Cognitive Aspects of Color

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color names; color dictionary; color thesaurus; categorical perception

Abstract:
Color is a perceptual phenomena that can be explored through psychometrics and modeling of attribute correlates. Color is also a cognitive phenomena that can be researched through color naming or categorization. We begin with a review of previous research, with an emphasis on the challenges and applications of this work. Building on a large unconstrained color naming corpus collected online from over 4,000 volunteers we demonstrate the long-tail of color naming and derive an online color interface tool based on the thesaurus model of synonyms and antonyms. To further improve the quality and quantity of the underlying naming corpus we introduce two novel feedback mechanisms to the Italian version of the online color thesaurus, instance based harvesting of missing names and optional user ranking of included names. This allows a more efficient creation of a higher quality color naming corpus.

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Cognitive Aspects of Color

Aspetti cognitivi del colore

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Como, 18 settembre 2008

Outline

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1 Introduction

1.1 New Challenges in Color Management

For the past 25 years the focus of research in color management systems (CMS) has been the development of algorithms for device independent color reproduction and of standards for device characterization data exchange (profiles). A decade ago, some of the early pioneers in this field saw emerging on the horizon new challenges prompted by disruptive technologies that could not be solved incrementally with the current color management framework [5].

Emerging Display Technologies



The biggest changes are in display technology. Current paradigms for color management were predicated on cathode ray tube (CRT) displays. New technologies present some radical differences:

- Liquid crystal displays (LCD) are not linear (see Fig. 1)
- LCDs are not limited by the small gamut of efficient phosphors (see Fig. 2)
- LCDs are viewed in photopic rather than mesopic mode (see Fig. 3)
- When bright ($\geq 500 cd/m^2$), displays are seen in film mode rather than surface mode
- Organic LED (OLED) are even brighter (see Fig. 4)
- Displays based on reflective micro-electro-mechanical systems (MEMS) can be made arbitrarily bright (see Fig. 5)

We wrote about the impact of LCDs on color reproduction technologies in our AIC 2001 paper [5]. While CRTs are purely emissive and additive, in an LCD display a white light source is filtered and the colored light is attenuated with a light valve formed by liquid crystals. The non linearities stem from photon leakages in the light valves and crosstalk between photosites (pixels). On the positive side, it is possible to specify color filters with a higher chroma without incurring a hight manufacturing cost, so that a wider color gamut is possible.

The largest difference between CRT and LCD is, however, in the luminance direction of the gamut. After calibration, a CRT has typically a maximal luminance of 80 cd/m^2 for a white pixel, while for an LCD display this value is typically above 250 cd/m^2. The luminance level has an impact on both photon detection in the early vision mechanisms and in the higher mechanisms.

In the retina, scotopic vision is assumed below 0.034 cd/m^2 and photopic vision above 3.4 cd/m^2. However, the ranges of typical scotopic, mesopic, and photopic vision overlap. Cones start responding at about 0.001 cd/m^2, while rods respond up to 100 cd/m^2. This means that on a CRT there is always rod intrusion.

At the higher vision mechanisms, there is a change in in the color appearance mode. In a typical working environment, the CRT is surrounded by brighter stimuli, thus colors on the CRT are perceived in surface appearance mode, i.e., the visual system treats the color as an attribute of a surface. Above 500 cd/m^2, the colors are perceived in film mode, i.e., the viewer completely adapts to the color image regardless of the surround [5].

This has important consequences for the perception of yellows, because we can speculate that rod intrusion can shifts its apparent hue towards green. In fact, Shinoda et al. [23, Fig. 3] report that yellow is assigned only at luminance levels above of 20 cd/m^2 in the case surface colors.

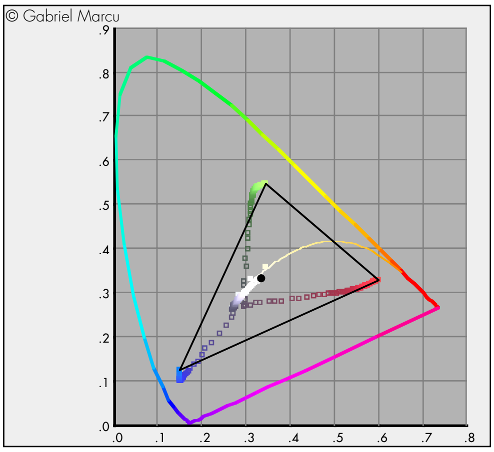


Figure 1: LCDs cannot be modeled linearly like CRTs because the chromaticities of the primaries vary with the input level. Due to backlight unit (BLU) leakage, the primary chromaticities migrate towards the center of the diagram. The migration in hue is due to the liquid crystal transmittance's dependency on wavelength and luminance level, in combination with the BLU's spiky power spectrum distribution. Graphic by Gabriel Marcu, reprinted with permission.

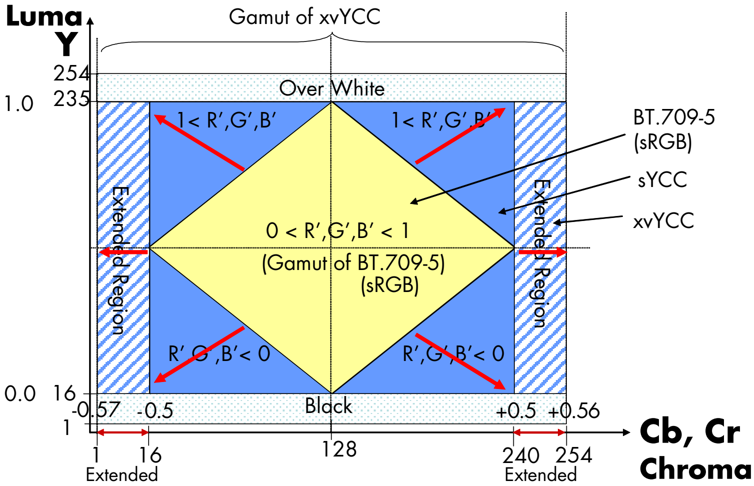


Figure 2: Today's television sets use the larger xvYCC gamut [18], which is backwards compatible to sRGB.

Figure 3: The HP DreamColor LP2480zx Professional LCD Display has a typical brightness of $250cd/m^2$ and a typical contrast ratio of $1000 : 1$. The BLU is a tri-color LED backlight and it covers 97% of the DCI-P3 gamut.

Figure 4: The Sony XEL-1 TV has a typical brightness of $500cd/m^2$ and a typical contrast ratio of $1,000,000:1$. It covers 105% of the NTSC gamut.

