A Research of Image Difference Algorithm Based on the Correlation of Color Attributes

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***Abstract*—The CIE color difference formula was developed using simple color patches in controlled viewing conditions. They are not suitable for predicting color differences of spatially complex images. In order to quantify color differences between the original and reproduced images, we present an image difference algorithm based on image contents. This formula uses the Contrast Sensitivity Functions (CSF) to reduce the spatial complexity. The CSF serves to remove information that is imperceptible to the human visual system. This algorithm determines the color attribute weights by means of the correlation analysis between image pairs. Psychophysical experiments confirmed that the metric correlates strongly with the human perception. The proposed algorithm can be used to assess the performance of color image compressions, color image enhancement algorithms, gamut mapping algorithms and so on.**

***Index Terms*—image processing, color vision, color difference, image difference**

I. Introduction

The goal of research on color differences is to use numeral values to evaluate color differences between two objects. In order to develop easy-to-use color industrial applications, CIE recommended two color difference formulas: 1976CIELAB and 1976CIELUV[1]. These two color difference formulas are used directly to represent the distance between two points in the corresponding color space. Since CIELAB and CIELUV are not completely uniform visual color space, the distance between two points cannot represent the exact visual difference. Then CIE launched CIE DE94[2] and CIE DE2000[3] color difference formulas, which put color difference researches to a new stage. These color difference equations improved the accuracy of the mapping between physically measured stimuli and perceived differences. However, these complex formulas can only predict simple perceptible differences between a pair of color patches under a given viewing condition, they cannot predict color differences between images with spatial complexities.

In order to quantify the color difference between complex images, S-CIELAB[4] was proposed as the first image difference model based on the CIELAB color space and color difference formulas. This model is an extension of traditional color difference formulas, in which image pixels are considered as separate objects, and Contrast Sensitivity Function(CSF) was added before calculating the color difference of image pairs. The use of CSF can remove the information of image that is imperceptible to the human vision. S-CIELAB model has been modularized[5], and the corresponding module can be added or modified to develop a new image color difference formula. Image Color Appearance Model(iCAM)[6,7] which is accomplished as a spatial filtering pre-processing can be used to calculate the image difference before a pixel-by-pixel color difference calculation in an uniform color space IPT[8].

In order to represent the image difference more accurately, this paper proposes a new image difference algorithm based on the S-CIELAB model. In our proposed algorithm, the spatial statistic characteristics of each image have been analyzed and combined with the current image difference model so that the calculated image differences will be more correlated with human vision responses. In this work, we modified the image difference model by adding the CSF function to minimize variation caused by different viewing angles and then further adjusted the color difference by carrying out color attributes correlation analysis on each image. The performance of the proposed algorithm has been evaluated and tested on different types of distorted images, and the results indicate that the image difference calculated by the proposed algorithm is more consistent with the human visual response than the traditional image difference model.

II. The Proposed Image Differnce Algorithm

The framework of image difference model has been proposed in an earlier work[9], in which spatial pre-processing modules are extensible with great flexibilities. Our proposed image difference algorithm is based on the

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current image difference model by adding individual models. Figure 1 illustrates the framework of the calculation process for the color difference of the image pairs.

