A Stochastic Model of Color

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Abstract

Color classification relies heavily on a biological actor’s perceptible environment. To counteract this, we construct an industrial chromatography apparatus as an objective observer. Through analysis, we uncover an emergent scientific model of color.

1 Scientific Models of Color

This research arises from color naming in the field of relative linguistics. Here, we note the emergence of obstructions to our western model of color by studying color naming across languages.

Traditionally, samples from the Munsell color system based on minimal perceptible difference to the human eye are presented and the difficulty to provide a name (as in [6]) or number of linguistic categories is measured.

In certain cases such as the Native American Zuni language, we encounter multiple words for a single color as noted in [8] and referenced in [10, 335]. Here, we can first note the lack of a universal understanding/identification of how to distinguish colors in language. Lucy later notes Conklin’s encounter the Philippine Hanunoo language in which he discovers the lack of a term for color itself, needing to perform his analysis by prompting for adjectives in general. [3] This counters our assumptions that the Western color identification is universal.

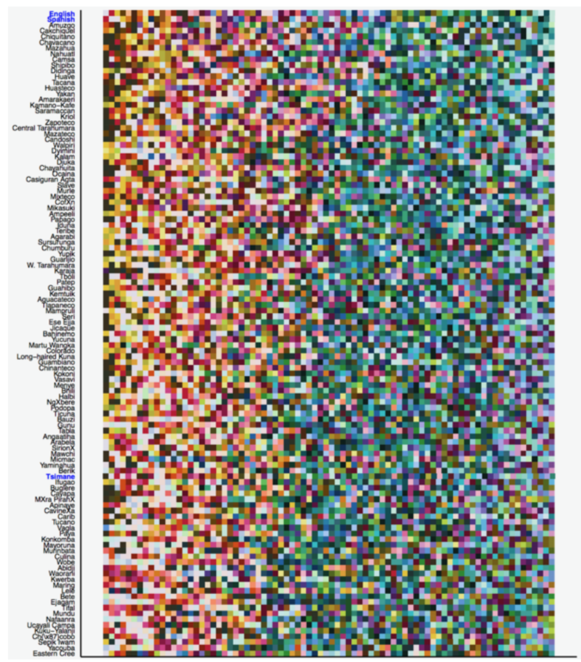

Figure 1: Distribution of most identifiable Munsell colors by language from [6]

The general trend in more readily naming warm colors results in a prominent theory in which color naming is more developed for important or rare foreground colors as discussed in [6, 10788] for cultures with cool background colors. In agreement with this theory languages such as that of the Himbas in the Namibian desert have developed substantially many names for greens relative to other languages due to a primarily warm background. [12]

Historically, these studies had revealed consistent systems of naming even in similarly remote communities which Lucy counters using a primitivist argument in which the researchers’ western bias in presentation enters. [10, 334-337] In another context, we may consider this universalist system as a Kuhnian [9] scientific model. Here, the western color paradigm is assumed to be universal and analogies are demanded to explain these anomalies.

In order to explore this system, we may construct an analogous model to generate emergent color properties. In researching color, a traditional chemistry classroom experiment may involve paper chromatography of food-safe dyes. In this process, a solvent front migrates along a column dragging each *pigment* at a rate based in its relative size and polarity. The resultant ratio in distance among the furthest point of each *pigment* and the solvent front reveals an emergent measurement consistent given a solvent concentration and column geometry. [5] The same process has many industrial applications such as chemical separation and cheese art.

Our goal, then, is to construct a similar experimental apparatus which consistently resolves a relative emergent property of *pigments* while also emulating the act of perception. Color perception as viewed by physiological models lies in finely tuned contrast sensitivity transfer functions of relative fluctuations in wavelength intensity. In developing these models, the major complications lie in adaptive phenomena including

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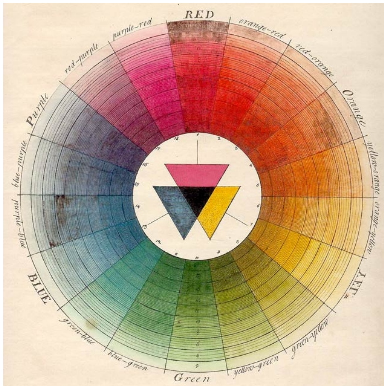