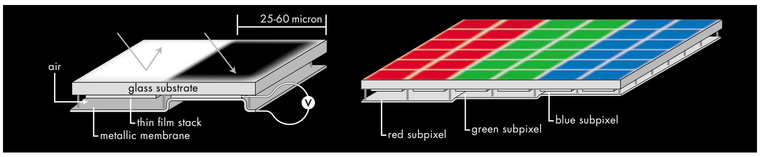


Figure 5: In an interferometric modulator (iMoD) the image element is a simple MEMS device that is composed of two conductive plates: a thin film stack on a glass substrate and a metallic membrane suspended over it. The iMoD element only has two stable states — when no voltage is applied, the plates are separated and light hitting the substrate is reflected (shown left). When a small voltage is applied, the plates are pulled together by electrostatic attraction and the light is now absorbed — turning the element black.

Today's Nomadic Road Warrior Works Wherever

With the surge of that tidal wave called the Internet, we also recognized that the new generation of humans, grown up with video games, search engines, and online encyclopedias would become more nomadic and read documents on displays of portable computers [2], as had been predicted by Marshall McLuhan in his 1964 *Understanding Media: The Extensions of Man*.

Since colorimetric color management entails the strict control of the viewing conditions, one of its basic tenets is lost. The sRGB standard prescribes the display conditions in Tab. 1 and the vieweing conditions in Tab. 2. In the display conditions, the luminance level is unrealistic for today's displays and all of the viewing conditions are unrealistic for the nomadic user. Fortunately, when emerging displays can be viewed in film mode, color reproduction will actually be easier from an algorithmic point of view.

Table 1: sRGB reference display conditions

Display parameter	Reference conditions
luminance level	$80cd/m^2$
white point	D_{65}
gamma	2.2

Table 2: sRGB reference viewing conditions

Viewing parameter	Reference conditions
screen background	20% of reference display area
surround	20% of ref. ambient illuminance level
proximal field	20% of ref. display illuminance level
ambient illuminance level	$64Lux$
ambient white point	D_{50}
veiling glare	1%

Color Management Is Just Expected to Work

Today's users no longer receive training in new technologies and no longer read manuals. A product's user interface has to be so simple and consistent, that a user can learn it just by trial and error. However, color management has always been a nightmare for users [17]. If we cannot devise a color management system that is simple to set up, at least it has sufficiently robust so it delivers usable results even when it is set up incorrectly.

Color Integrity

At the 1997 panel discussion on color fidelity vs. color integrity at the Color Imaging Conference in Scottsdale we had argued:

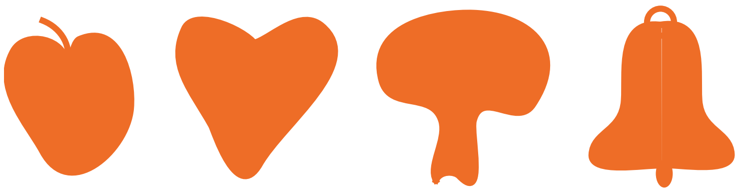
- Color fidelity cannot be achieved in consumer applications like Internet shopping
- A color never comes alone: it is part of a palette
- Color fidelity is not necessary if color integrity is maintained
    1. Foveal colors should not cross name boundaries
    2. The error vectors should have a uniform flux
- Distortions are unavoidable, we need to control them

In fact, we predicted [3, 1] the demise of color fidelity as a user requirement just at the point in time when color fidelity was the generally accepted holy grail of color management research. Instead, we postulated the importance of color consistency, by which we meant the preservation of the relations among colors during reproduction across devices. As techniques to pursue this new goal we proposed the analysis of divergence in color error vector fields and the analysis of color name boundaries.

Naming of Colors

In real life, the names of colors are often *less* important than the names of colors of objects

Example 1. Delk & Fillenbaum experiment (1965)



The argument for divergence-free color error vector fields was that this requirement corresponds to the avoidance of virtual light sources that would impede the color constancy phenomena that can be expected with the emerging display technologies. Similarly, the argument for not crossing color name boundaries was that cognitive phenomena modulated by object recognition and memory colors can create a high tolerance for color synonyms.

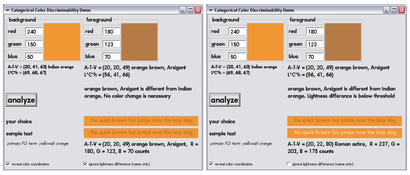
In a 1965 experiment, Delk & Fillenbaum [9] cut shapes of various objects from a single piece of cardboard. When asked to name the cardboard color, subject replied with the memory color associated with the specific shape.

The divergence issue is easy to control, because standard mathematical techniques can be used. The name boundary crossing problem instead is very difficult. Essentially, the problem requires solving two steps. The first step consists in compiling a color name dictionary, which is a rather tedious task that can be never-ending, as there is no limit to color designers' creativity. The second step is to find the color name boundaries, i.e., to categorize the color names into groups of synonyms. Finally, it is necessary to understand how this categorization is performed, so it can be modeled.

More Applications of Color Naming

Once we have facilities for processing color by name, we can find more applications:

- Better user experience in GUIs
- Automatic nudging of text and logo colors for readibility in variable data printing



- Gamut mapping for HDR and wide gamut displays
- Culture-independent preferred color rendering
- Thematic rendering

Once this task has been accomplished, a number of problems can be solved. For example, in graphical user interfaces (GUI) it is difficult to communicate with the user using color coordinates, even when they correlate well with perceptual quantities. If a program can use expression like *the lighter red*, it is easier to understand than $\#ef3d47$ or $\mathcal{A} = \{\langle C_i, \alpha_i \rangle | C_i \in \mathcal{C}\}$, where $\alpha_i = G_n(p, \mu_i, \sigma_i)$ and $C_i = \langle \mu_i, \sigma_i, l_i \rangle$.

In variable data printing, each copy of a document is different, therefore, it is no-longer possible to proof-read a document for color clashes. During document generation, it becomes necessary to check the color compatibility of all intersecting and adjacent elements. When for example their colors become so close that they are hard to tell apart, or text is no longer readable, the colors have to be nudged slightly.

