2013

Color by Numbers: An Exploration of the Use of Color as Classification Notation

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Abstract—Notation is a fundamental component of a classification scheme, especially library and bibliographic classification. However, notation is often considered an afterthought or auxiliary to classification itself. With the advances in technology, classification systems, including their notation, must evolve. What, if any, possibilities lie beyond alphanumeric characters and symbols? The author explores the possible use of color as classificatory notation by looking at the traditional qualities of notation and the classificatory needs it must accommodate, various theories and standards of color, and their possible applications to classification notation. Theoretical and practical implications are considered and discussed, as well as larger implications for notation and classification overall.

INTRODUCTION

Color and classification intertwine throughout history. Classification consists of ordering subjects and/or objects into groups called "classes" based on characteristics of division—i.e., things they have in common or things that make them different. Color is an obvious physical characteristic by which to group like items. Elaborate color classification schemes arose over time to classify things like insects, soil,[1] and even human races based on skin tone.[2] It is obvious that there is a fundamental relationship between color and classification. In addition to using color as a classificatory characteristic of division, tints and hues themselves are organized into standardized color schemes, such as the Pantone system[3] and assigned identifying notational labels based on pigment mixtures and combinations. All of these examples reflect color

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1. Soil Survey Division Staff, *Soil Survey Manual,* US Department of Agriculture Handbook 18 (Washington, DC: Soil Conservation Service, 1993).
2. Audrey Smedley, *Race in North America: Origin and Evolution of a Worldview,* 2nd ed. (Boulder, CO: Westview Press, 1999), 160–61, 263.
3. Pantone, Inc.,"About Pantone: What We Do," http://www.pantone.com/pages/pantone.aspx?pg=19306.

Art Documentation: Journal of the Art Libraries Society of North America, vol. 32 (fall 2013)
0730-7187/2013/3202-0005 $10.00.

as an element of Ranganathan's idea plane, the intangible universe of concepts that can be made manifest only through translation into words and notation.[4] Concepts of color are articulated into words like "blue" or "duskish colour, like roasted quinze"[5] or "18-2120 Honeysuckle" (Pantone's 2011 color of the year). Yet with human ability to distinguish over 10,000 different hues of color, language offers only about a dozen hue names.[6]

Over time, color order systems were developed to combat this very issue, harnessing notation itself to describe ideas of color rather than relying on the vagaries of words.[7] Notation, in classification, is "the set of characters (numerals, letters of the alphabet, and/or symbols) used to represent the main classes and subdivisions of a classification system."[8] In library and bibliographic classification, notation is generally intended to represent subjects such as those from Ranganathan's idea plane. But unlike other subject tools such as thesauri, which also express ideas, characteristics, and relationships via words, a classification scheme also uses notation in an attempt to express these concepts in an even more explicit and definite way than words could express. Notation is an attempt to reduce verbal vagueness and uncertainty, like synonyms, homonyms, and differing word use and connotations. A classification system makes such order explicit through schedules, rules, instructions, and notation as well. In addition to such explicit definition, notation also provides a filiatory order,[9] in order to organize physical materials on library shelves and demonstrate the relationship between a particular document and those around it. Such notation is exactly what allows for subject browsing and wayfinding in physical bibliographic collections.

Therefore, notation is a fundamental component of a classification scheme, especially library and bibliographic classification. Yet, often in library classification, notation is considered an afterthought or "necessary but auxiliary."[10] And it may continue to seem so even as physical libraries evolve into digital collections. However, while digital collections may not need one single linear material order, the relationships described explicitly via classification notation may improve digital information retrieval. As library collections and technological capacities evolve, so too must the classification systems and in turn, their notation.

CHARACTERISTICS AND QUALITIES OF NOTATION

As a classificatory device, notation needs to encompass many qualities and characteristics. Rita Marcella and Robert Newton[11] suggest that notation should convey order, indicate hierarchy, be brief and simple, be hospitable to new topics, have mnemonic qualities, and indicate facet change or phase relationships. Eric Hunter[12] enumerates

4. S. R. Ranganathan and M. A. Gopinath, *Prolegomena to Library Classification*, 3rd ed. (New Delhi, India: Ess Ess, 1967), section MD1.

5. Smedley, *Race in North America*, 159.

6. Harald Küppers, *Color: Origins, Systems, Uses* (London: Van Nostrand Reinhold, 1973), 15.

7. Kenneth R. Fehrman and Cherie Fehrman, *Color: The Secret Influence* (Upper Saddle River, NJ: Prentice Hall, 2000), 199–211.

8. Jean Reitz, "Notation" in *Online Dictionary of Library and Information Science*, Libraries Unlimited, 2010, http://www.abc-clio.com/ODLIS/odlis_N.aspx.

9. Keith Davison, *Theory of Classification* (London: Clive Bingley, 1966), 42.

10. Bernard Ira Palmer, *Itself an Education: Lectures on Classification* (London: Library Association, 1971), 36.

11. Rita Marcella and Robert Newton, *A New Manual of Classification* (Aldershot, England: Gower, 1994), 46–61.

12. Eric J. Hunter, *Classification Made Simple*, 2nd ed. (Burlington, VT: Ashgate, 2002), 70–72.

other qualities of notation, some of which parallel Marcella and Newton and others which diverge. In addition to simplicity, brevity, and hospitality, Hunter adds uniqueness (the idea that one concept may not be mistaken for another), flexibility (the ability to rearrange order), and expressiveness. Keith Davison[13] claims that the main goal of a classification system's notation is to "consolidate an agreed-upon order of schedules." To do this, notation must fulfill three functions:

- It must provide a clear alternative name for the subject; this name is the actual notation symbol which is used to express the subject in short form.
- It must be clearly distinguishable from all other symbols so as to individualise the concept and enable the second function to be carried out, that of relocating the subject when it has been put into the system.
- The notation should relate the subject to subordinate, coordinate and superordinate terms, either directly or indirectly."[14]