(a) The western primary-secondary-tertiary or "Wheel" system. [7]

(b) Dieter Roth, *Cheese Race* (1970) - chromatography applied to the cheese wheel

local and global dependence of these responses on environmental conditions seen directly in modeling [4] or indirectly as in Albers' pure experimentation. [1]

Lastly, we mention the quantum mechanical model of color where the energy of photons is restricted to the difference in eigenvalues of the Schrodinger equation for a given arrangement of atoms [usually approximated by perturbations as in molecular orbital theory]

$$\left(-\frac{\hbar^2}{2\mu}\nabla^2 - \sum_{i\neq j}\frac{ke^2}{r_i - r_j} + \sum_{ij}\frac{ke^2}{r_i - R_j}\right)\psi = E\psi$$

and the statistical mechanical model of blackbody radiation which utilizes a canonical ensemble of thermal fluctuations to provide a distribution of frequencies

$$\rho(\omega) = \frac{1}{V}\frac{\partial}{\partial\beta}\frac{dN}{d\omega}\ln\left(\sum_{n=0}^{\infty}\exp\left(-n\beta\hbar\omega\right)\right)$$

As we seek a qualitative description, these models provide only an inspiration for the stochastic nature of this work.

2 The Cybernetic System

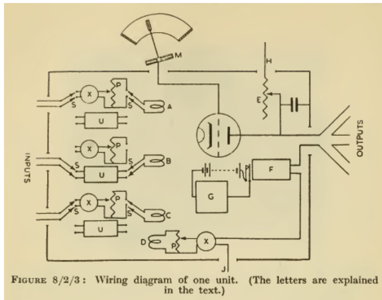
2.1 Concept

To provide a system both consistent in behavior and conscious to the act of perception, we hope to employ a robotic device which performs as the result of a biological actor - a role fulfilled by cybernetics.

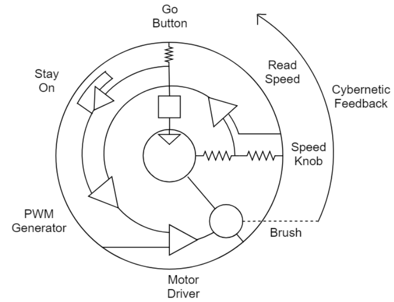
Historically, the emergent property of cybernetic systems has been adaptation on the part of the biological actor. For example, the 60s British cybernetic response by Stafford Beer to future automation relied in the need for adaptation in the autonomous ideal factory. Otherwise, systems such as external market pressures would cause such a factory to fail. Thus adaptation, specifically from a biological actor is necessary as seen in further foundational pieces by Gordon Pask.[11, 474-477] Attempts to emulate adaptation without the need for biological actors resulted in systems of positive and negative feedback loops. Ultimately, these culminate in Ashby's self-modifying control systems which reconfigure in response to unexpected/excessive inputs. [11, 473]

In the above paper, Pickering sees this emulation as a diversion from the biological foundations of adaptive systems. For our purposes, we will step back and leave the role of cybernetic feedback to the artist engaging with our mostly self-contained apparatus.

We will start by allowing the system to propel *pigment* in the stochastic process of splatter painting. By transitivity of control, we maintain the hand of the artist in the work via control inputs and mechanical



(c) W. Ross Ashby, *Homeostat* (1948) - in [2]



(d) Conceptual diagram for *Splatterbot*

staging of the brush and *pigment*. With the other hand, the artist begins to record the resulting distribution. Using biological feedback, the artist adjusts the staging until a consistent distribution is achieved for a given color - retraining the machine after each *pigment* to change to maintain consistent speed, angle, wetness, and orientation.

2.2 Palletization

The process of palletization is an essential warehouse (artistic) activity in which raw materials (*pigments*/mechanisms) are organized into a palette (palette/base) for internal distribution. We attempt this by gathering solid/liquid *pigment* and constructing a mechanical chromatographer.

Experimentation began using a cheap solid watercolor palette for testing as acrylics were difficult to splatter given the brush size demanded by the need to measure the distribution.