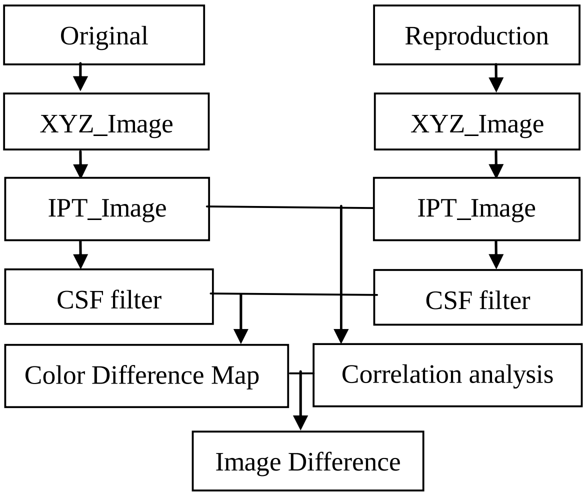


Figure 1. Flowchart of Image Difference Measurement Difference Metric

The calculation of the image difference of an image pair is divided into two parts. The first part is image processing using CSF filter, which is designed to simulate some visual characteristics of human eyes so that the filtered image will meet some aspects of visual features of human eyes. For example, S-CIELAB and iCAM image quality measurements are using CSF functions to simulate spatial frequency behavior of the human vision. The second part is pixel by pixel color difference calculation, which can use color difference formulas recommended by CIE. The calculated image difference can be recorded using statistical methods, such as the average color difference of all pixels, the overall deviation, the maximum value and so on. This framework inherits the characteristics of iCAM image quality measurement, and the color difference is calculated in the uniform color space IPT, which is the key part of the of an image appearance model. This framework allows great flexibility in the choice of color spaces and in this model we also use IPT color space because of its excellent color uniformity.

The proposed image difference algorithm mainly includes three aspects. The first one is CSF filter pre-processing which describes the behavior of the human visual system in regards to spatially complex stimuli. The CSF is described as a post-retinal opponent color space, with a band-pass nature for the luminance channel and low-pass nature for the chrominance channels. More are discussed in details by Johnson and Fairchild[10]. The following equations[11] explains the CSF in this framework:

$$CSF(f,l,i^2) = ((3.23(f^2 i^2)^{-0.3})^5 + 1)^{-0.2} \times A1\varepsilon f e^{-(B_1\varepsilon f)} \sqrt{1+0.06e^{B_1\varepsilon f}} \quad (1)$$

$$A1 = 0.801\left(1+\frac{0.7}{l}\right)^{-0.2} \quad (2)$$

$$B1 = 0.3\left(1+\frac{100}{l}\right)^{0.15} \quad (3)$$

Where f is spatial frequency in cycles per degree of visual angle(CPD), i^2 is image size, ε is frequency scaling constant, l is the light adaption level(cd/m2).This function is capable of predicting the effects of many changes in the viewing conditions, which contain the image size, viewing distance, environment luminance and so on.

The second aspect is IPT color space conversion, and more details of IPT can be found in the literature[8] in references.

The third aspect is the calculation for the correlation of three attributes of color, which is completed in the IPT color space. The calculation of the correlation of color attributes is the most important part of the proposed algorithm, and will be described in details in the next paragraph.

III. Principle of Image Difference Calculation Based on Color Attributes

The biggest innovation of the proposed image difference algorithm is to add image color attributes correlation analysis and calculation. Image pairs' correlation will be analyzed in the IPT color space, and the respective correlation coefficients of color components will be determined and used as weighting factors to calculate image differences. The color difference between the original and the reproduced images can be understood as a color similarity between two images. The meaning of the similarity includes differences between a pair of images of both color values and spatial distributions. The average color difference value of all pixels is used to represent the overall deviation. The correlation coefficient is calculated to measure the difference of image pixels in spatial distributions. The correlation analysis is carried out in IPT color space which is an orthogonal space, therefore it is equivalent to the analysis of correlation with three attributes of color: hue, lightness and saturation. The problem can be mathematically solved by computing the correlation of two sets of data as Equation 4:

$$r_{xy} = \frac{s_{xy}}{\sqrt{s_{xx}}\sqrt{s_{yy}}} \quad (4)$$

Where r_{xy} is the correlation coefficient of two sets of data. s_{xy} is the covariance of two sets of data, $\sqrt{s_{xx}}$ and $\sqrt{s_{yy}}$ represent the separate variance of two sets of data respectively. r_{xy} is the correlation coefficient and $|r_{xy}| \le 1$. The value of the correlation coefficient can represent the degree of similarities between spatial dichotomous data sets. If the absolute value of the correlation coefficient is 1, it means that the two sets of data is equal, so the associated color component is equal.

Small absolute correlation coefficient values may indicate large distribution differences of the two sets of data and large differences for the image color components, so the color differences between the image pairs should be large as well.