Davison's functions reflect notation as an explicit instantiation of the verbal plane, its ability to eliminate homonyms and synonyms, and its ability to reflect not just subjects, but relationships between subjects. A master of classification theory, S. R. Ranganathan puts forth the following canons for notation:[15]

- Synonym
- Homonym (both reflecting "uniqueness")
- Relativity vs. uniformity (relates to expressiveness)
- Hierarchy vs. non-hierarchy (relates to expressiveness)
- Mixedness vs. purity (relates to capacity as well as ease of use)
- Faceted vs. non-faceted (relates to capacity)
- Co-extensiveness vs. under-extensiveness (relates to expressivity as well as broad vs. close classification)

Ranganathan also postulates that notation should be capable of large capacity due to an ever-expanding and infinitely divisible universe of subjects.[16] Such an ever-growing organism requires that any notation be hospitable to both extrapolation and interpolation as well as expressive of subjects and relationships.[17] Ranganathan mentions the qualities of brevity, pronounceability, and mnemonics; all are interesting features but not inherently necessary. All of his principles of notation serve in an attempt to organize an *n*-dimensional universe into a single-dimensional line—that is, a prescribed filiatory order appropriate for arranging physical library materials in a line on a shelf.

An aggregation of these different views of qualities of notation show commonalities and differences. Clearly the important emergent qualities of notation are hospitality, expressiveness of both subjects and relationships, and uniqueness (Table 1).

13. Davison, *Theory of Classification*, 41.

14. Ibid., 41–42.

15. Ranganathan and Gopinath, *Prolegomena to Library Classification*, section J.

16. Ibid., section HD.

17. Ibid., section L.

Table 1. Qualities of Notation Shared Across Authors

	Davison (1966)	Ranganathan (1967)	Marcella and Newton (1994)	Hunter (2002)
Brevity		√ (optional)	√	√
Convey Order			√	
Expressiveness (subject and/or relationships)	√	√	√	√
Flexibility				√
Hospitality		√	√	√
Indicate Hierarchy			√	
Large capacity		√		
Mnemonics		√ (optional)	√	
Uniqueness	√	√		√

Some of the other recommended qualities are not shared unanimously. Brevity, for example, is advocated by some, especially in the context of physical material marking such as spine labels or time spent on data entry, or for ease of direct use by library patrons. Lengthy notation "seems cumbersome to librarians,"[18] and Marcella and Newton dub lengthy notations from the Colon Classification "awkward" for end users.[19] Mnemonic qualities may be argued due to the canons of consistency, but the notation is hardly memorable for end users.

Ranganathan also argues that classification systems must encompass a large capacity due to the ever-increasing universe of subjects.[20] Large capacity can be achieved in a variety of ways; simply increasing the length of a class mark infinitely is one. While it is the most direct approach and easiest to understand, lengthening does conflict with the ideal of brevity, and it may be physically impossible. Therefore, Ranganathan offers alternate suggestions, arguing that notational capacity is a function of two variables: the number of digits in the base and the number of digits allowed in a class number. The impossibility of increasing the number of digits in a class number has already been noted; there is not much capacity to be gained there. Therefore, capacity must be enlarged via the first variable, the number of digits in the base. This is traditionally achieved through addition and improvisation of ordinal numbers. A pure base of traditional Indo-Arabic numerals (0–9) and a limit of digits in class number to six allows for a capacity of approximately 531,000, whereas a mixed base of Indo-Arabic numerals (0–9) and Roman capital letters (A–Z, excluding the capital I lest it be confused with the numeral 1) allows a capacity of approximately 1.3

18. John P. Comaromi and Mohinder P. Satija, *Brevity of Notation in Dewey Decimal Classification* (New Delhi: Metropolitan, 1983), 5.

19. Marcella and Newton, *A New Manual of Classification*, 103.

20. Ranganathan and Gopinath, *Prolegomena to Library Classification,* section HD62.

Table 2. Examples of Co-Expressive and Under-Expressive Notation[25]

Subject	Colon Classification (7th ed.)	Dewey Decimal Classification (7th ed.)	Rider's International Classification
Diseases of Stomach	L24;4	616.33	UJK
Gastritis	L24;415	616.333	UJK

billion.[21] Sectoring digits and improvising additional ones increases the capacity even more, although Ranganathan is careful to advise restraint in the improvisation of additional digits: "no basic ordinal number should be improvised unless the existing set is definitely proved to be inadequate to meet the situation."[22]

While the reasons behind a desire for brevity are clear, they must be considered in balance with the desire for expressivity, a quality advocated by all of the authors mentioned above. "Brevity is something more than desirable but less than a necessity,"[23] while expressiveness is explicitly stipulated as a necessary characteristic. The ability to express an explicit subject and its various types of relationships in short symbolic notation is at the heart of classification. The expressive abilities of notation are what allow for easy human comprehension of the classification system and subjects of the materials classified. Although this is particularly applicable to physical library collections searched and browsed by human beings, explicit expressive notation, especially one that indicates phase relationships, can be used by computers and digital systems to interpret and display such relationships in an accessible way. The uniqueness and formal definitions and constructions inherent in classification can be harnessed for machine use as well as for human perception.

One issue of expressive notation is the issue of subjectivity regarding broad versus close classification. Notation can express only how a classifier classes the material: depth of subject analysis and subsequent classification may vary among classifiers. Ranganathan touches on this in his canon of co-extensiveness versus under-extensiveness, where a co-extensive notation is one that expresses "even the very last characteristic in the succession of characteristics,"[24] therefore expressing every aspect and nuance of a document's subject in the notation. An under-extensive notation, on the other hand, reflects a broader classification in that it does not reveal all aspects of subjects included in a document, but perhaps just a larger over-arching subject. In Ranganathan's example above (Table 2), the Colon Classification and the Dewey Decimal Classification both demonstrate co-extensive expression, while the Rider's International Classification classes both subjects with identical notation despite differing levels of subject description.