To achieve a splattering effect, a brush must gain momentum then stop propelling paint by inertia. To achieve a unique stochastic distribution for each *pigment*, we must control for a number of variables which influence the design. First, a servo motor provides granular control of angle and speed accurate relative to the motion of the *pigment* along with constraining motion to a plane. We intersect this plane with a screw to stop the motion abruptly. The rest of the apparatus was chosen for structural stability (preventing motion during the throw). A trough was later added to increase flow towards the brush and to facilitate one-pass cleaning.

For control, the servo motor is tied to an Arduino with a speed control knob and Go button. Upon pressing Go, the the speed setting is read then mapped to an empirical range which ensures splatterability. The brush is led 5 cycles against the trough to saturate then propelled 15 times to an empirical angle then back to the defined stroke starting point (15 was found to mostly desaturate the brush). This program was written in 15 minutes 2 months ago on another person's computer.

For maintaining records of the distribution, relatively thick 17"x25" paper is used with measurements of radial distance from the machine denoted either before or after splattering. For later experimentation, Michaels^{TM} Artist's Loft^{TM} Fundamentals^{TM} Watercolor Paint tubes were used mixed in a 1 to 3 then later 1 to 6 ratio with water.

Figure 2: *S*platterbot I

During experimentation, we configured the apparatus for reliability. Upon each initialization, the brush began within a 10 degree offset. The artist reset the position by reinstalling the brush holder. At other points, the stopping impulse of the screw caused the brush to slide out of the holder. This is apparent as splotches in figure 9. Often, the brush would continue to slide against the trough until halting the servo. In these instances, the artist re-secured the brush in its original position. Our remaining difficulty remained securing the angular distribution of the brush in the holder as it remains stiffly asymmetric causing a directional bias in the distribution. The cost of a brush impeded constant replacement.

3 Results

3.1 Depalletization

The process of depalletization is an essential warehouse (artistic) activity in which intermediate materials (sets of *pigments*) are separated from a palette (palette) for internal distribution. We attempt this by separating individual *pigments* for analysis.

For the original palette, the lack of resolution beyond 6in of data as seen in Figure 3 prevented any thorough comparison between runs. Peaks at 1,2,and 3 inches may allow a system of discrimination of brown, pink, and red based purely on their distributions. This system allows for unambiguous definition of color within the palette. Sadly, long distance interference could not be predicted from these models. From this data, though, we can utilize the central limit theorem to produce a Gaussian generator of these diagrams based on the mean and standard deviation.

$$p(r) = \frac{1}{\sqrt{2\pi(< r^2 > - < r >^2)}} \exp\left(\frac{-(r- < r >)^2}{2 < r^2 > - < r >^2}\right) \tag{CLT}$$

The promising results of this modeling for 3 *pigments* can be found in Figure 8. By qualitative comparison to real data, this cybernetic system appears to be easily mimicked in the large N limit.

3.2 Repalletization

The process of repalletization is an essential warehouse (artistic) activity in which finished goods (works) are reorganized into a palette (palette) for external distribution. We attempt this by comparing the behavior of separate *pigments*.

Upon moving to the newer palette, certain comparisons arise from Figure 4 - notably more precise peaking and peaking at a further distance related to the decreased viscosity which both allow for more precise identification. Densities shown in Figure 5 reveal distinct peaks for blue, red, and green peaking individually at a given length and an anomalous tail in that for burnt umber.

After constructing a pseudo-landscape as depicted in Figure 9 using distributions started on opposite sides of the paper, we can test our long-range distributions by comparing the sum to our measurements as in figures 7 and 6. For burnt umber, the general shape of secondary peaks falls out directly from superposition as expected for this limited data. For this color, the artist remained consistent in concentration and brush configuration to arrive at this data. For green, the general trend of a harsh fall off is predicted however the real distribution is substantially more spread likely related to more moisture in the brush by this layer.

Overall, we have generated a new model of a subset of colors based on replicable physical characteristics under a repeatable machine-based process. This focus on materiality contrasts the abstract nature of the western color wheel and avoids ambiguity across language while remaining more accessible than wavelength colorimetry.

