WHY 3 BASIC COLORS? WHY 4 BASIC TASTES?

Vladik Kreinovich
Computer Science Department
University of Texas at El Paso, El Paso, TX 79968

Abstract. In this paper, we give a general explanation of why there are 3 basic colors and 4 basic tastes.

The main advantage of having an explanation on a system level (without involving physiological details) is that a general explanation works not only for humans, but for potential extra-terrestrial intelligent beings as well.

INTRODUCTION

Why 3 basic colors? The mainstream color perception theory, dating back to Thomas Young (1801) and Hermann von Helmholtz (1850's) states that every color that we see can be expressed as a composition of three basic colors: red, green, and blue (see, e.g., [D86]). It is not only a theory: TV sets give us perfect colors by combining the three basic ones, and the nice colors on the computer that I am typing this text on are also composed of the same three basic colors. Why three?

Colors from a physical viewpoint. From a physical viewpoint, different colors correspond to different wavelengths (or, equivalently, different frequencies) of light. However, the fact that three colors are sufficient for a human eye has nothing to do with this physical observation: in real physical world, no combination of lights of wavelengths $\lambda_1, ..., \lambda_k$ can make a light with a new wavelength $\lambda \neq \lambda_i$.

So, the physical viewpoint does not help us to answer the question: why 3 basic colors?

There are 4 basic tastes. According to the mainstream theory (see, e.g., [B71], [L89]), any taste can be represented as a combination of a basic four: salt, sour, sweet, and bitter. Why four?

Existing explanations. One of the possible explanations (see, e.g., a popular survey [F93] and references therein) is that 4 basic tastes have the following meaning: sweet means high-energy food, salt means salt, bitter means poison, and sour means unripe.

What is wrong with this explanation. It is not very convincing. If the nature decided to distinguish between high-energy food and salts, why not go one step further and distinguish between different types of sugars? Or between sugars and proteins?

Another reason why this explanation may not sound convincing is that although some other species (with a similar biochemistry of life) also have 4 basic tastes, but their tastes correspond to somewhat different sets of chemical substances (see, e.g., [B71]).

What we are going to do in this paper is to provide a new explanation of the existence of exactly 3 basic colors and exactly 4 basic tastes. This explanation will not be based on any biochemical details, and can be thus potentially applied to any lifeform.

2. WHY 3 BASIC COLORS?

The following idea was first proposed in [K79].

We want the smallest possible sufficient number of colors. The more colors, the harder it is to implement them. So, let us find the smallest number of colors that would be sufficient for a human being.

What are colors for? Informal description of a problem. Among the main purposes of vision in a living creature are the necessities to notice potential food and potential menace (predator). How many colors are sufficient for that purpose?

Suppose that we are approaching some surface (e.g., the border of a forest, or a hill). A predator does not want to be noticed beforehand, so he tries to hide on that surface. Similarly, the creatures that are potential food for us want to hide. When is hiding efficient?

Formalizing this problem. If no colors are used (i.e., if everything is in only one color, black and white), then every point $\vec{x} = (x, y)$ on this surface is characterized by its brightness $I(\vec{x})$, i.e., in physical terms, by the intensity of the light emitted by this point. If we use c basic colors, then to characterize a point, we need the intensity of each of these colors. In other words, to characterize a point $\vec{x}$, we use c numbers $I_1(\vec{x}), ..., I_c(\vec{x})$.

Suppose that the color of a creature that wants to hide (i.e., a predator or a prey) is described by parameters $p_1, ..., p_c$. Then, a creature will be able to hide successfully if he can find a point (x, y) in which his colors are exactly the same as the background, i.e., if $I_1(x, y) = p_1$, ..., $I_c(x, y) = p_c$. So, we have c equations for two unknowns (the unknowns are the coordinates x and y).

Whether a system of equations has a solution, depends on the relationship between the number of equations (in our case, c) and the number of unknowns (in our case, 2). If there are more unknowns than equations, then in general, there is a solution. If there is exactly the same number of equations as there are unknowns, then there is in general a unique solution. If the number of equations exceeds the number of unknowns, then the system is over-determined, and in general, it has no solutions.

In our case, if $c \leq 2$, then in the general case, we do have a solution, so 1 or 2 colors are not sufficient. If $c = 3, 4, ...$, then we have a system of $c > 2$ equations with 2 unknowns. In general, such a system is inconsistent. Therefore, the smallest number of basic colors that enable us to detect a hiding creature is 3.

This explains why there are 3 basic colors.

Comment. The relationship between the numbers of parameters and the existence of the solution is an informal idea. However, under the appropriate formalization of the term "in general", this statement can be made precise (for an example of how similar argument in thermodynamics can be formalized, see, e.g., [G81], Ch. 10). Another physical applications of the similar line of argument can be found in [K92].

4. WHY 4 BASIC TASTES?

What are tastes for? Informal description. When we have a mouthful of useful food, it is necessary to detect whether there is any unwelcome part in it. One of the purposes of taste is to detect this part and thus not allow it into the organism. When is it possible?

Formal description. In this case, we have a 3-dimensional area filled with pieces of food that have different tastes. If we use t basic tastes, then to describe the taste in each point $\vec{x} = (x, y, z)$, we need t values: components of these tastes $I_1(\vec{x}), ..., I_t(\vec{x})$.

Suppose that the taste of the unwelcome part of food is described by parameters $q_1, ..., q_t$. Then, this part can remain undetected only if there is a place in this chunk of food with exactly the same values of taste parameters, i.e., when there is a point $\vec{x} = (x, y, z)$ such that $I_1(x, y, z) = q_1$, ..., $I_t(x, y, z) = q_t$. So, we have t equations for three unknowns x, y, and z.

Similarly to the colors case, we can conclude that in general, this system is solvable if and only if the number of equations does not exceed the number of unknowns (i.e.,, when $t \le 3$). Therefore, the smallest number t of basic tastes for which this system is not in general solvable (and for which, therefore, tastes make it impossible to hide an alien object inside the food) is $t = 4$. This explains why there are 4 basic tastes.

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