Progress and Poverty: An Inquiry into Color Appearance Modeling and Increase of Want with Increase of Wealth

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Abstract

In 1879, in post-civil-war America, Henry George published a very popular, and still referenced, book entitled "Progress and Poverty: An Inquiry into the Cause of Industrial Depressions and of Increase of Want with Increase of Wealth: The Remedy." The title of this paper is an obvious play off of George's title. George suggested that the so-called "Gilded Age", which was supposed to be a time of economic growth and reform for everyone in the nation, was not for many as the increase in wealth for some was accompanied by increased poverty for many others. George also had several creative solutions to these problems. When looking over the research and application of color appearance models (and fundamental colorimetry) across the 20 years of Color (and) Imaging Conferences, it becomes clear that there are also cycles of increased progress (wealth) followed by increased poverty (want) that somewhat parallel George's main thesis. In general, when new capabilities are developed, their shortcomings are quickly and sometimes vociferously elucidated and it can appear that the want of the shortcomings outweighs the wealth of the advances. In some situations that is indeed the case. This paper traces some examples of that path and reaches a destination describing one view of the status quo of color science.

Wealth and Want in Color Science

Looking back to the very first paper presented at the very first IS&T/SID Color Imaging Conference in Scottsdale, AZ in 1993, we find a very familiar and distinguished author, R.W.G. Hunt.[1] Hunt's title was "Color Reproduction and Color Vision Modeling" and included an exposition of Hunt's very elegant and comprehensive color appearance model of the day (although he preferred to call it a "Color Vision Model", and rightfully so). This illustrates that research on color appearance models and their applications (such as in color reproduction systems) lies at the very foundation of the Color Imaging Conference, CIC. While the term "Color Appearance Model" has since been used many times in CIC paper titles, it appears to not have been directly used in any papers from the first conference. Clearly Hunt's paper was largely on color appearance modeling and the paper of Kim, Berns, and Fairchild comes closest that year to laying the claim of being the first CIC paper to explicitly mention such models in its title, "Comparing Appearance Models Using Pictorial Images."[2] Strangely, those authors left the word "color" out of the title, perhaps assuming it was a given for the conference in question. In this author's one other shot at predicting future importance at the first CIC, color appearance models were a mere afterthought in a paper, with Nathan Moroney, on selecting the optimal color space for JPEG image compression.[3] The results of that paper seem to have been largely ignored despite the massive numbers of JPEG-compressed photographs created every day.

So the start was somewhat auspicious, but color appearance models were far from the main concern at the first CIC. Turning to Fig 1, one can trace the cycles of wealth and want in color appearance modeling and basic colorimetry (with the disclaimer that this is but one viewpoint that could easily change with a slightly different perspective or objective) with the aim of pondering our progress. The top of the figure corresponds roughly to 1993, the year of the first CIC. In the domain of color appearance modeling, there was CIELAB as a standard color space and some research into more advanced modeling going on by scientists like Hunt and Nayatani and some newer kids on the block such as Luo and the author. CIELAB had proven to be a very useful color space for color specification and tolerances and research was showing that it did a respectable job of predicting appearance scales of lightness, chroma, and hue for near-daylight illumination of moderate luminance level (it still does). Our wealth in 1993 was CIELAB, our want was that it just wasn't enough. What was wanted were "true" color appearance models that functioned over greater ranges of viewing conditions, included more appearance effects, and predicted more appearance attributes along with a simple and accurate color difference equation.

On the fundamental colorimetry side of things, the wealth in 1993 really consisted of the two CIE standard colorimetric observers that had well withstood the test of time since 1931 and 1964. The want consisted of a rumbling desire for more accurate color matching functions and an accurate representation of the variability in color matching functions across observers, or observer metamerism.

The wants in color appearance modeling (with no help for those wanting a simple color difference metric) were fulfilled by the CIE in 1997 with the creation of the CIE 1997 Color Appearance Model, CIECAM97s. The euphoria surrounding this major advance in color appearance modeling was amazing and yet very short lived as papers pointing out errors in shortcomings in the 1997 model were published as early as 1998 and the first technical committee formed by the CIE in Division 8 (Image Technology) was aimed at developing an improved version of CIECAM97s. Other wants at the time included desires for models incorporating more complex spatial interactions in the scene, for more predictive accuracy, for intuitive output over technically-correct but obtuse predictions, and, yes, for that simple color difference metric. Nothing really happened in the world of color matching functions, the fundamental input to color appearance models, in this particular time period.