3.3 Limitations

Currently, the replicability of these experiments independent of brush orientation remains an open problem. Likely the solution lies in a ratio of probability density functions to weight asymmetric bunches projected by $\cos(\theta)$ on the plane. Following the analogy of theoretical physics, after naming our distributions as colors and resolving this issue, we could attempt to resolve the geometry of the brush utilizing more variables of each such as spread relative to a central axis. This data was not measured due to detector limitations.

Preliminary data on mixed blue and white *pigments* suggests an additive distribution. In essence, as a secondary pigment is inserted, a binomial distribution of distances emerges. The lesser effect on viscosity than predicted appears to be due to heterogeneity from a lack of direct *pigment-pigment* interactions. Future iterations should thoroughly mix *pigments* to confirm these results.

Despite these issues, we have established the ability to develop a language of color in terms of our splattered pigments.

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Figures

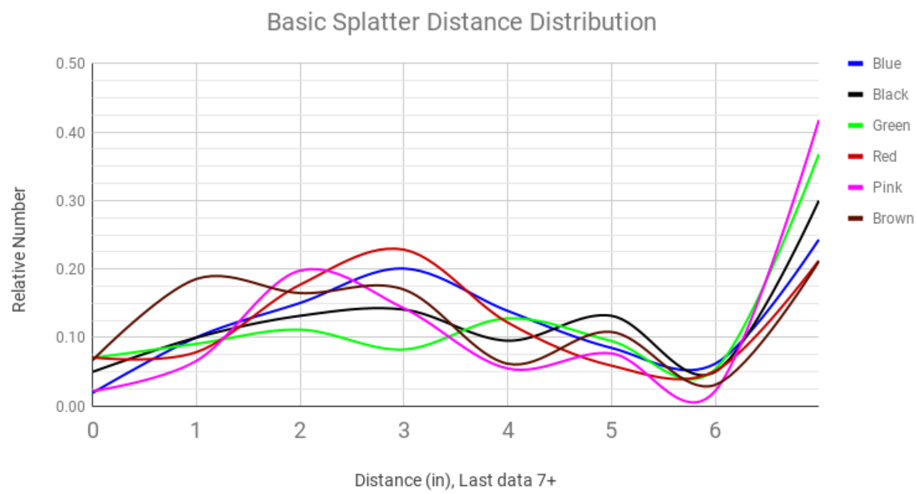

Figure 3: Rough measurement of plate-based palette under constant hydration, angle, speed

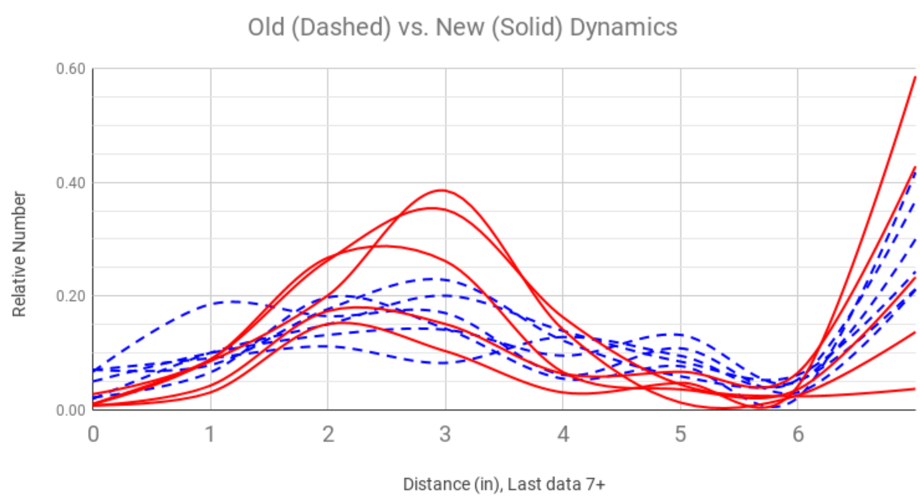

Figure 4: Comparison of general dynamics between old plate and new tube-bound materials at constant angle, speed