21. Ibid., section HD.
22. Ibid., section HA7.
23. Comaromi and Satija, *Brevity of Notation in Dewey Decimal Classification*, 6.
24. Ranganathan and Gopinath, *Prolegomena to Library Classification*, JH1.
25. Ibid., section JH.

RATIONALE

Many current and popular library classification systems, while perhaps appropriate in their contemporary periods of design, no longer align with the modern aggregated qualities desirable in notation. Additionally, library classification is often not driven by quality or appropriateness to collection, but rather by a form of inertia. The same systems are used because they have always been used. The Dewey Decimal system is used by over 200,000 libraries in at least 135 countries,[26] and the Library of Congress Classification is currently one of the most widely used library classification systems in the world.[27] While this certainly supports historical consistency, the reduction to limited choices and implementation based on tradition rather than either theoretical foundations (such as the qualities listed above) or user-based needs assessment continue to impact the applicability of such classification schemes in this modern, rapidly changing era.

As new technologies continue to arise, classification should no longer be bound by standards and tools of the past. While in the early twentieth century classification notation was laboriously handwritten or typed on cards, and books were manually labeled and shelved, libraries no longer follow such models. The process is no longer limited by how quickly or legibly a librarian can write on a card, or by which alphanumeric characters appear on a typewriter. Advances in printing and computing opened up new realms of possibilities for notation, both for application to physical materials as well as for implementing standards in a mechanized and automated way. These new technologies of the twenty-first century are ripe for exploration, and it is incumbent upon librarians to explore possible improvements and new ideas and technologies that may afford opportunities for notational systems that achieve hospitality, uniqueness, and both brevity and expressiveness, rather than sacrificing one for the other.

APPROACH

The author proposes the use of color as a notational base for bibliographic classification. In the following sections, various historical and contemporary theories of color are discussed, along with their possible applicability to serve the purposes and better encompass the desired qualities of notation than do current systems of digits. Special attention is paid to the ways in which color can address issues of notational expression such as hospitality, interpolation and extrapolation, and phase relations and relationships between subjects, as well as advantages and disadvantages for physical and mechanized applications. Color as an improvised digit is explored in illustrative examples, both alone and in mixed bases with traditional alphanumeric characters. These examples are then analyzed with respect to both theoretical support as well as practical implementation.

26. Online Computer Library Center, "Countries with Libraries that Use the DDC," http://www.oclc.org/dewey/about/translations/countries.htm; "Dewey Services," http://www.oclc.org/dewey/default.htm.

27. Library of Congress, "Library of Congress Classification," http://www.loc.gov/catdir/cpso/lcc.html.

A BRIEF HISTORY OF COLOR THEORY

Color has been explored from the perspective of a variety of domains, from art to psychology to physics. Over the course of human history, various theories about color have emerged and evolved. These theories typically fall into one of three categories, summarized and defined by Edith Anderson Feisner:[28]

- Additive color (the process of mixing light together)
- Subtractive color (the process of mixing pigments together)
- Paritive color (the process of placing colors side by side to produce different reactions)

Aristotle was one of the first to attempt to explain the composition of colors as well as their relationship to one another.[29] Such an early recognition of these relationships helps establish the idea that color might be an appropriate notational device to illustrate relationships among concepts in a classification scheme. Leonardo da Vinci was the first color theorist to define the idea of "primary" colors and to rank colors in an order of importance.[30] This begins to lend itself to the idea of color order, which also relates to classification in regards to filiatory order and organizing subjects and/or materials in a single-dimensional line. Moses Harris, an entomologist in the eighteenth century, used the three primary colors (red, yellow, blue) to create one of the first instances of the color wheel, a two-dimensional representation of color incorporating hue (the color itself) as well as light and dark values (Figure 1).

Philip Otto Runge created the first three-dimensional color model with his *Color Sphere* in 1810. Numerous others put forth theories and models, but it was not until A. H. Munsell's model that color begins to have a universal, standardized classification. Munsell wanted a "rational way to describe color" that used objective numbers instead of "foolish" and "misleading" names.[31] He specified the three dimensions of color (Figure 2) as hue, value (light or dark), and chroma (saturation or brightness) and assigned a notational system to pigment mixtures representing each of the three dimensions.

The Munsell notation is composed of alphanumeric designations for hue, value, and chroma. This standardization allowed artists to determine color components without experimentation and to provide precise color specifications which motivated industry standardization.[32] Because one of the purposes of classification notation is to explicitly and uniquely express a particular concept, the quantification and standardization of color may lend itself to this formal purpose.

Wilhelm Ostwald[33] expanded on the three-dimensional color model, converting the traditional spherical approach into a cone composed of triangles. Ostwald's sys-

28. Edith Anderson Feisner, *Colour: How to Use Colour in Art and Design*, 2nd ed. (London: Laurence King, 2006), 8.

29. Rolf G. Kuehni and Andreas Schwarz, *Color Ordered: A Survey of Color Order Systems from Antiquity to the Present* (Oxford: Oxford University Press, 2008), 28.

30. Feisner, *Colour*, 13.

31. A. H. Munsell, *A Color Notation* (Boston: Geo. H. Ellis Co., 1905), 7–8.

32. Feisner, *Colour*, 16–18.

33. Wilhelm Ostwald and Faber Birren, *The Color Primer: A Basic Treatise on the Color System of Wilhelm Ostwald* (New York: Van Nostrand Reinhold Co., 1969).