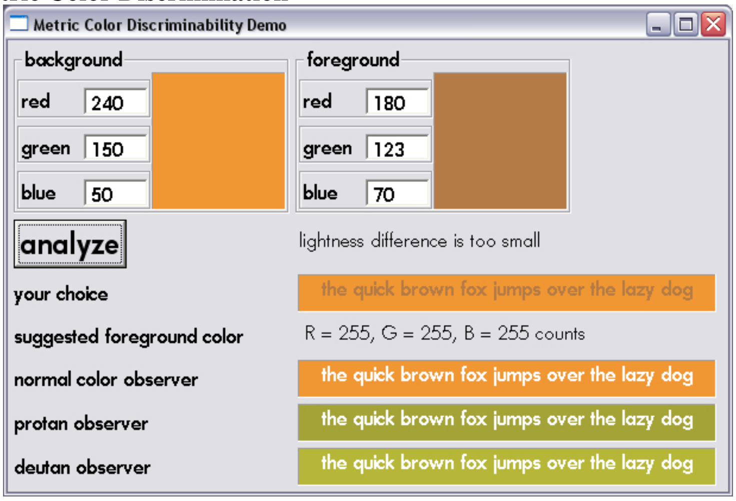
The gamut mapping problem is that images look better when he total gamut of a rendering device can be used. When users edit their images created on a large gamut device (e.g., with a single lens reflex (SLR) digital camera) on a large gamut display, these images will occupy a large gamut. When users request prints of their images, these will have to be gamut-mapped to accommodate the smaller gamut of a reflection device based on a subtractive color technology. With today's devices there is a considerable probability that for example a banana can become mustard, which by Delk & Fillenbaum's experiment is acceptable but which is not necessarily esthetically pleasing.

By culture-independent preferred color rendering we refer for example to the old and well understood problems that while in western cultures a tan complexion is preferred, in Asian cultures whiter shades of pale are preferred. In our case this means that the category of the color *complexion* (sometimes called *flesh* or *tan*) should be different for different cultures.

Finally, by thematic rendering we mean that especially in the case of functional color, we would like to be able to change the mood of an image by changing the regions of color categories [15]. For example, an image can be made more gaudy by saturating the color categories.

1.2 Lexical Color

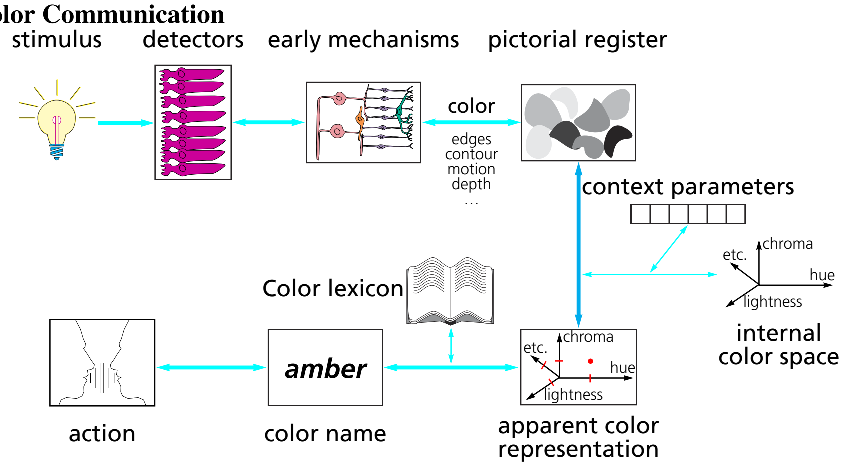
Metric Color Discrimination



Readability can be assessed by considering the color's coordinates in a perceptually uniform space, like CIELAB. In effect, in such a color space, the Euclidean distance correlates with the perceived distance as a multiple of just noticeable differences (JND). In our implementation, we found that 27 is a good threshold for readability [4]. In the figure above, the two colors are too close and the system suggests replacing the brown with white.

The color difference formulæ in perceptually uniform color spaces are derived for small differences. Even if it has been reported [10] that these metrics can be modified for large color differences, everybody who has tried to implement gamut mapping in CIELAB knows that for some colors a small difference can be very visible (e.g., from a reddish to a bluish violet), while for other colors the tolerances are much larger.

Color Communication



The various colorimetric color difference formulæ have been developed to solve the color matching problem, i.e., to determine if two colors match within a pre-determined tolerance. In applications such a variable data printing, we are not interested in color matches, but in color discrimination. For example, we are interested in whether two color can be easily told apart.

The colorimetric color difference formulæ are based on modeling the early color vision mechanisms. Advanced color difference metrics take into account color appearance, i.e., they are based on modeling the apparent color representation. For color discrimination, we have to go all the way to color communication, labelled *action* in the diagram.

Color Naming Constraints

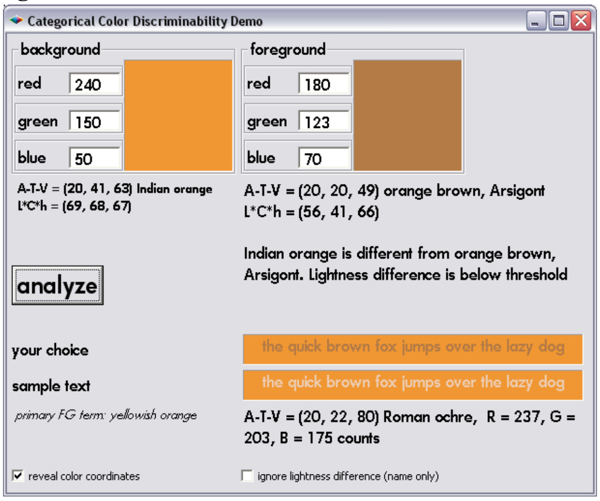
1. Physiological basis of color perception

2. General color cognition
   - basic vs. derived color categories
   - role of prototypes
   - formatting of internal representation
3. Color communication
   - sharable knowledge about the world
   - metaphorical names
   - semantic and syntactic constraints

Result: an observer can discriminate more efficiently between a pair of colors straddling a category boundary than between a pair in the same category

There is a rich literature on the constraints on color naming for the creation of models for the generation of color lexica [25]. Color discrimination leverages on categorical perception, where the categories are color names. The experimental procedure consists in measuring the response time to a discrimination task or in measuring the number of errors in such a task. Observer can assess differences faster, with less errors, or with higher precision when the two stimuli straddle a category boundary than when they are in the same category [12].

Categorical Color Discrimination

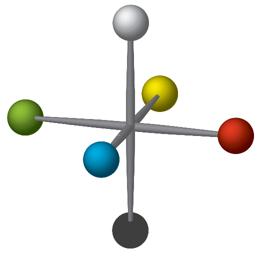


The categorical perception we are interested in are color names. We define a metric by counting the number of color name boundaries between two colors. In our experiments depicted in the above demo tool, when established that if two colors have the same name or adjacent names, then they are too close for robust readability. As shown in the above figure, increasing the lexical distance from 1 to 2, i.e., putting one color name in between, we can generate algorithmically the more readable Roman ochre as a foreground color on an Indian orange background.

1.3 Color Naming

Development of Color Naming

- Color naming is acquired, not genetic
  - socio-economic status (SES)
- Occurs late in child’s development, but age is decreasing with increase of technology
  - 1900: basic four colors @ 8 years
  - 1950: @ 5 years of age



As described by Davidoff [8], color naming is an acquired skill. This has two consequences. The first is that since everybody grows up in a different environment, everybody has a different color lexicon. The second consequence is that the color lexicon will have a strong dependence on the socio-economic status (SES), because in most societies poor people tend to be less well educated or less exposed to color decisions.

