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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