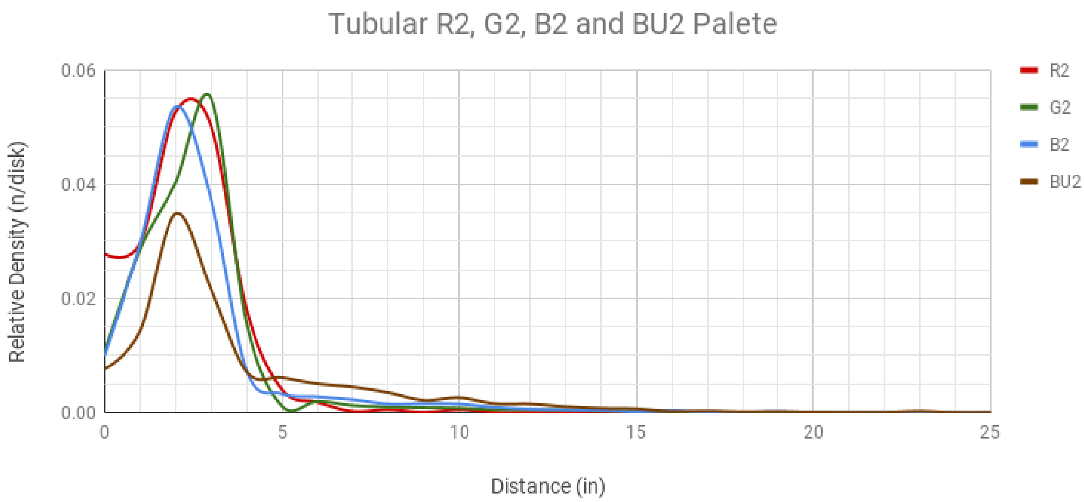

Figure 5: Density from exact measurement of professional palette under constant hydration, angle, speed

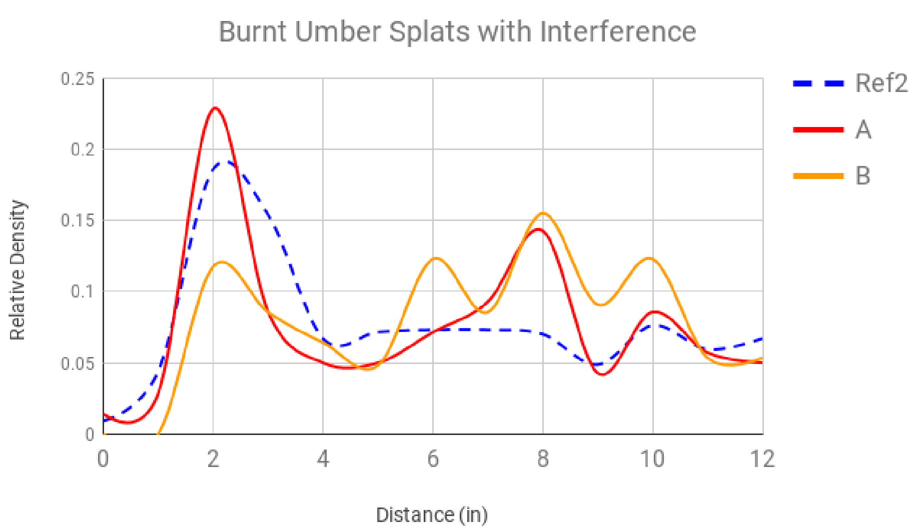

Figure 6: Burnt Umber thrown from opposing sides at constant hydration, angle, speed compared to superposition