The color lexicon also evolves in time. For example, in classical Greece the quality of light was more important than colors. Similarly up to about a thousand years ago, the Japanese used only black (kuro) and white (shiro) to designate color, with a term for colorful (aka), which now is red. About a thousand years ago indigo dye was introduced to Japan and a new color name came into use, namely (ao) for dye. Ao was used for grue, i.e. green or blue, and only in the 14^{th} to 15^{th} century green and blue were categorized into midori and ao [26].

As we are exposed to a more colorful environment at an earlier age, we learn earlier in life how to name colors. For example, if in 1900 we learned the basic four colors by age 8, in 1950 we learned them 3 years earlier.

An interesting experimental finding [28, page 149] is that that art students are slower in naming colors than chemistry students, because the former are more inclined to describe color impressions rather than the perceptions of physical sensations. Specifically, they use more modifiers, a trend that actually decreases as art students proceed to their senior years.

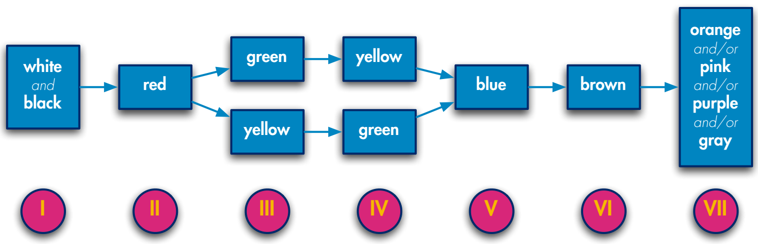
This teaches us that the richness or size of a color lexicon is not a measure of color fluency.

The global village is a large consolidator of archetypes, and with it, color names are becoming more universal and less tied to the availability of local natural dyes and pigments. This can be seen in the general increase of the use of color names from foreign languages. For example pink is finding adoption in several languages, but while the Japanese pinku is equivalent to the English pink, in German pink is different from its dictionary translation rosa.

In summary, the methodology for compiling a color thesaurus must be easy to execute, so it can be cranked periodically.

Color Ontogeny of Languages

- Brent Berlin and Paul Kay, University of Berkeley, 1969
- The physiology underlying even the unique hues is unknown
- There is no *natural* categorization

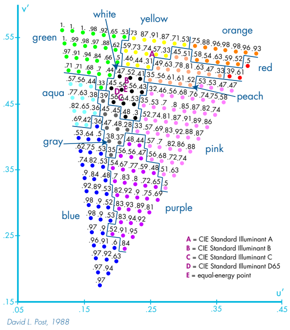


Berlin and Kay [6] studied the color ontogeny of a number of languages, and their work has sparked a large amount of scientific publications on the subject. Here, we are not interested in this ontogeny, nor in a dictionary of color names; the interested reader can easily find an extensive literature.

The Structure of Color Naming Spaces

1. What is the set of color names?

2. Where are the boundaries for synonyms?
   - Without a natural categorization, it is not clear where the boundary for synonyms are
   - An important problem in avionics
3. How are the color names categorized algorithmically?



If we are not interested in color names nor in their ontogeny, what is our interest? To solve the problems mentioned earlier, we need the structure of color naming spaces, we need to know the categorization of color spaces by color naming, i.e., the boundaries between color names. One of the fundamental methods we use in language is the organization of terms into hierarchies, where the elements in each category are related at a given hierarchical level.

If Berlin and Kay's basic color terms and a lexicon of all known color names are the two extremes, we are interested in the set of synonyms that forms the intermediate level in this hierarchy.

What is A Color Thesaurus?

Definition 2. A *thesaurus* is a compilation of synonyms (and antonyms) with etymological and semantical information as well as examples to disambiguate the synonyms

- There is a number of dictionaries of color names
- In 1955 Kelly and Judd produced an early color thesaurus
- In 2007 Nathan Moroney created an online thesaurus of color names
  - based on an earlier online color naming experiment

To a good writer, there are no two words with the same meaning. Similarly in the communication of colors there are no two names to describe a color. To create a thesaurus, we start with a color lexicon and then structure the elements into categories. For example, we may categorize the color names in Tab. 3 into a class called *very light blue*

Table 3: Plochere synonyms of very light blue

Color name	Color designation
baby blue	Bgg 1-g
baby blue eyes	B 2-e
blue appeal	Bgg 3-g
blue heaven	Bg 1-e
blue ridge	B 1-f
dream blue	Bg 1-f
romantic blue	Bgg 1-f

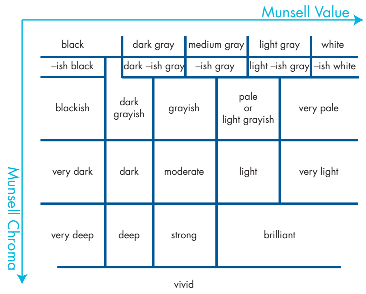
The codes in the right column are the ISCC–NBS color designations of the names from the Plochere Color System and are used to disambiguate the synonyms in the thesaurus [14, page 68, synonym 180].

2 Previous Work

2.1 Attempts to Compile Thesauri

The ISCC–NBS Method of Designating Colors and A Dictionary of Color Names

- Kenneth L. Kelly & Deane B. Judd, 1955
- Names from over a dozen compilations in use in the USA; uniformity in Munsell space
- 1933 recommendations by I.H. Godlove + scheme of hue modifiers + heuristics



In 1955 the National Bureau of Standards (NBS, now National Technical Information Service NTIS) published circular 553 with a vocabulary of 7,500 color names with the purpose of assisting scientists, businessmen, and laymen to understand the different color vocabularies used at that time in the many fields of art, science, and industry in the USA [14].

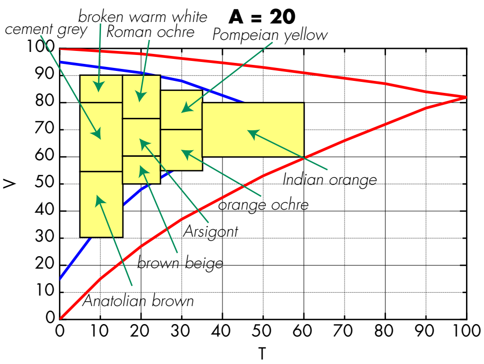
A subcommittee of the Inter-Society Color Council (ISCC) defined the boundaries of 267 color name categories in terms of the Munsell renotation. This categorization was based on some recommendation made in 1933 by I.H. Godlove, a scheme of hue modifiers shown in the figure above, and heuristics.

The ISCC subcommittee checked the color boundaries by observations of all the color standards obtainable for which Munsell renotations were available at the time. The final charts were much more complicated than the original ISCC–NBS system shown in the figure and differ significantly from one level of Munsell value to another.

