

## When Artificial Intelligence Meets Printing The Evidence of Black Generation

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### Abstract

Recent years wit a rapid development of new technologies. As a significant part, artificial intelligence leads to a great change of our life. While the color printing technique which is struggled with obstacles such as color reproducing now finds a revolutionary approach to overcome the difficulties. The new method significantly improved the accuracy although it requires the parallel computing process to deal with the complexity of computing. This paper firstly introduces the brief histories and the basics of black generation technique of the printing process and artificial intelligence. Then comes to the traditional techniques of black generation. In the next part we suggest an artificial intelligence approach to black generation. At last we make a comparison between various methods and point out the advantages of the new approach.

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### 1. Introduction

Printing technique as a traditional subject is playing an important role in publishing. Especially the four-color printer which is the most common device used in the paper media, still maintains the leading position in the industry. Color management, the key part of printing workflow, tends to be important and attracts various attention. As some researchers pointed out[1], a certain color could be separated uniquely into red, green and blue components by the additive color process or into cyan, magenta and yellow by the subtractive color process. While the combination of cyan, magenta and yellow is not pure black, we should add black component to calibrate the separation. Black generation which is the methodology to generate the black component considers to be an important part of color management. There are some traditional ways to do black generation such as gray component replacement, under color removal and so on[1].

While the results of the methods could not satisfy the professionals quite well. The researchers in some famous corporations such as Adobe and Xerox are searching for a new method to improve the accuracy

of black generation technique. Nowadays, the advent of artificial intelligence offers a potential way to reach the goal.

Artificial intelligence is developing for over 60 years. The concept was introduced to deal with the imitation game and, as Turing says, to make machine think[2]. After that, the topic attracts much more interests of the people in the fields of computer, cognitive neural science, psychology and some other subjects. Especially in the recent decades, considerable applications of artificial intelligence are taking place in all walks of life.

As the most popular structure in artificial intelligence, the construction of neural networks appears similarity to the workflow of the black generation in the printing as the iteration. This inspires us to consider the potential application of the neural networks into the process of black generation in the printing.

This paper focuses on the the combination of black generation and artificial intelligence and is arranged as following. The basics and history of black generation will be introduced and followed by the traditional techniques. Then we come to the history of artificial intelligence and the model of neural network. At last we introduce a new approach of black generation applying the thought of neural network construction.

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## 2. Printing

Printing is the science concerns on the quality of the mechanical copy of the documents. It is relevant to color science, material science, visual communication, physics and some other subjects as well. As a traditional industry, it is including lithography, gravure and screen printing. The pattern to be printed is traditionally embodied in a physical form. Nowadays, the industry represents a major area of economic activity and the patterns to be printed are defined digitally[3].

### 2.1. The basics of printing

Printing, especially inkjet printing is based on inks, print engines and imaging medium such as papers. The science concerns on the properties of inks as fluid, colors based on optics, human visual systems, the materials of paper, the feelings of human related to psychology and much other aspects[3]. It could be sophisticated with the cross-subject foundation. This feature makes it much challenging to deal with the issues in any aspect of the technique.

### 2.2. Color management and gamut mapping

Color management which is treated to be an essential participant in the printing workflow was initially introduced in early 1930s. With the development through these decades, kinds of approaches have been applied into this area.

As the printing devices are different from each other, the gamuts are also various. To compare with each other and get the accuracy of representation, we should firstly map all the gamuts into link space which is called profile connection space(PCS). As PCS is used to link different devices, it commonly should be device independent. There are several different device independent color spaces defined by the International Commission on illumination, which is abbreviated as CIE for its French name—Commission Internationale de l’Eclairage. CIELab, CIEXYZ and CIELuv are the PCSs most commonly used. To map the colors in different spaces, one should apply the connection space as a link[1].

## 3. Black generation

Black generation refers to the quality of color printing. As the most commonly used color in the printing, black significantly influences the quality of reproducibility of the presswork. The aim of black generation is to get the appropriate black color in order to increase the gamut size, reduce the costs, improve the quality of details and make gray balance more stable[4].

The color management technique has taken place since early 20th century with the appearance of printing. As a part of color management, black

generation technique—although is not called in this term in some occasion—is developing for several decades. Nowadays the wider application of printing leads to an urgency requirement of black generation to improve the quality and control the cost of the printing. Several companies such as Adobe and Xerox have made some effort for that goal, but the result of the experiments are still not with an industrial implementation by now.

### 3.1. ICC profile

ICC, the abbreviation of International Color Consortium, is also used as a file format which is focusing on storing the key information through the gamut mapping workflow. ICC profiles provide numbers of color transformations usually in the form of lookup tables, matrices and curves. Each profile is defined for a specific combination of device and media. ICC profiles play important role in the color reproduction system and are typically applied for color reproduction by combining a source profile with a destination profile to enable input data to be transformed to that required to give the required color on output[5].