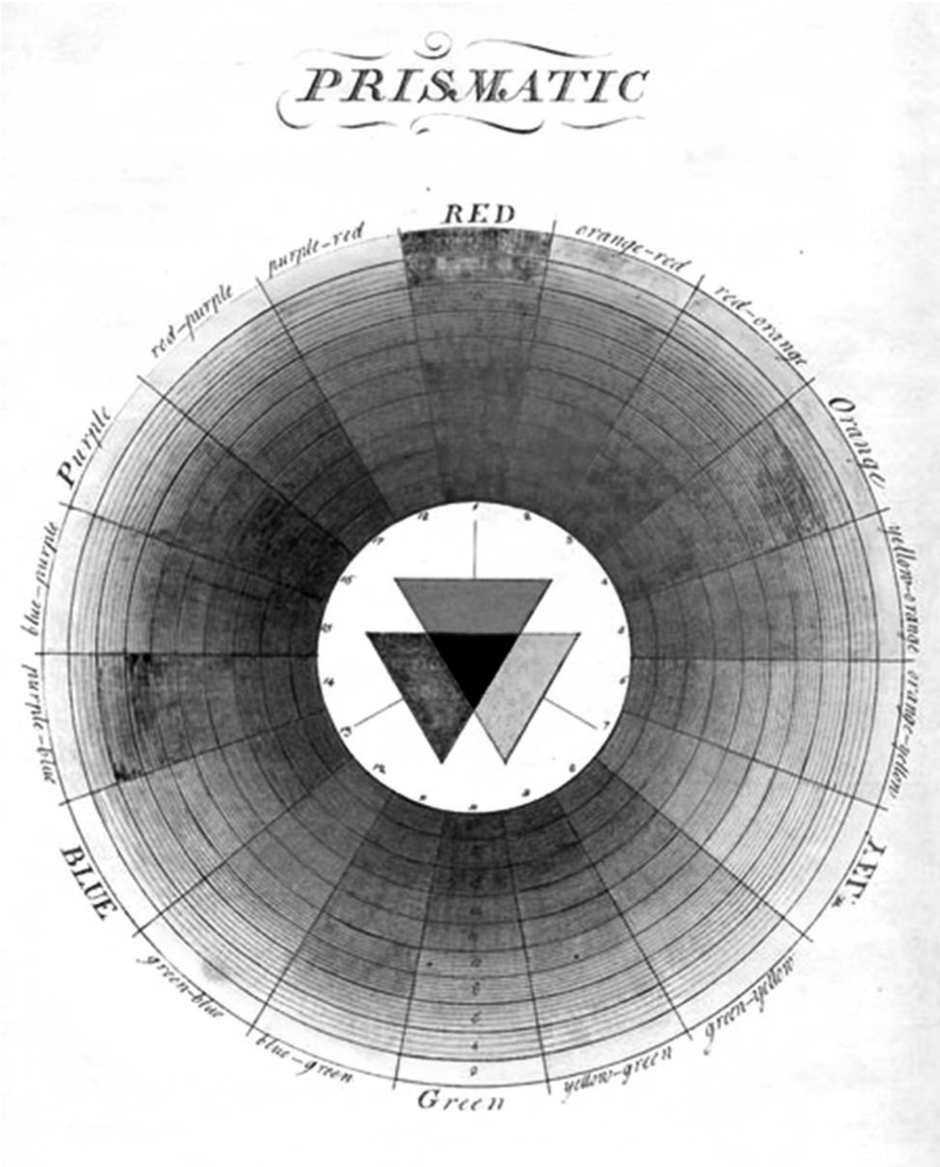

Figure 1. Moses Harris. "Prismatic" color chart. Etching with color tint. ca. 1772. Wikimedia Commons, http://commons.wikimedia.org/wiki/File:Moses_Harris04a.jpg. Please see the online edition of *Art Documentation* for a color version of this image.

tem is based on the idea that every hue can be modified toward either white or black, and these infinite shades form a triangle (Figure 3). A triangle for each hue placed on an axis around the black and white shades forms a double cone (Figure 4). While the possibilities of color expressed in this model are theoretically infinite, Ostwald recognized the limitations of human perception and divided and allotted colors accordingly, in twenty-four hues derived from the six primary colors of the spectrum.

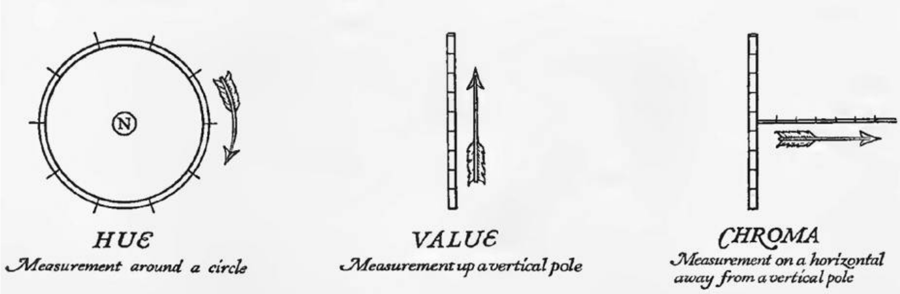

Figure 2. Munsell's three dimensions of color: hue, chroma, value. From T. M. Cleland and A. H. Munsell, *A Grammar of Color: Arrangements of Strathmore Papers in a Variety of Printed Color Combinations according to the Munsell Color System* (Mittineague, MA: Strathmore Paper Company, 1921), 13.