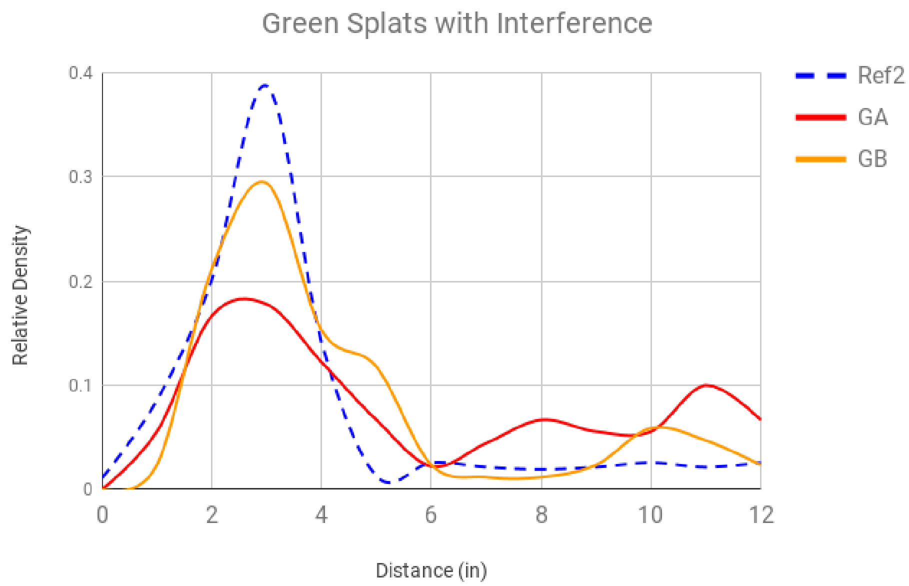

Figure 7: Green thrown from opposing sides at constant hydration, angle, speed compared to superposition

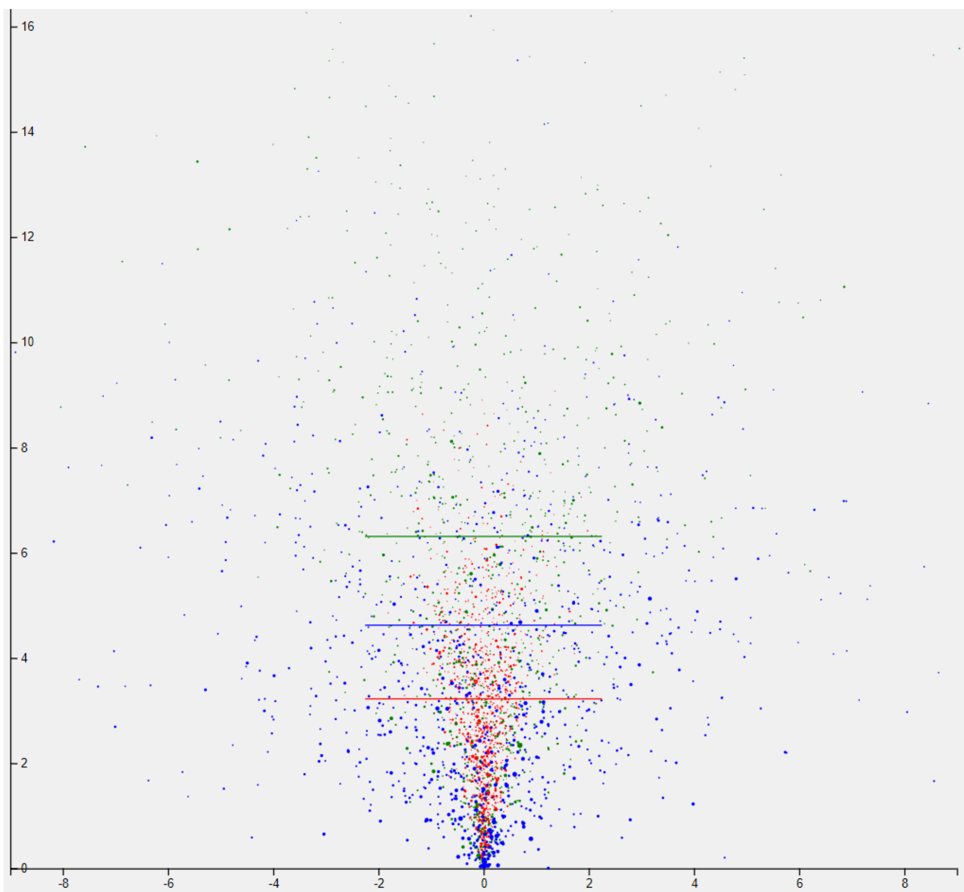

Figure 8: Color diagram produced from Gaussian radial distribution based on data

Figure 9: Landscape interference data pre-analysis