The resulting compilation is a true color name thesaurus.

Coloroid Color Names Antal Nemcsics, 1993

- Historical pigment names; process and structure not documented; 70'000 observers
- Structure hierarchy: 7 domains, 76 primary colors
- Several errors and inconsistencies



Antal Nemcsics compiled a color dictionary for his Coloroid system to help color designers communicate with their customers [20, page 118]. He introduced a hierarchy of names. The Coloroid system has 48 *primary hues* A numbered from 10 to 76 with gaps. Each set of tens (e.g., from 10 to 16) is called a *color domain* with names yellow, orange, red, violet, blue, green 1, and green 2. Within each domain the primary hues are then assigned names like yellow 1, yellow 2, yellow 3, warm yellow 1, warm yellow 2, orange yellow 1, orange yellow 2.

For each Coloroid hue, Nemcsics then gives a table of names with the ranges specified in terms of rectangles of width in T (saturation) and height in V (lightness). No reference is made on how the names were compiled and how the category boundaries were determined. An example for hue 20, yellowish orange 1, is shown in the figure above. The red curve indicates the boundary of the Coloroid color space and the blue line indicates the boundary of the surface colors.

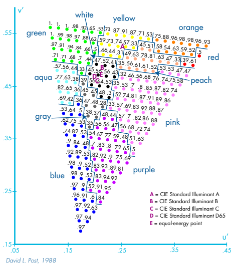
From a conversation with Nemcsics, I suspect that he just made a substantial intellectual effort to come up with a consistent system, rather than formal psychophysics experiments as was done in the ISCC–NBS system; it is more akin to alchemy than to chemistry. For more information see Ref. [22, Appendix III]

When one browses the dictionary, many names that may be well known to designers, are rather arcane to the general public. While in a design process a designer can educate a customer in the naming of colors, this is not possible when one communicates anonymously with the public in general, as when a user interface is designed.

2.2 Extensions of the Basic Color Terms

Color Names for Avionics David L. Post and collaborators, 1985–1989

- Start with 12-name vocabulary (basic terms + peach)
- Psychophysics; present 210 stimuli (uniform in UCS) on various backgrounds under various illuminants
- Boundaries enclose areas within which the modal color-name response corresponds with the color name
- Probability of obtaining the modal color-name response



David Post and his collaborators [21] performed a number of experiments from 1985 to 1989 in which they collected data for two symbol sizes presented on a CRT under a wide range of background colors and ambient illumination conditions. The two sizes were 2° representing area fills, and 20′ representing symbology.

Post used a fixed 12-name vocabulary consisting of the 11 basic color terms plus peach. The main goal of these experiments was to identify robust colors for avionic applications.

Influence of Culture on Color Naming Heinrich Zollinger, ca. 1975

- What is the link between the neurobiology of color vision and color naming (embodiment)?
- Subjects native speakers in:
  - chemistry students in German, French, English, Hebrew, Japanese
  - art students in German, Hebrew
  - Japanese children
  - analphabets in Kekchi, Misquito
- Tasks:
  1. list minimally necessary color names
  2. list supplementary color names
  3. total must be 12
  4. name 117 Munsell chips

Zollinger's protocol was as follows [28]. First, the observers were asked to write down a number of color terms, which they were to divide into two groups

1. the first group consisting of words considered absolutely necessary for a minimum color lexicon

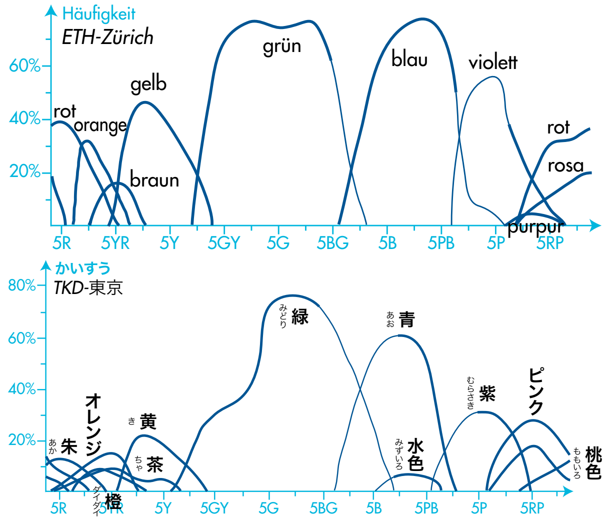
2. the second group including words considered to be of secondary importance

The total number of words allowed was *arbitrarily* set to twelve. Next the subjects were shown and asked to name a set of 113 to 117 Munsell color samples. This system was made up of 20 Munsell hues at three to four levels of brightness and three to four levels of saturation. Each sample had to be named within 20 seconds. Each subject could describe a particular sample by using a word from his or her chosen lexicon, or by using any other words. If the sample could not be described within 20 seconds, the corresponding space in the questionnaire was left blank.

It is a pity, Zollinger et al. restricted the total colors to 12, maybe because the color ontogeny with 12 basic term is so engrained in the literature. Without this restriction, they might have obtained interesting results on the cultural dependence of color categories [27]. This is why we are calling the research presented in this subsection of the basic color term extensions.

An interesting observation in their paper is that the Japanese could not call color TV *irono terebi* when it was invented, because *color* and *achromatic* are not antonyms like in English, black and white being colors in Japanese. They ended up calling it *tennenshoku terebi* or natural TV.

Frequency of Occurrence Chemistry students

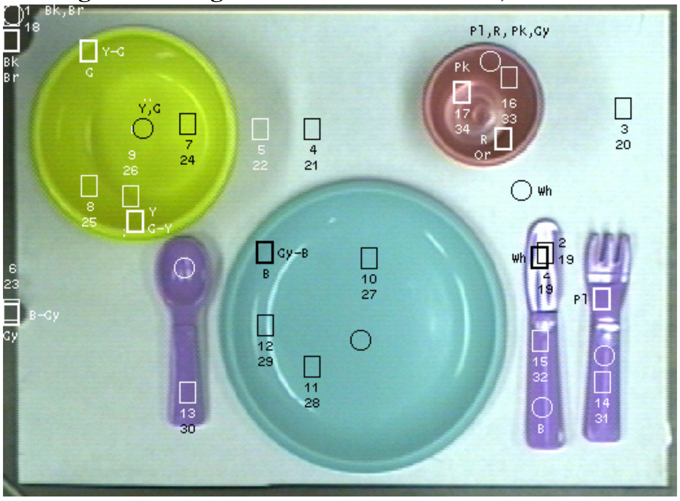


The frequency of occurrence is the percentage of subjects mentioning a specific term for a specific sample. The certainty of determination is the sum of all color terms given to a specific sample, or to all twenty hues at specific levels of value and chroma.