Color standards continued to be developed by the International Commission on Illumination (Commission Internationale de l'Eclairage, or CIE) in 1931, which explored the need for standardization of not just color itself, but of its notation as well. The CIE standards reflect light rather than pigmentation, but they are similarly composed of three variables: luminance (intensity), hue, and saturation. "The advantage of the CIE system is that it provides industry with the means of accurately and consistently matching colors of barely perceptible differences."[34] Even though slight variances in color might not be perceptible to the human eye, the CIE system can still account for and standardize them. This revealed the idea that color can be standardized despite perception, something critical if color is to be applied as notation in a classification scheme. This is especially applicable for machine systems.

Alfred Hickethier devised a system of "numerical order" for subtractive color rather than light.[35] He standardized pigment color by using code numbers—giving notation to color rather than the other way around. Hickethier's system is based on numerical assignments of amounts of subtractive pigments of three primary colors: cyan, magenta, and yellow. The saturation, or amount of hue in a given color, can vary from white (the lack of any hue whatsoever) to 100 percent hue or maximum saturation (Figure 5). All of the hues between these two extremes are possible and infinite in number. This is called continuous gradation.[36] However, such minute differences in a continuous gradation are incapable of perception by the human eye. Therefore, Hickethier suggested dividing gradations into ten discrete steps (Figure 6). Combining a specific saturation of one hue with specific saturations of each of the other hues resulted in a specific and definite color composition. The theoretical constructs of Hickethier's model were highly influential and laid the foundations for contemporary CMYK color printing methods.

In the 1970s, Dutch color theorist Frans Gerritsen (along with software developer Gerriet Hellwig) used psychophysical findings to publish a new color system based on human perception capabilities rather than the traditional additive, subtractive, or

34. Feisner, *Colour*, 19.
35. Küppers, *Color*, 95.
36. Ibid.

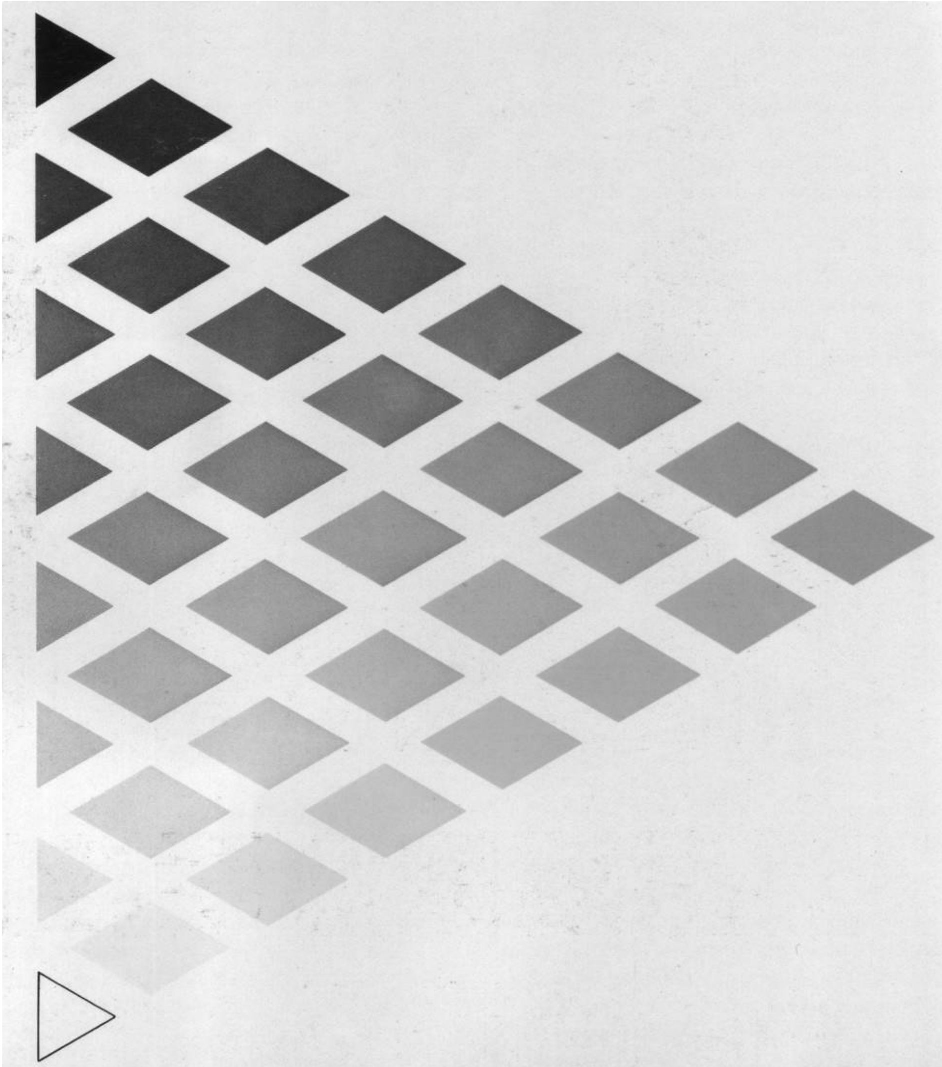

Figure 3. Example of an Ostwald color triangle. From Harald Küppers, *Color: Origins, Systems, Uses* (London: Van Nostrand Reinhold, 1973), 105, figure 61. Please see the online edition of *Art Documentation* for a color version of this image.

paritive theories. Gerritsen concluded that because the human eye has specific color sensitivities, then primary color should be based on that perception, rather than pigments or light. Thus, red, green, and blue—the colors to which the human eye is most sensitive—became Gerritsen's primary colors, and he fixed them as the primaries for all future color theory work.[37]

Both of these later twentieth-century developments influenced the systems of color currently in use. Hickethier's theories led to today's subtractive CMYK color printing

