Image Reproduction: An Oxymoron ?

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In our daily lives dealing with images, we have the mental notion that we are reproducing an original. This notion is generally helpful in guiding image and color processing decisions, but often it turns into a hindrance when artificial constraints are imposed on the conceptual original. This paper describes some scenarios in which a broader view than "reproduction" might be beneficial.

Introduction

When asking the question if image reproduction is indeed an oxymoron, it is helpful to take a look at the definition of the words. Since "image reproduction" seems to be the easy part of the statement, I will start from the back. A definition of "oxymoron" can be found as "a combination of contradictory or incongruous words"[1]. From this, it is easy to understand the term and one can easily find nice collections of oxymorons giving examples like:

wireless cable
proprietary standard
paperless office
original copy
unbiased opinion
self service
only choice
crash landing
negative gain
taped live

[1] Merriam-Webster on-line dictionary at http://www.m-w.com/home.htm

Despite the widespread use and acceptance of some of these terms, it is generally agreed that they are good exemplars of oxymorons. This leaves us with the more familiar "image reproduction" piece of the statement. Here it is sometimes helpful to also create a listing of exemplars from our interaction with other people that might not be as deep in the field as we are. From my personal experience I collected two actual statements that I will review individually. The first statement is

- **Accurate Colors that Look Good**

This statement is - on first look - an oxymoron, since it mixes the incongruous words "accurate" an objective metric with the subjective metric "good". The second statement is even more illuminating in that context

- **Make it Look Better - but You Can't Change the Data**

A dictate to change "make [..] better" followed by the clear statement that change is not permitted. Another oxymoron that will cause a smile on the face of every person familiar with image processing and image reproduction.

But both statements were made by people not in imaging, but in both cases these people were also educated and intelligent. It is thus not easy to just dismiss the statements as obviously misguided. Rather it should show us that we all operate in boundary conditions that contain some explicit and some implicit parts and that we are often unaware of that distinction. To be more fair to the people who made the previous statements, consider the following questions:

- **When you Listen to Your Favorite CD, Do You Want A Reproduction Of The Original Sound?**

- **What Are The Treble, Bass, Loudness, etc. Settings on Your Stereo Equipment?**

Answer both questions for all your different listening environments, answer them for yourself and for the other family members. How often did the answer to the second question contradict the answer to the first? And if they contradict each other, what will your remedy be? Will you change your amplifier settings or will you just say that you "like" the sound the way it is? In effect, the answer to the

first question is often nothing more than a reflex just like "accurate" and "can't change" were reflexes in the other responses. Acknowledging these reflexes is an important step in redefining the solution space in which we are trying to find the answers to our imaging problems. It also allows us to ask the questions in a different way:

Do we know the "original" and its physical quantities?

Can we reproduce these quantities?

Do we "want" to reproduce these quantities?

As soon as we answer a single of these question with "no", we also have to admit that we are picking a solution that has hidden failure modes. This can be understood with a simplistic example from image processing. Consider a noisy image and your favorite noise removal algorithm. Is removing the noise in an image you receive the right thing to do? The hidden failure mode in this scenario is the possibility - however small - that you received the photo in order to estimate the source of the noise so that some other problem could be solved.

The following will give a few examples to illustrate options that might arise when one of the above questions is answered with "no".

Lossy Compression

In lossy image compression such as JPG, JPEG2000, etc. the overall compression is achieved by a combination of entropy encoding and quantization, where the quantization introduces an unrecoverable loss. The operation $10/3$ results in the identical value as $9/3$ or $11/3$. Thus we have the situation of a many-to-one mapping where the reconstruction is not unique, as shown in Figure 1.

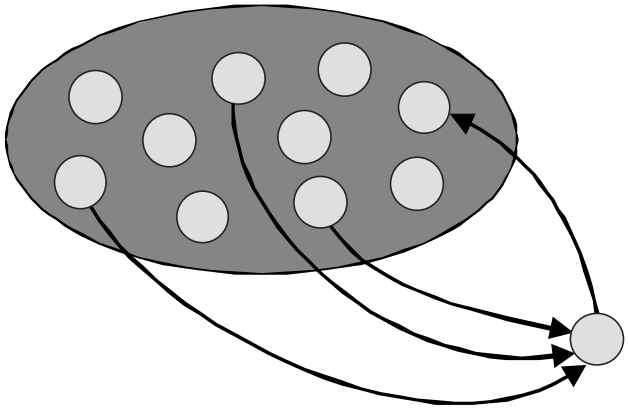

Figure 1. A many to one mapping found in lossy compression.