The graphs indicate that certainty of determination is medium for German and and low for Japanese. Zollinger writes [28, page 147]:

> "Science students — test subjects with fairly comparable backgrounds of schooling, professional interests, and age — were studied for five different mother-tongues. The results for native speakers of German, French, English, and Hebrew cannot be differentiated further, although the probability is that French has a higher certainty of determination of 60–70% as revealed by statistical tests.
>
> "The certainty of determination of Japanese students is, however, clearly lower (probability > 90%). Drawing on my own experience of Japanese culture, I assume that the tasks in these tests are more difficult for Japanese students than for their Western counterparts. Japanese etiquette requires very subtle and intricate forms of addressing the person to whom one is speaking and is much more important (and difficult) for a Japanese in all situations; this applies also to color naming."

Robotic Agent Naming Colors Johan Lammens, 1994



Johan Lammens [16] implemented a framework enabling an autonomous robotic agent to name colors of objects in its field of view, and to point out examples of objects with specified colors in its environment. Membership in a category is thresholded, and there are the 11 named basic color categories plus a null category for stimuli not reaching the threshold for any category.

2.3 Summary

Number of Color Categories

- Berlin & Kay: 11 basic terms
  - white, black, red green yellow, blue, brown, orange, pink, purple, grey
- ISCC–NBS: 267 categories
- Nemcsics: 76 primary colors
- Boynton & Olson: 15 nonbasic terms are frequently used
  - tan, peach, olive, lavender, violet, lime, salmon, indigo, cyan, cream, magenta, turquoise, chartreuse, rust, maroon
  - $11 + 15 = 26$
  - 2 uninformed subjects were presented twice the 424 OSA patches and asked how many colors they saw
  - one subject estimated 30, the other 80
- 11 is too low a number to categorize colors

Boyntons and Olson's research [7] was on the OSA coordinates of the basic color terms and to investigate the failure of color constancy. Unfortunately they used a $3000°K$ (effective) light source instead of a simulator for the D_{65} illuminant used to scale the OSA color space.

Limitations of These Solutions

- Only ISCC–NBS has a *bona fide* thesaurus
  - 266 color categories with annotated synonyms
- Even with 7,500 color names, the dictionary is very limited
  - a snapshot in time (1955)

- mostly government and industry related
- only in English

- It is not clear how many categories there are
- These limitations make it less useful

To date, the 1932 vision of ISCC's first chairman E.N. Gathercoal of the University of Illinois College of Pharmacy to develop a means of designating colors has been unparalleled. This is the more astonishing as it was accomplished before the availability of automation tools and by a relatively small group of people.

3 Our Results & Contribution

3.1 Color Naming on the Web

Research Constraints

- We are interested in the names of color patches
- Not in free lists of color names
- Not in color object names
- Not in the evolution of color names

From the examples of previous work discussed above, it is clear that we are interested in the names of unrelated colors, i.e., when observers are shown a color patch, how they would name the patch's color. More specifically, we are not interested in the observer's ability of coming up with creative color names, but in their ability to communicate efficiently a color to another person.

In free lists of color names, observers are asked color compile a list of all color names that come to their mind in a fixed time interval, typically a few minutes. Such lists probably reflect more on the observer's recent colorful experiences than on the lexico-neural mechanisms of color naming. For example, Smith et al. [24] report color names like *baby shit brown*, *puke green*, and *wispy blue*.

Similarly, enumerating the color names in a dictionary or counting the frequency of color names in text corpora says probably more on the author's personal exposure to color names than on general principles.

We have seen earlier in the discussion of memory colors, that when a presented color is associated with an object, the identification of color appearance is much less precise.

Finally, there has been a large body of publications following from Berlin and Kay's work. For example, the ontogeny of Japanese color terms in the centuries has been documented in various papers and books, based on the study of literary works (see for example [27]).

Goal

1. Large dictionary
   - extensive, through crowd-sourcing
   - evolves through time
   - not limited to one language
2. Number of synonym categories $\gg 12$
   - decided though crowd-sourcing

  - not 266 like in ISCC–NBS thesaurus
  - . . . or 26, or 30, or 80. . .

3. Algorithm for determining categories
  - explicitly ask user for a specific and a general name
  - construct separate categorizations for each
  - explore boundary-finding algorithms

Today we not only have automated color measurement devices, powerful computers, fast networks, and the instantaneous reach to a substantial portion of the world population. We have the meme of crowd-sourcing [13] and we have machine learning systems that can reduce the collected data. However, note that methods like Amazon's Mechanical Turk (see Fig. 6) are not suitable due to the SES dependency of color naming.

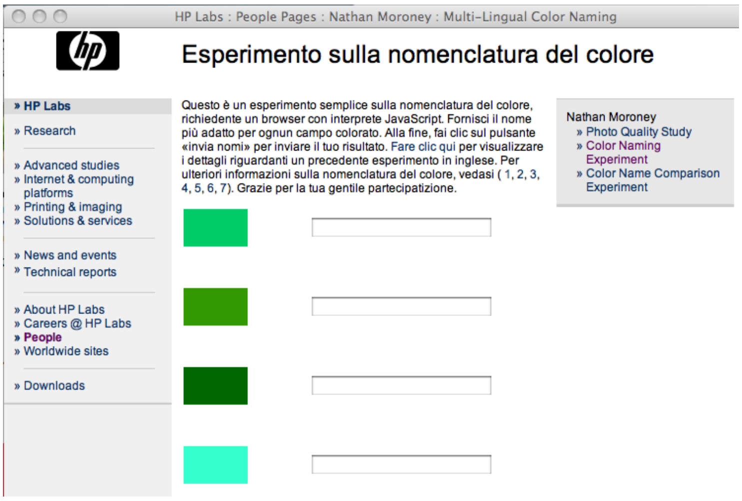
Figure 6: Johann Wolfgang Ritter von Kempelen de Pázmánd (1934-1804) built a fake chess-playing automation that among others beat Napoleon Bonaparte and Benjamin Franklin. The Turk inspired Amazon to create a software service powered by humans called Mechanical Turk.

Our goal is to proceed in three steps. In the first step we collect large dictionaries in various languages. In a second step, we will ask users to propose color categories. A key idea is not to define a priori a number of categories, but to let the users make suggestions and then "average" the proposals.

The third step will then be to further determine the "averaging." For a start, we are asking users to suggest two color names for a patch: a specific name and a more general name. This will yield two categorizations of color space, one with the names of small neighborhoods in a perceptually uniform color space, and one for the classes of synonyms.

As soon as we will have sufficient data, we will be able to explore boundary-finding algorithms, whose results we can compare to the synonym classes proposed by the observers. We anticipate, that there will be a strong language dependence in the computer algorithms, while we expect the synonym classes proposed by humans to be less culturally dependent.