### 3.2. 3D-LUT: the basement of black generation

In modern printing systems, look up table(LUT) is the basement of color calibration. It is constructed by sampling from the gamut of the printer and mapping into the PCS by the colorimeter. According to the dimensions of the color space, the LUTs could be classified as 1D-LUTs, 2D-LUTs, 3D-LUTs and so on. The 3D-LUTs are commonly used to get the samples in 3 dimensional spaces especially the CMY(K) space and the CIELab space. Based on different sampling techniques, we could get uniformly spaced LUTs and nonuniformly spaced LUTs which slice the color space in various ways[1].

## 4. Interpolation technique and spline function: the key point of black generation

The common method for calibrating a function with scatters is interpolation. There are different interpolation methods[6, 7] to simulate the 3D-LUT, such as trilinear interpolation, pyramid interpolation, prism interpolation, tetrahedral interpolation. All the methods listed above are restricted to some certain cases and specific types of LUT to achieve the best accuracy, although the methods for the nonuniformly spaced LUTs still satisfy the uniformly spaced case[1].

### 4.1. GCR

Gray component replacement(GCR) is a part of the common way of black generation. As pointed out, color

has three interrelated attributes: hue, saturation and value(HSV). GCR is the process using black to replace the equal portions of cyan, magenta and yellow. As these three colors are overprinted, the two predominant ones determine the hue while the lesser third one determines the saturation and converts parts of the color into gray. That is why the procedure is called gray component replacement[8]. An approach to implement the GCR is using Neugebauer Equation[9].

#### 4.2. UCR

Under color removal(UCR) could be treated as a special case of GCR. It takes replacement of CMY by achromatic or near-achromatic colors to maintain the color. The substitute could be gray or black depending on the level of the CMY combination[5].

#### 4.3. Gray balance searching: accelerating method of the workflow

Before discussing the gray balance, we should first come to some basic concepts of human visual systems. Human visual system which is abbreviated as HVS is modeled by a linear function. It considers the reaction of human neural systems to the color. The gray balance approach combines cyan(C), magenta(M) and yellow(Y) to achieve a neutral gray state. In order to do this, we should determine the relative proportions of CMY in the gray balance state. While the nonlinearity of the proportion under different degree of gray(0–255) makes it difficult to calculate the accurate analytical solution of the gray balance function only with the sample nodes. To get the gray balance status, we should set the control points to neutral[10]. After the process of gray balance, we could take the operation of channel-independent linearization to get the tone reproduction curve, which is the curve that shows the relationship between reflectance and the ink density[1].

#### 4.4. G7 Calibration

Another trick used in the process is called G7 calibration. It was designed by the International Digital Enterprise Alliance which is a professional group from America focusing on printing, publish and design. The letter G stands for gray and the number 7 means the seven basic colors used in printing: red, green, blue, cyan, magenta, yellow and black. G7 calibration is applied to the process of black generation and is based on the gray balance technique. The method utilizes two neutral print density tonal curves, black and combined CMY gray, to achieve the target of CMYK near neutral gray balance[11].

#### 4.5. delta E: The accuracy criteria

The reproducing of colors is essential to printing and different methods are developed to estimate the goodness such as color matching function. The official standard is called delta E which is initially introduced by the International Commission of Illumination. Before coming to the details of delta E, we should first discuss the ways to measure a color. A color could be described with three independent features. There are several ways to separate a certain color such as Lab, Luv, RGB, HSV and so on. Different ways concern on the different aspects of the color and separate the color into different spaces.

The concept of delta E is firstly introduced in 1931 on the conference in Cambridge held by CIE to measure the difference between two colors. This first version is called CIE31 standard. During the later decades, some other versions like CIE76, CIE94 and CIE2000 are suggested. Delta E could be approximately considered as the distance between two colors—usually the target and the simulation. The later versions apply distinguishing equations with various parameters from the former ones in order to estimate the difference more precisely.

### 5. Artificial Intelligence

Artificial intelligence(AI) is not a new concept but draws much attention just for about nearly ten years. While the last decade saw a great boom of AI and—as a result—a rapid change in the industry and our life. In this part, we come to some basics for artificial intelligence.

#### 5.1. Brief History

The concept of artificial intelligence was introduced by Alan Turing in 1950[2]. Some former works were done by Warren McCulloch and Walter Pitts in 1943. Artificial intelligence is designed to simulate the workflow of the human brain. It combines philosophy, mathematics, economics, neuroscience, psychology, computer engineering, control theory and linguistics[12]. In recent years, the rapid development of new industries related to the AI technologies makes a revolutionary progress in the society.

#### 5.2. Basic concepts and mathematical foundations

The primary ways to implement artificial intelligence are commonly based on linear algebra and probability to describe the workflow of human brain. It employs the input vectors to represent for the stimulation to the network. An activation function is introduced to control the response of each layer. The function is commonly sigmoid or linear to figure out the thresholds of the different outputs based on the change of inputs. The

state of each node in the network is a result of the influence of the former layers and affects the following layers as well. The final output should be judged by some criteria such as the precision rate and the ROC.