All the circles in the larger ellipse represent possible source images for the identical compressed form and reconstructing any one of the possible source images will always be only an approximation to the input original. Figure 2 shows an a reconstruction of an input image based on using JPG compression. It is obvious from Figure 2 that there are pronounced noise artifacts in the image.

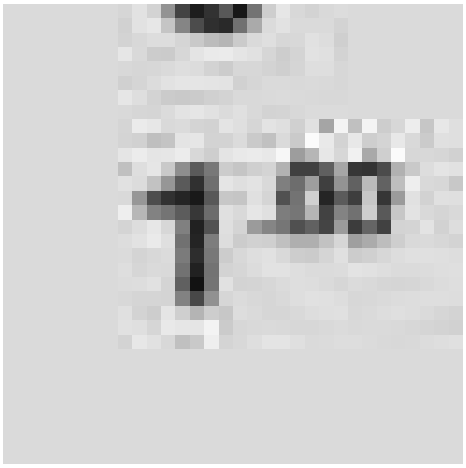

Figure 2. Obvious noise artifacts from compression. Or not?

Considering the reflex response, we have to acknowledge that there are no clear noise artifacts in the image unless we make some assumptions that might or might not be correct. Is this image intended to be an illustration in a JPG book? Or is this image a copy of a bill I requested? Making the assumption that the ringing present in Figure 2 is not part of our "desired" solution, we can derive a filtered image as shown in Figure 3.

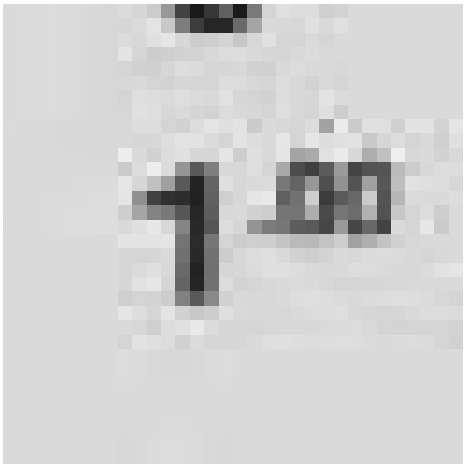

Figure 3. Noise filtered decompression maintaining data integrity.

The important aspect of Figure 3 is that the image is "as true" to the compressed form, as the image in Figure 2. Both images have the bit for bit identical compressed form. As such, this image is not a noise filtered version of Figure 2, but rather a different, less noisy reconstruction of the compressed data, where "noise" is intended to designate visual perception, rather than signal disturbance.

Gamut Mapping

Any mapping of an input to a new output that is caused by the inability of the output device is in itself a sign that the physical quantities can not be reproduced. Ignoring the fact that the tristimulus values are already a transformation that includes a variety of assumptions and approximations. Consequently, any so called "objective" gamut mapping can be viewed as the objective adherence to subjective criteria, thus rendering it "objective" in name only. Figure 4 shows the example of a gamut mapping experiment, where experts were asked to judge the quality of "reproduction" for two gamut mapping algorithms labeled "A" and "B".

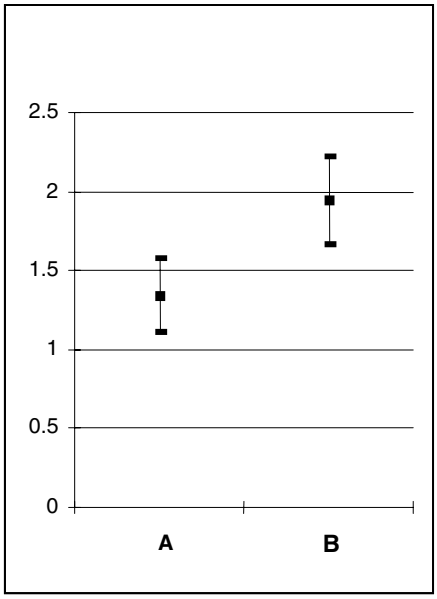

Figure 4. Quality of reproduction as rated by expert observers.