Color Naming Experiment



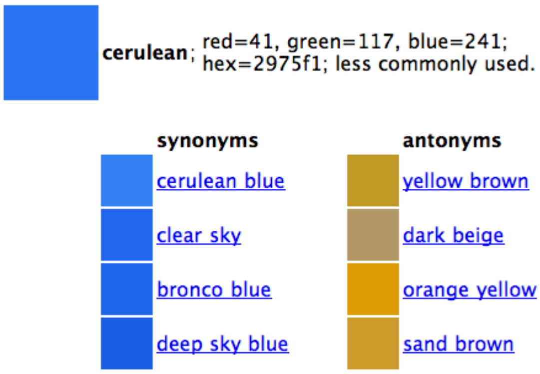
In 2003 Moroney [19] described a color naming experiment based on crowd-sourcing. He implemented a web page on HP Labs' external server where he would display seven color patches with colors selected randomly from a grid in sRGB. Visitors were asked to register the best possible color name for each of the seven patches.

This experiment was extended to 20 other languages, including Italian.

3.2 Tools Leveraging the Corpus

The Color Thesaurus in English

The ephemerality is built in!



`http://www.hpl.hp.com/personal/Nathan_Moroney/color-thesaurus.html`

In 2007 Moroney followed up with a color thesaurus tool based on the collected names. This time, instead of advertising the tool through a link on a static web page on the HP Labs external server, he advertised the tool by posting a blurb on HP's external color blog. Using a blog is important because of its ephemerality, the link to the tool automatically fades away with time. Moving the link from the HP Labs server to the HP Corporate server also gives a higher branding value, and with it, more credibility and visibility.

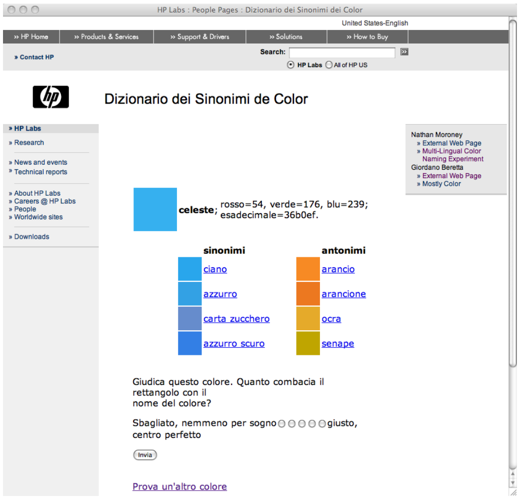
Color Zeitgeist

- Can easily derive secondary tools
- Tag cloud visualization of the color name queries

Example 3.

It is easy to implement derivative tools, like the Zeitgeist tool shown in the figure, because the large data corpus collected makes the displayed result very meaningful.

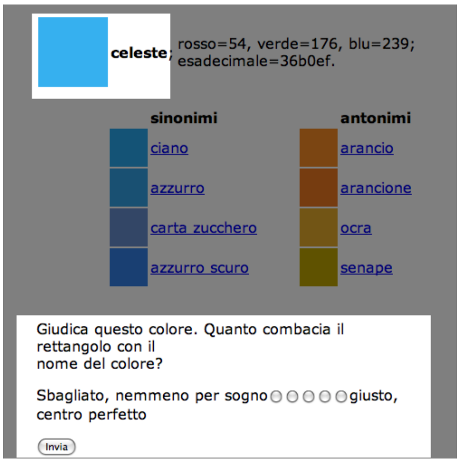
Italian Color Thesaurus



From the beginning, the color naming tool was implemented in approximately 20 languages. However, only in English there was sufficient data to provide a meaningful thesaurus tool. In summer 2008 we made a special effort to advertise the Italian naming tool to be able to offer an italian thesaurus.

Qualifying the Corpus

- Problems:
  - we observed about 5% disruptive participants in the experiment
  - variability of rarely used names
- Solution is to collect explicit feedback on the global statistics from each participant
- More efficient than recruiting domain specialists



One characteristic of crowd-sourcing is the anonymity. Since the participants providing the data know that we do not know them, there is no incentive to be honest. Fortunately, we discovered that only a small number of participants is disruptive. To automatically cull bogus data, while reducing errors due to our own ignorance, we have provided a mechanism allowing other participants to judge the quality of a color-name pair. In particular, we allow negative scores to reduce the weight of bogus data.

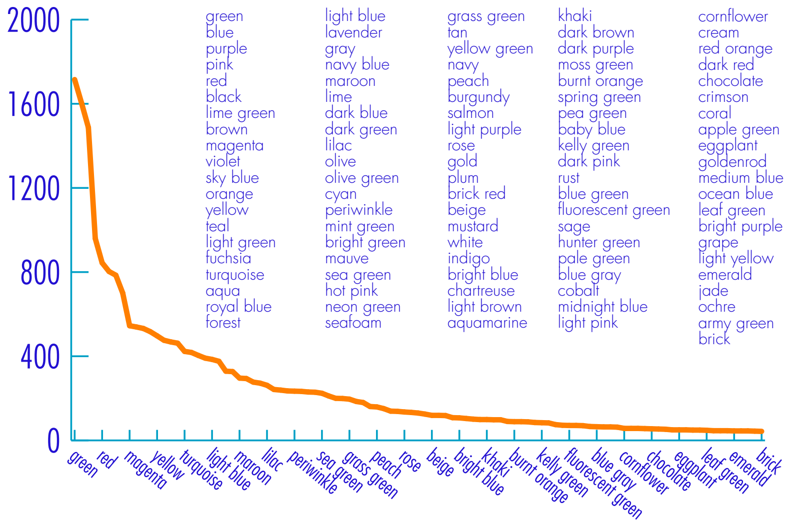
Expanding the Corpus

- Problem: Insufficient data in non-English corpora
- Solutions:
  1. brute force: adding a hundred names require tens of thousands of participants
     - because of redundancy (long tail distribution) this is very inefficient
     - when a name is missing, the cost for completing the corpus is high
  2. targeted harvesting: get participants to find sparse regions. . .
  3. . . . and submit relevant data

A more difficult task is to recruit a sufficient number of participants providing valuable data. Since English is the universal language of the internet, we have a sufficient amount of data in the English corpus. However, for the other languages we have found it very hard to obtain data.