37. Feisner, *Colour*, 21–22.

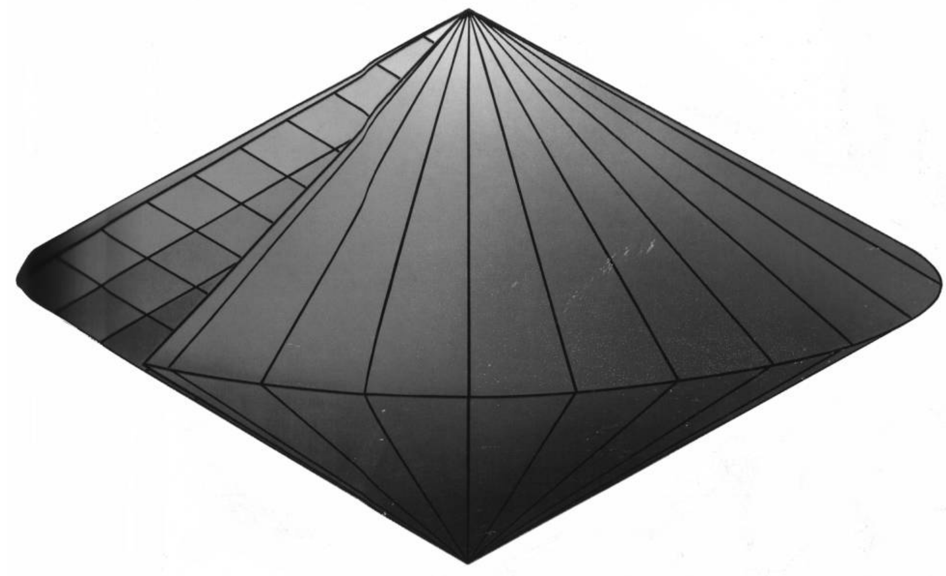

Figure 4. Ostwald's double cone. From Harald Küppers, *Color: Origins, Systems, Uses* (London: Van Nostrand Reinhold, 1973), 107. Please see the online edition of *Art Documentation* for a color version of this image.

process; Gerritsen's ideas led to the RGB color model, an additive model used in electronic display devices like televisions and video screens, image scanners, and digital cameras. With the advent of the World Wide Web and ubiquitous graphical user interfaces, new color models and standards arose. RGB colors are expressed on the web as hex triplets: six-digit, three-byte hexadecimal numbers. Each byte represents one of the primary colors (red, blue, or green) with a hexadecimal number between 00 and FF. For example, consider the color where the red/green/blue values are decimal numbers: red = 36, green = 104, blue = 160 (a grayish-blue color). The decimal numbers 36, 104, and 160 are equivalent to the hexadecimal numbers 24, 68, and A0, respectively. The hex triplet is obtained by concatenating the six hexadecimal digits together, 2468A0 in this example. This standard notation is parsed by applications like HTML and CSS to display color on the web. The hexadecimal range allows for 256 shades of each primary color, much increased over the models of Munsell and Hickethier, meaning that the number of possible colors that can be represented by the hex system is 256 × 256 × 256 or 16,777,216.

Figure 5. Example of Hickethier's continuous gradation. Image by Rachel Ivy Clarke. Please see the online edition of *Art Documentation* for a color version of this image.

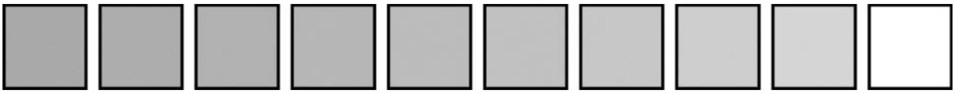

Figure 6. Example of continuous gradation divided into ten discrete steps. Image by Rachel Ivy Clarke. Please see the online edition of *Art Documentation* for a color version of this image.

COLOR AS NOTATION

All of these theories explain the properties of color, how color works, and how it is perceived. Psychological studies come closest to using color itself as a notational device—generally called a "code" in the field—to classify personalities and traits. "A person may be a 'red,' a 'blue,' and so on . . . the colors have merely been used as tags and could easily be replaced with a numerical or other tag code, such as a, b, c, or 1, 2, 3."[38] Given the options afforded by color theory, it is entirely possible that color could shift from needing a notation of its own to performing the role of notation for other classification systems.

First, color is infinite. The range of hues, tints, and saturations, while often discretely divided for perceptive convenience, is infinitely divisible (Figure 7). An infinite universe of subjects requires a notational system capable of infinite expansion. Earlier in this article, Ranaganthan's calculations[39] for pure bases of Indo-Arabic numerals and Roman alphabetical characters were described, as well as the increased capacity afforded by a mixed base of the two. Pure numerals offered a base of nine; the mixed base of alphanumeric digits offers thirty-three. In contrast, even if infinite division is not possible due to human perception, a pure base of hexadecimal colors as modeled in the web is over sixteen million. Given that the capacity of a notational system largely rests on the size of its base, color allows a far larger capacity than any current digits in use in bibliographic classification. If a larger capacity is called for, colors could be repeated in a way similar to rounds of facets in Colon Classification.

All of the color theories described above attempt to impose or formulate some sort of color *order*. Ogden Rood, a nineteenth-century American physicist, even went so far as to propose a natural order for color, which, when not adhered to, creates unacceptable discord.[40] This recurring trend demonstrates that color, like numerals, alphabetical characters, and other symbols, can be improvised as an ordinal number such as Ranganthan describes.[41] In what order colors file may be designated by classification rules in the same way that they stipulate that capital letters file before numerals, which file before lower case letters. Color can clearly reflect and stipulate filiatory order.