For S-CIELAB and iCAM, during the calculation of the image difference, the average value of color differences of all of image pixels is considered as the image difference. However, the average value can only reflect the variation of concentrated locations of image data, it does not reflect the characteristics of spatial dispersion of those data sets. The color property of images is space-related, to obtain the color difference between image pairs, analyzing of the spatial distribution of the image pairs' color data will be much more significant than obtaining concentrated locations. Because the average value does not fully represent the mean image color difference between a pair of images, so in this work based on the conventional color difference formula between image pairs, modified image difference formula has been established. Weight coefficients are the correlation coefficients for the respective color component plane of image pairs. Therefore, the color difference formula between image pairs based on traditional color difference formula is modified as Equation 5:

$$\Delta E = \sqrt{\frac{\Delta I^2}{I_r} + \frac{\Delta P^2}{P_r} + \frac{\Delta T^2}{T_r}} \qquad (5)$$

Where, ΔE represents the color difference between image pairs, ΔI represents the average value of the brightness component , ΔP and ΔT represent the average value of the chromatic component, I_r represents the correlation coefficient of I plane, P_r represents the correlation coefficient of P plane and T_r represents the correlation coefficient of T plane.

IV. Objective Evaluation

In order to verify the performance of the proposed image difference algorithm, we selected several different types of distorted images from TID2008 database[12]. TID2008 is designed for the evaluation of full-reference image visual quality assessment metrics, and it allows estimating how a given metric corresponds to the mean human perception. TID2008 contains 25 reference images and 1700 distorted images (25 reference images x 17 types of distortions x 4 levels of distortions). Mean human perception (MOS, Mean Opinion Score) is used to represent average visual image quality, and higher value of MOS (0 - minimal, 9 - maximal) corresponds to higher visual quality of the image. In our evaluation experiment we chose three distorted type of images: Gaussian blur, JPEG compression and Contrast change, and all images are chosen randomly. Each distorted type is divided into four levels, so there are 36 pairs in the trials. The MOS values are shown in Table 1.

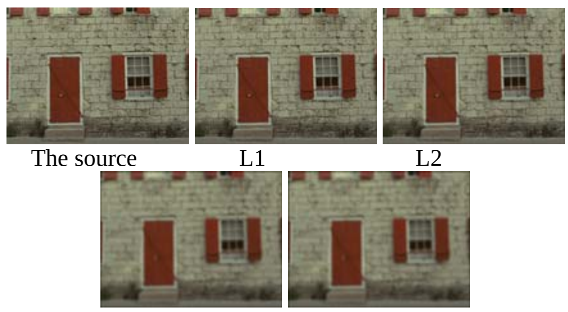
Table 1.
The Evaluation Datas of Objective

Distorted types		Test images					
		Image 1		Image 2		Image 3	
		MOS	ΔE	MOS	ΔE	MOS	ΔE
Gaussian blur	L1	4.7353	0.012	5.7931	0	5.4063	0.004
	L2	3.9143	0.016	5.2414	0	4.6875	0.006
	L3	3.2778	0.021	4.0000	0.003	3.5313	0.007
	L4	2.1765	0.023	3.0690	0.007	2.7500	0.008
Jpeg compression	L1	5.9444	0.003	6.3929	0.002	5.8667	0.002
	L2	5.1667	0.007	5.4138	0.002	5.3438	0.002
	L3	3.3056	0.044	3.1667	0.016	3.2813	0.043
	L4	1.4571	0.041	2.2667	0.021	1.2581	0.069
Contrast change	L1	6.5000	0.104	7.2000	0.122	7.2188	0.051
	L2	4.9714	0.081	5.5333	0.100	5.2258	0.042
	L3	6.1944	0.181	7.0667	0.163	7.2813	0.132
	L4	3.9722	0.131	4.5333	0.163	3.7742	0.072

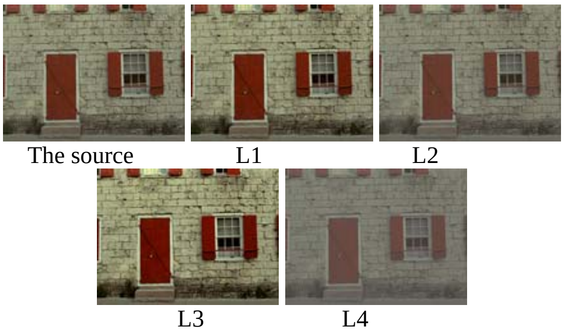
Color differences between the source images and the corresponding distorted images are calculated and the results are also shown in Table 1: small ΔE values indicate the difference between two images is small, and bigger ΔE values indicate larger color differences for image pairs.