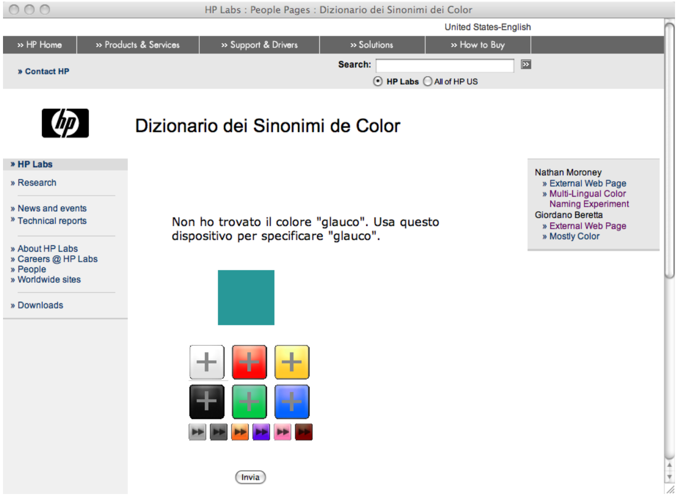
Because the participants operate autonomously, there is a high amount of redundancy in the data and it is clustered around the most frequent color names, due to being basic color terms or being in fashion at the moment. This prompted us to devise a mechanism to prompt data for sparse regions.

Contributed Name Distribution



This graph shows the frequency of the 101 most frequent contributed color names. This long tail distribution entail that it takes many contributions until less used names like warm pink are contributed in sufficient number to compute the average color for that name.

Expanding the Corpus



We achieved this by allowing participants to add a name when it is not found in the thesaurus. To make the graphical user interface somewhat interesting, we decided to deploy a kind of a remote control, which suggests a behavior somewhat reminiscent of that of a video game. We found a set of slider to adjust for example the CIELAB correlates for lightness, chroma, and hue would be two boring for our target participants. Of course, we could have implemented both and looked which one is used most, but lack the implementation resources for that.

3.3 Work in Progress

Limitations of the First Experiments

- We have solved:
  - how can we screen out bogus data?
  - how do we get scalability?
  - how can we make the experiments more collaborative?
- Remaining problem:
  - the categorization lacks fixed boundaries
  - synonyms are formed *ad hoc* by searching for the color names with the smallest CIECAM02 color difference greater than $5\Delta E^*_{02,C}$

In the first iteration the synonyms are formed *ad hoc* by searching for the color names with the smallest CIECAM02 color difference greater than $5\Delta E^*_{02,C}$. This means that instead of a lexical metric, we have an ordinary JND-based metric.

For a true thesaurus, we have to find the boundaries of categorical perception, i.e., the category boundaries across which color discrimination is more efficient than within [12]. One possibility would be to leverage on the work of Zuffi and her team, which has performed this kind of web experiment [29]. If their corpus contains enough data, it could be combined with our data to find the color categories.

Planned Extensions

Algorithm for determining categories

- explicitly ask user for a specific and a general name
- construct separate categorizations for each

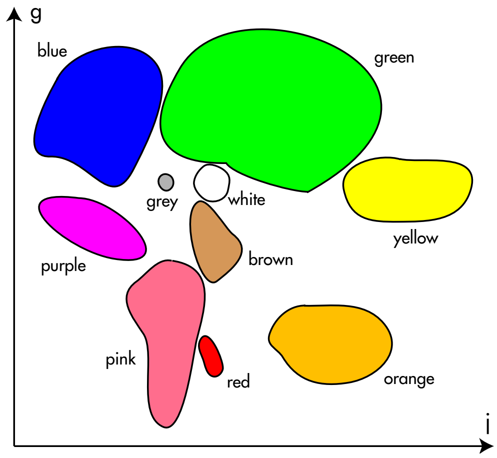
- explore boundary-finding algorithms

For the immediate future we plan to ask participants for two names when they specify the name to be used for communicating the appearance of a color. The first name would be a specific name for the displayed patch, while the second name would be more general. We would then use an averaging algorithm to find the categories for the color names in the corpus.

By filling a bucket data structure indexed by the colorimetric color coordinates of all color names and containing the averaged category names for each color as a decoration, would yield the color name boundaries, i.e. the perceptual categories.

If the resulting structured data could be compared with that of an experiment similar to that proposed by Zuffi [29], new insights into the mechanisms of color cognitions could be gleaned.

The Density of Color Names



The above figure is a plot in the g-j plane of the consensus color for the basic color terms from the Boynton-Olson paper [7, Fig. 2]. The color space is not tiled by the basic color terms, indicating that the basic color terms are not sufficient to categorize color names. This sparseness of the basic color terms has prompted many speculations and many papers on future trends in color ontogeny.

For example, Zollinger argues [27, p. 407] that with the invention of phtalocyanine dyestuff some 65 years ago, turquoise has become a common color all over the world and therefore is becoming a new basic color bridging the gap between blue and green.

Guest and Van Laar [11] have speculated that in addition of a new basic term for turquoise, there might also be new basic terms for mauve/violet/lilac between blue and purple, and khaki/mustard between green and yellow. The last term is a red herring, in that they were presenting the colors on a CRT in such low luminance levels, that yellow was only rarely named, with khaki and mustard being named instead.

Our technique based on crowd-sourcing may yield a tiled color thesaurus as that of the ISCC–NBS, updated for today and covering many languages.

3.4 Results So Far

Statistics

- 120’760 synonyms served from September 2007 through August 2008
- Syndicated by
  - Core Design 77 `http://www.core77.com/blog/object_culture/online_color_thesaurus_7966.asp`
  - Aubrey Jaffer `http://people.csail.mit.edu/jaffer/Color/Dictionaries`
- MagCloud reference magazine, available from `http://magcloud.com/browse/Issue/2344`

At the intersection of web-based development, natural language processing and color imaging is a powerful modality for modeling, manipulating and enabling new color imaging tools, techniques and analysis. Using color naming as a proven cognitive category with worked proof of concepts, we have created a machine color naming engine that exceeds any given human color naming. This artificial competence is then built into tools, processing techniques and analysis algorithms. This project then targets high-level content creation, organization and navigation problems by using the web to create tools that "get smarter" the more they are used. The initial focus will be on the color naming domain but we will have a progressively larger component considering other cognitive categories, such as shape, texture and image quality attributes. In addition, there will be considerable short term effort on identifying transfer paths and applications but there will also be a component devoted to securing fundamental results in a high profile publication. Our goal is to create the next generation of interface tools to enable more intuitive, efficient and ubiquitous content generation and to automate aspects of the current workflow that are currently beyond the scope of current tools.

Summary

Summary

- There are *applications* requiring a color thesaurus
- *Current solutions* are not adequate
- We have a *promising* early solution that scales well

- Outlook
  - Research is required to tile the color space and build a true thesaurus
  - Eventually, the tool should be so robust we can run it for a language none of us speaks

Acknowledgments
We are indebted to Prof. Lucia R. Ronchi of the Fondazione Giorgio Ronchi in Florence for many fruitful discussions and for compiling the book on *Color and Language*

Questions and Discussion

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