Those wants were addressed (again ignoring those pesky color difference equations) with the creation of great wealth,

CIECAM02, through the fruits of great labor by the member of CIE TC8-01. In a parallel train of work, spatial and image quality questions were addressed in the framework of iCAM, an image color appearance model. Finally, it appeared that great wealth was available to all, the computational power was present to avail it, and the gilded age of color science had arrived. On top of that, a new cache of wealth in the world of color matching functions also arrived a few years later with publication of the CIE 2006 model for color matching functions as a function of field size and observer age.

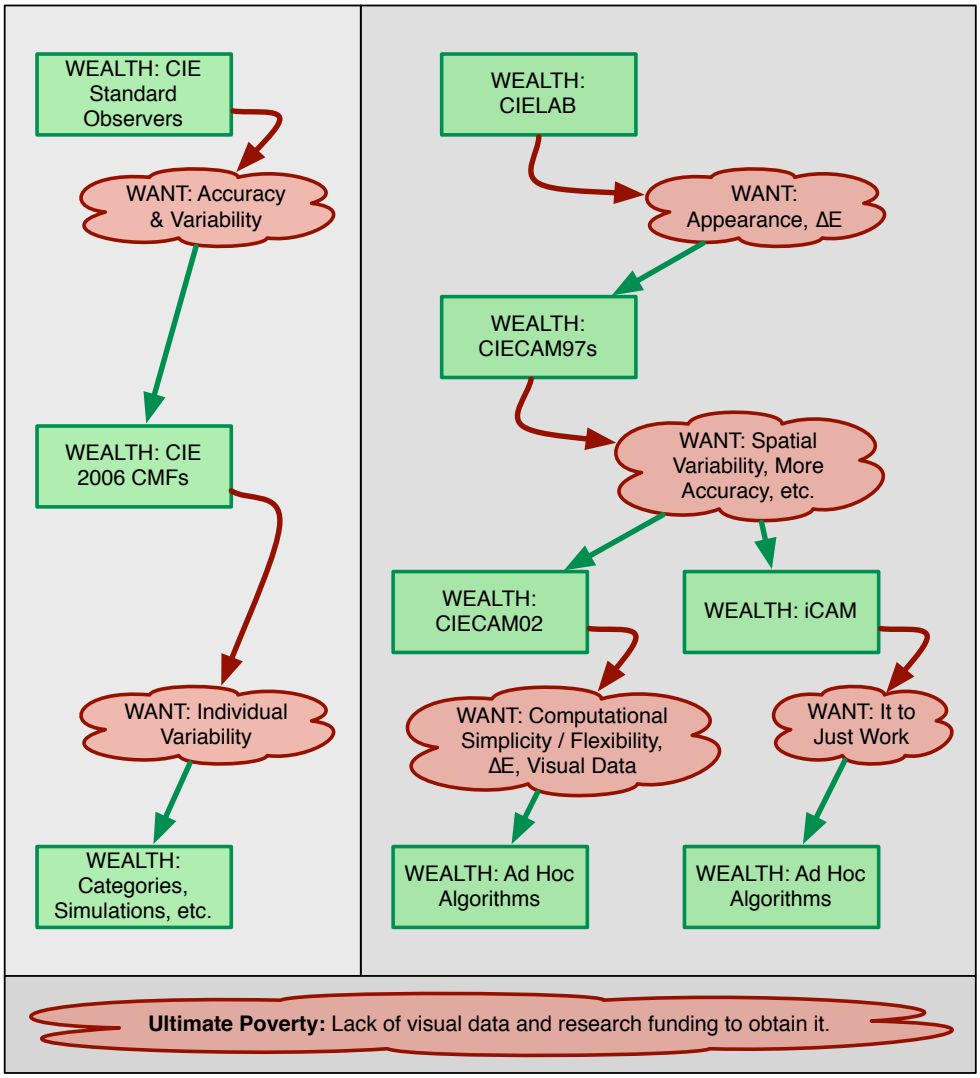

Figure 1. One view of the cycle of progress and poverty in research and application on color appearance models and fundamental colorimetry when pondered over the past 20 years of Color (and) Imaging Conferences.