In this table the MOS is arranged in the descending order for each distortion. It is clear that the calculated image difference values are in ascending orders. With the decrease of the MOS values, the trend of image difference values increases for each type of distortion. This result confirms that the proposed image difference algorithm can predict the effect of image distortion, and is consistent with human visual perceptions.

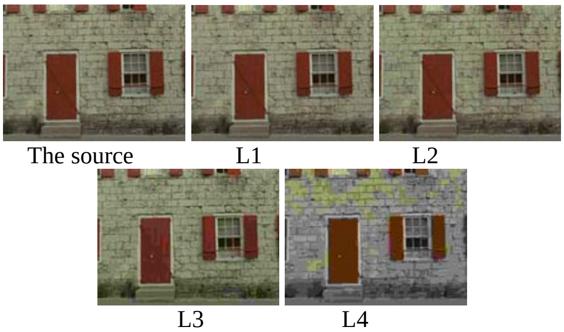
Testing images are shown in Figure 2. Image quality is in descending order with the MOS.



The distorted images of Gaussian blur



The distorted images of Contrast change



The distorted images of Jpeg compression

Fig.2 Testing image in this objective evaluation

Because of the limited space, here we only give testing image1 as an example, others images can be found in TID2008 database.

TABLE 2.

THE CORRELATION COEFFICIENT EVALUATION

Distorted types	Test images		
	Image 1	Image 2	Image 3
Gaussian blur	0.96521	0.96452	0.96944
Jpeg compression	0.8997	0.97795	0.9919
Contrast change	0.211205	0.09247	0.367274

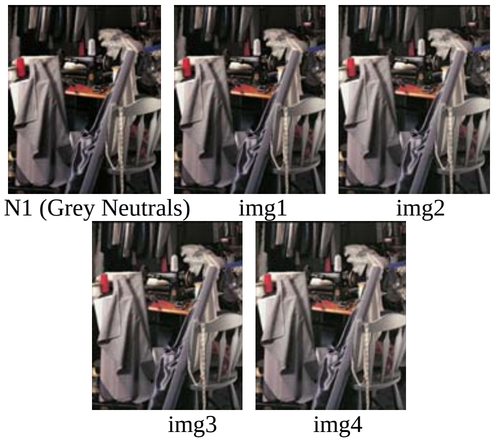
Table 2 shows the correlations between the image difference and MOS. For the 'Gaussian blur' and 'Jpeg compression' distortion, correlation coefficients are bigger, which means that the calculation result of the image difference and the MOS is in a good consistency. The framework of image difference is used to evaluate the image quality. But the predicted results of the 'contrast change' distortion is poor. The result suggests the framework has been improved, especially the spatial filtering module.

V. PSYCHOPHYSICAL EVALUATION

In order to further verify the performance of the proposed algorithm for the image color difference, a psychophysical experiment was also carried out [13-15]. five typical images were selected from image database recommended by ISO SCID 400 Standards. They are Grey Neutrals (N1), Memory Colors (N2), Painting Kids (N3), Red Couch (N4) and Ski (N5). These 5 images represent different types and contents, which include memory colors (sky, grass, color, etc.), bright colors (bright clothing, color, etc.) and neutral colors (cloth, etc.), so human visual sense of color differences between images with different contents can be tested. The mode of original images is RGB, and sRGB profile is embedded within the image file. In sRGB space different power functions are used for color adjustments as Equation 6:

$$Out = \max(in) \times \left(\frac{in}{\max(in)}\right)^{\alpha} \qquad (6)$$

In Equation 6, Out is an output of the calculation, in represents an input value, α is adjustment parameter. In this experiment α value was chosen in the sequence of: 0.95, 0.85, 0.80, 0.75, therefore visual differences of 20 image pairs were obtained. Each image was adjusted through different power functions, so the results were four images, given serial number img1, img 2, img 3, img 4 respectively. Testing images are shown in Figure 3.