### 5.3. Common neural networks and models

The common models used in artificial intelligence are called neural networks. Those are the architectures constructed by nerve cells, or similarly, the perceptrons which are used to represent the states of each period. All the states in the same period make up the layer in the network. We also add the so called activation function into the network architecture to simulate the response of the nerve cells to the stimulus. The kernel function is introduced to deal with the information flow through the network. According to the various structures of neural networks, the activation functions and the kernel functions could be various.

## 6. New way to black generation: an inspiration from artificial intelligence

In the above, we remind the interpolation method of the black generation based on the lattice in the color space. We also come to the construction of the neural networks which depends on the hidden states. Compare with each other, it is delighted to see that the workflow of color management employing the sequential interpolation lattices is similar to the construction of the convolutional neural networks with hidden layers[1]. It is a natural thought that the method to construct the neural networks may give us some inspiration to black generation. The following parts will focus on this topic and try to find some new ideas to realize this goal.

### 6.1. Similarity: Neural network construction and color management workflow

In the construction of neural networks, one should consider the inputs and the outputs of each layer, the activation function and the relationship between layers which is usually described by matrix. Compared with the workflow of color management, the similarities are revealed as the application of psychology, cognitive neuroscience and the construction process. In the gamut mapping process, the LUT could be treated as a lattice and the lattice-based sequential interpolation provides an approach for the gamut mapping workflow. The stages could be simply described as following. Firstly decompose the color space into several subspaces. Then for each subspace, do the following operations. 1) Generate a uniformly spaced lattice and independent test target in CMY space by invoking a random number generator. 2) Measure the CIELab values for both the lattice and the test target. 3) Get the

LUT that maps CMY to CIELab through all these sample values. 4) Select a three-dimensional interpolation technique to obtain the CIELab estimations of the CMY samples, then compute the delta E between measured and computed CIELab values. 5) Write the average and 95 percentiles of delta E as functions of the lattice size. After that, we could get the new color which is visually similar to the sample color[13].

### 6.2. Difference: Mathematical basics and tricks

Aside from the likeness, some distinctions can also be figured out between the two techniques. Black generation is based on the traditional interpolation method and focuses on the simulation technique. While artificial intelligence turns to be more probabilistic. The structures of each layer could be similar while the relationships between layers are built up in different ways. In the black generation workflow, the relationship is constructed by a direct substitution. On the other hand, an activate function with threshold is employed to simulate the relationship between hidden layers in a neural network. The later one provides more flexibility which means a wider range of application.

### 6.3. A potential approach of combination: applying neural network ideas to black generation

As we discussed above, although the traditional ways to generate the black components are widely used in the printing systems, there are various of obstacles faced in the workflow. The similarities of neural networks and color management inspire us to think about the probability of combination. Some researches[13] have made some attempts for this goal. Based on these works, we suggest an approach for the black generation workflow. Firstly, we get the initial estimation to the target color following the steps in section 6.1. Then we combine the results of the subspaces sequentially to achieve a smaller interpolation error. New samples and slices could be added into the iteration until the accuracy of the result is acceptable.

### 6.4. Comparison of the accuracies of different black generation ways

In this section, we apply four different ways to interpolate the LUT and compute the delta E as the accuracy of simulation. The four interpolation methods evaluated here are trilinear interpolation, tetrahedral interpolation, shepard interpolation and sequential linear interpolation(SI) which is described in the previous section. The criteria we applied here is the average of delta E, the 95 percentile of the sample delta E and the standard deviation(std dev) of the sample delta E(dE). We reproduce the same color set using different samples. For each sample, we employ all the

four approaches. At last we measure the delta E(dE) with the colorimeter and get the sample average delta E, 95 percentile(95 pct) of delta E and the standard deviation of delta E.

Method	trilinear	tetrahedral	Shepard	SI
avg dE	1.149	1.448	1.644	0.044
95 pct	2.764	2.736	2.735	0.281
std dev	0.809	0.524	0.545	0.118

From the table we could see that the the sequential interpolation method reaches the lowest delta E and standard deviation and makes a significant improvement to the traditional ways.

## 7. Conclusion

We now could take a brief summary and draw to a conclusion. As we can see, the artificial intelligence, especially the construction of neural networks shows a similarity to the workflow of black generation. We try to find out a new approach for implementing the traditional technique. The new approach takes advantage in the following aspects. Firstly, it applied the iteration theory to reduce the error of interpolation. Secondly, the utilities of neural network construction are employed to accelerate the interpolation process. But there are still some issues to be solved. The first one is the error control including the simulation error, the measuring error and the precision of computation. The computation complexity is another factor to be considered and a parallel computing architecture should be employed. There is a balance between the complexity of computation, the memory requirements and the accuracy of approximation in practice. In our experiment, the error is controlled within the limit of recognition.

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