Alas, the riches didn't materialize. Those CIE 2006 color matching functions, while a great advance that has still not been fully utilized, provide a measure of changes in the population mean, but still do not fully predict the variability of individual observers, a remaining want. CIECAM02 is widely used and generally successfully but also leaves want among its wealth. There are calls for intricate, but important, corrections to mathematical issues in the model that might improve its mathematical simplicity and flexibility. And, yes, there remain calls for a simple and accurate color difference equation that might be facilitated by an appearance model (since the efforts within CIELAB seem to have to give up "simple" to approach "accurate"), and there remains a severe paucity of visual data with which to test and improve the model. With respect to the wants resulting from the iCAM framework, it seems that there is a strong desire for such a model to solve everything with a simple flip of a switch. Unfortunately iCAM is not such a model, it is a framework, and it takes more effort to implement for a particular situation. Perhaps one day such a simple to implement model will be created, but it will be no easy task. To paraphrase Hunt, "the human visual system is very complex, that's why the model has to be complex".

Where does that bring us in terms of current wealth? In color matching functions there is a resurgence of interest in observer metamerism led by those interested in matching color across displays with wildly different spectral properties (*e.g.* laser primaries vs. broad-band filtered xenon primaries). Interesting results such as Sarkar's observer categories or recent attempts at simulating observers show some promise of finally solving research questions posed four or five decades ago. In the world of color and image appearance modeling it seems the great computational power now available (*e.g.*, essentially real-time HDR tone mapping in a smartphone) has led to a bit of a resurgence in the development of ad hoc algorithms to simple make images look "good enough" for a given application with little concern for the complex color vision science behind the perceptions. Perhaps that is for the best given the ways images are used and viewed in wildly disparate viewing conditions. This does bring up the question of whether the last 20 years of progress and poverty has gotten us anywhere at all. We could still improve our current imaging systems with material presented at that first Color Imaging Conference![1,3]

Alas, we can't take such a simple snapshot to judge the worth of 20 years of research as there is no question that the questions we can pose today and the tools that we can use to solve them have come a

long way indeed. Perhaps they aren't cycles of progress and poverty after all, but simple natural cycles that we keep trying to make into something more linear.

As we reach the 20th Color and Imaging Conference we can ponder the papers being presented. This author is presenting a new way to look at color appearance models as individual appearance scales instead of some intrinsically geometrically-related space.[4] This tears apart the foundations of previous models and builds a new paradigm for color appearance modeling that just might solve that pesky color difference problem as well. And the scientist who started us out 20 years ago initiates the final day of this conference with a talk entitled "The Challenge of Our Unknown Unknowns".[5] It seems that if they are unknown, then they shouldn't pose much of a challenge but I'm sure they will and will probably be topics of discussion at the fortieth Color and Imaging Conference

Where Do We Stand and Where Are We Going

At the bottom of Fig. 1 is a representation of the poverty created by the current wealth. In simple terms, the success of ad hoc algorithms (among many other factors) leads to a decreased desired for fundamental understanding in applied sciences. In terms of color appearance and observer metamerism, the severe poverty we are left with is a serious lack of visual data. Such visual data are very difficulty and very costly (time and money) to obtain. However, until such data are collected, the visual models of observer variability, chromatic adaptation, and appearance scales cannot be significantly improved. With corporate research budgets limited (or non-existent), the task of collecting such data falls upon the many qualified universities around the world. And those universities face the additional poverty of research funding from industry (that used to fund this sort of research) and from government agencies (that often fund more "fundamental" topics). These two challenges of funding for university programs and the desire to collect data fundamental to color science will need to be addressed by the greater community at some point. (Interestingly, David Wright, one of the fathers of colorimetry, made this same point about university funding in a paper he presented over three decades ago.)

It's not what you look at that matters, it's what you see.
-Henry David Thoreau

Please forgive the less than scholarly job of referencing this paper, really just an extended abstract. It's a keynote, it's late on deadline day, and the more detailed story along with hundreds of appropriate references can be found in the future.[6]

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And thank you to everyone involved with each and every Color (and) Imaging Conference for making this such a wonderful community to be a small part of.

So long and thanks for all the fish...
- Douglas Adams

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