Psychological and emotional connotations aside, color can allow for expressiveness just as much as alphanumerical digits, if not more. Hues can be assigned to basic subjects[42] the same way Roman capitals have been assigned in the Colon Classifica-

38. Fehrman and Fehrman, *Color*, 200.

39. Ranganathan and Gopinath, *Prolegomena to Library Classification*, section HA7.

40. Fehrman and Fehrman, *Color*, 200.

41. Ranganathan and Gopinath, *Prolegomena to Library Classification*, section HA64.

42. Ibid., section CR32.

Figure 7. Example illustration of the infinite divisibility of color. http://www.istockphoto.com/stock-illustration-19095065-infinity-set.php?st=00196f6, used under Standard License Agreement. Please see the online edition of *Art Documentation* for a color version of this image.

tion, or the hundreds-level place value has been assigned in the Dewey Decimal System. Color can indicate hierarchy within a basic subject or facet by varying the saturation or tint: perhaps the broader the subject, the higher in the chain, the darker the tint; while the greater the subject intention, the whiter the saturation. Such expressiveness can also support hospitality in the same way, accounting for interpolation and extrapolation and displaying it through infinite gradations of hue.

Support for expressing relationships between subjects can be accommodated by color through the blending or mixing of hues. Lamination and loose assemblage[43] are subject relationships easily expressed through color blending. In the case of Ranganathan's example of "agriculture in Java,"[44] if agriculture were to be represented by a pure hue of red while Java had the notation of blue with 50 percent saturation, "agriculture in Java" might be represented by the shade of reddish purple formed by the combination of the two. Using further dimensions of color may even allow for expression of phase relationships like bias, influence, comparison, and difference.[45]

Such extensive possibilities of hues, tints, and saturations, as well as color blending, allow for unique colors to be applied as notation, eliminating problems of synonym and homonym and creating clearly distinguishable numbers. Blending and combinations are inherently more concise than all but the shortest of class numbers built from traditional notational bases. A single color digit could offer immersive expressivity while still retaining more brevity than its multi-digit alphanumeric counterpart.

IMPLICATIONS

While the theoretical exploration of color as a classification notation portrays it as superior to traditional bases and digits, is this really the case in real-world applica-

43. Ibid., sections PC and PE.
44. Ibid., section PC3.
45. Ibid., section PE3.

Figure 8. DVD collection at the Openbare Bibliotheek Amsterdam. Photograph 2011. Copyright Rachel Ivy Clarke. Please see the online edition of *Art Documentation* for a color version of this image.

tions? Application of color notation to traditional physical bibliographic materials can present useful opportunities. For instance, the Openbare Bibliotheek Amsterdam (the Amsterdam Public Library) successfully arranges its public DVD collection by both title and genre through the use of color (Figure 8). While it is not classification notation in the strictest sense, the replacement of the original DVD inserts with new ones that are color-coded according to genre now allows for physical browsing on two dimensions rather than the single dimension afforded by traditional classification. However, reformatting the entire case label may hinder retrieval for those patrons searching or browsing by recognition. Other libraries in the Netherlands have implemented a locally designed classification scheme that uses color in combination with symbols and keywords with increased reports of patron satisfaction.[46] While these examples do not yet harness all the potential benefits that properties of color may offer, they are a first step in this direction.

Application of color to traditional physical bibliographic materials also faces problems. Matching the correct paint chips, mixing the right colors, deciding how to apply colors to materials and documents, and color change over time (like fading in the sun) all offer significant challenges to implementation of color as a bibliographic classification notation in a physical environment. Machines, on the other hand, may be quite

46. Rachel Ivy Clarke, "Picturing Classification: The Evolution and Use of Alternative Classification in Dutch Public Libraries," *Public Libraries* 52, no. 2 (March/April 2013): 34–37.

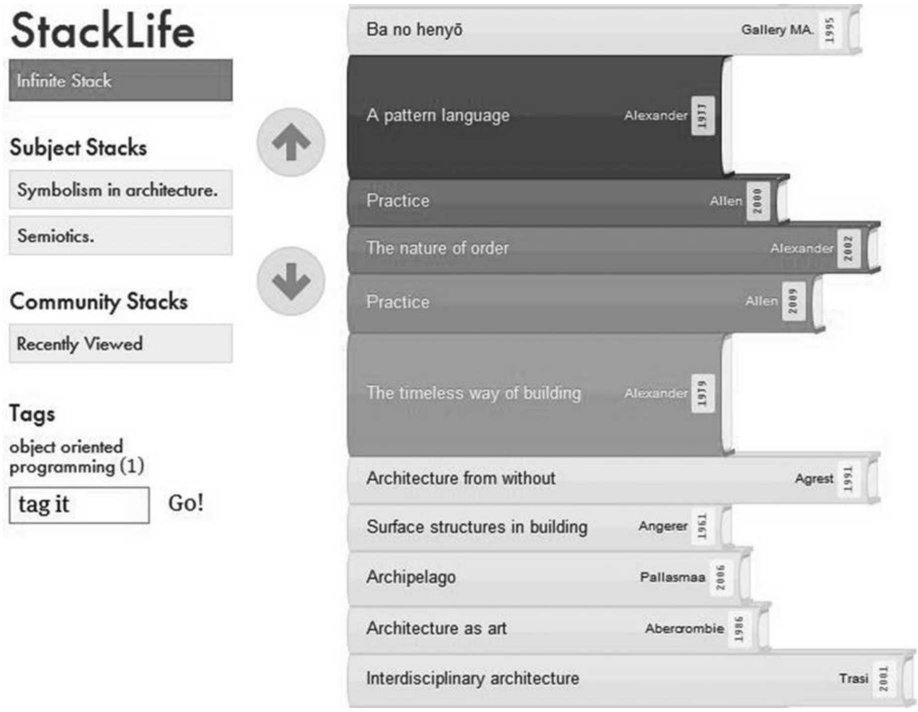

Figure 9. Using color to visualize circulation frequency. Harvard Library Innovation Labs. "Stack Life." Screenshot. 2013. http://stacklife.harvard.edu/item/a-pattern-language/D05D4F8D-428D-DF1E-CFCD-41B29C6B55AE Copyright 2013 The President and Fellows of Harvard College. Please see the online edition of *Art Documentation* for a color version of this image.

