasman
Eurographics Symposium on Rendering (EGSR), June 2011.