As can be seen from the Bradley-Terry scores, the method indicated as "B" was considered to yield better reproduction, despite the method indicated as "A" having a clearly lower "objective" metric in terms of ΔE. The outline of the method used in "B" is as follows. The input image underwent a standard gamut mapping algorithm, the difference between input and output was then considered process error - keeping in mind that the "original" already incorporated a large set of implicit assumptions, causing many more errors - and the process error was filtered using a well defined criterion. In our case, a high pass filter was used on the luminance channel and the chrominance error was ignored. This filtered error was fed back into the system and a secondary gamut mapping step was performed, this time emphasizing luminance preservation. The general layout is shown in Figure 5.

The real interesting part of the result of this experiment, however, is not the better performance of any of the method, but the experts response to a clear "reproduction" question. There are several explanations for this. The first one is that the experts have difficulties examining color differences. A second one is that even experts will subconsciously mix the explicit requirement "reproduction" with the implicit "preference". In all likelihood, the real answer is a mixture of these two and potentially some other explanations. The main lesson to learn is that not only lay people fall into the "oxymoron" trap created by implicit and explicit requirements, but that we as experts too are human.

Knowing that reproduction in this scenario is futile - we only needed to do the mapping exactly because we could not reproduce - one is better prepared to take a step back and investigate methods that are clearly and intentionally deviating from the implications contained in the word reproduction. The method shown in Figure 5 has the advantage, in this context, that the two interacting gamut mapping steps G1 and G2, as well as the spatial filter F explicitly show the locations where boundary conditions and thus trade-offs come into place. It is thus easier to turn the implicit requirements into explicit ones.

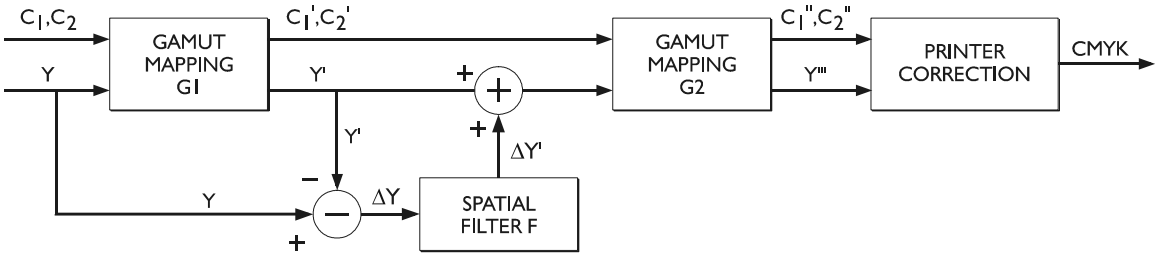

Figure 5. One possible structure for a spatial gamut mapping process.

Image Enhancement

Lossy compression and gamut mapping were cases where we did not know the original or did not have the means to correctly reproduce, but there are many more cases, where we actually do not *want* to reproduce what we have as input. The case of noise filtering is an obvious one, however, even here we should be more explicit in the assumptions we make about the inputs, the noise sources and the output requirements.

Another large area is the area of general image enhancement of other image attributes, such as contrast, color balance, sharpness, or the like. Often we keep certain attributes fixed, just because we have reproduction in our mind, but equally often, we forget algorithm side effects and make judgements that are heavily influenced by these side effects.

Conclusion

In our daily lives we are using terms that albeit neutral on the surface have a large value based component. Whenever we apply any of these words in our work we will also inherit a large amount of implicit baggage that goes with the term. "Reproduction" is one such word that appears to be neutral, but contrasting it with "preference" we see that we attach a strong value to the work. Conversely, we often use the same words to describe our work in order to add the perception of impartialness and truth. Quite often, however, these words are actually covering some of our implicit assumptions, assumptions that we do not communicate to the recipient of our work and assumptions that might simply be "wrong" in the context where our work is applied. We should therefor be more "honest" with ourselves and clearly state the assumptions we made, the common sense short-cuts that never seem to be common. This will give us and the users of our work to get a better estimate of the "odds" we are playing and the failure modes we might encounter.