capable of distinguishing such minute differences in color shades. Content-based image retrieval based on image color is one of the most widely used techniques.[47] Use of color computer vision can range from authenticating Jackson Pollack paintings[48] to distinguishing different types of quilt patterns,[49] demonstrating an ability to distinguish colors precisely. However, while projects such as these establish capability for such exact distinction, they use color as a processing tool rather than an end result. While examples of color as classification notation in library digital displays are rare, a related example may be found in the Harvard Library Innovation Lab's digital browsing tool, Stack Life. In this interface, color depth is used to visualize a resource's "shelf rank" or frequency of circulation.[50] The deeper the color, the more often that resource has been checked out (Figure 9).

However, like the DVDs at Openbare Bibliotheek Amsterdam, this example is an

47. Linda G. Shapiro and George C. Stockman, *Computer Vision* (Upper Saddle River, NJ: Prentice Hall, 2001), 187.

48. Mahmoud Al-Ayyoub, Mohammad T. Irfan, and David G. Stork, "Boosting Multi-Feature Visual Texture Classifiers for the Authentication of Jackson Pollock's Drip Paintings," in *Proceedings of SPIE—The International Society for Optical Engineering 7869, Computer Visions and Image Analysis of Art II* (San Francisco, CA, January 25–26, 2011).

49. Alhaad Gokhale and Peter Bajcsy, "Automated Classification of Quilt Photographs into Crazy and Non-Crazy," in *Proceedings of SPIE—The International Society for Optical Engineering 7869, Computer Visions and Image Analysis of Art II* (San Francisco, CA, January 25–26, 2011).

50. Harvard Library Innovation Lab, "Stack Life," http://stacklife.harvard.edu.

overall visualization rather than classification notation, although it does represent multiple aspects of a resource in the same way in which faceted classification is designed. This then raises the question of which aspects of a resource should be represented through notation. Traditionally, classification is intended to represent the subject of a work, although examples that include date, form, and genre are typical. Are there other metadata elements that might be useful to include in classification notation?

Despite the above examples that demonstrate the possibility of incorporating color into classification notation, other problems beyond implementation abound. Even if bibliographic materials migrate to entirely digital formats with successful machine parsing, display of colors to human end users still hinges on the limitations of human perception. While many of the advantages of color lie in its ability for infinite expression, theories of color have proven over time that human color vision can never perceive the minute distinctions of color that may be necessary to express an ever-expanding universe of increasing subject intension.[51] If the differences in class cannot be perceived, then the color notation is relegated to under-extensiveness rather than the desirable co-extensiveness. If a human search or browser cannot visibly distinguish between such minute gradations, it will appear that a variety of subject intensions have all been classed the same. Additionally, various types of color vision deficiencies (commonly referred to as "colorblindness") affect how human eyes perceive color. This may range in severity as well as in manifestation, from difficulty differentiating between colors—such as the inability to distinguish red from green—to the complete inability to perceive any color at all (achromatopsia). It is estimated that up to 8 percent of Caucasian men and 0.5 percent of women are born with some level of genetic color vision deficiency, but colorblindness may also occur later in life as a result of disease or injury.[52] Using a classification notation based solely on color runs the risk of alienating a substantial portion of library patrons. The limits of human perception clearly play a significant role in the implementation of color as notational device, and it is unlikely that color alone is sufficient to perform the function of notation for a universal population.

The issues of perception alongside the question of metadata and other elements to be included in classification raise larger questions. Is notation ultimately intended for use in backend architecture, either by librarians and staff in physical realms and machines in the digital world? Or is notation truly a tool for end users, helping them navigate a universe of information and subjects by defining and notating them in an explicitly expressible way? In a world increasingly dominated by computers, how important is classification display? Is 746.920942 more helpful to end users, or would they prefer it if the machine translated the notation for them into legible and parsable language, such as "fashion design in Britain"? Even if color does not solve the problems and embody the desired qualities of notation, it is time to investigate new solutions that could, and to determine how such solutions might apply in the digital age.

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51. Corinne Jörgensen, *Image Retrieval: Theory and Research* (Lanham, MD: Scarecrow Press, 2003), 14–15.
52. American Optometric Association, "Color Vision Deficiency," http://www.aoa.org/x4702.xml.

CONCLUSIONS

Color may be a successful theoretical model for bibliographic notation. It features all of the desirable qualities and characteristics of notation: large capacity, filiatory order, brevity, hospitality, and expressiveness. It makes sense that in a multi-dimensional universe of subjects, a multi-dimensional notation system would apply. However, physical limitations of color, including human color perception and lack of ability to consistently apply hue, limit the use of color as a notational device for physical collections.

Technological advances and the migration towards digital formats and resources may offer future tools and capabilities to harness the theoretical potential of color for classification notation, especially if used in combination with other notation such as alphanumeric characters. While this exploration provides some answers for physical implementation, ultimately it opens up more questions about classification in general, especially regarding notation and its display. Further work is needed in many areas. As some libraries move away from traditional classification systems like DDC and LCC to new, locally designed schemes, an investigation of how and if they incorporate color into their schemes may offer further examples for study. Collaboration with computer scientists could present possibilities to explore the use of color in digital interfaces. Finally, studies of user perceptions of classification notation are key to discovering whether classification notation is still useful and germane at this point in time.

ACKNOWLEDGMENTS

The author would like to acknowledge Leigh Haynes and David Talley for their inspiration in this area of work, as well as Andrew Brink, Monica Caraway, Erica Leigh Nelson, Julie Tanaka, and Joseph T. Tennis at the University of Washington for their support.