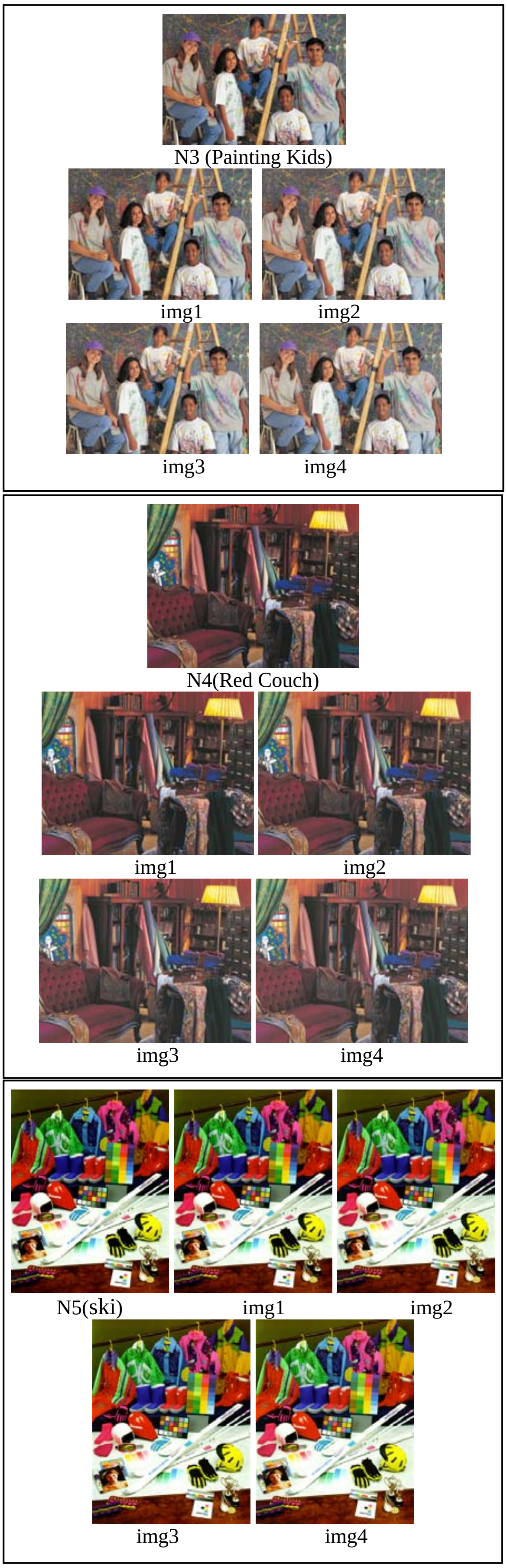


Fig.3 Testing image in this Psychophysical evaluation

EIZO ColorEdge CG21 LCD monitor was used in the subjective evaluation, and the setup of the experiment is as follows: r=2.2, white point D56, the monitor was calibrated with ProfileMaker5.0, color measurement instrument was GretagMacbeth Eye-One, the average color difference (CIELAB), the maxim color difference, ambient illumination is 200Lx-300Lx, observation background is neutral gray. 10 observers were recruited, each observer repeated experiment for three times, the monitor was warmed up for half an hour before each observation, each observer stayed in the observation environment for an adaptation for half an hour in advance, and the monitor color difference was calibrated. All evaluation images for observation are correspond to the source image, and the processed images were displayed as slide show using ACDSee software in a random order. Judgments on visual color difference are divided into five levels as Table 3:

TABLE 3.

THE VISION LEVEL OF SUBJECTIVE OBSERVATION

Visual experience	Score
No sense of perceived differences	0
A sense of barely perceptible differences, indistinctly, obscure or uncertain	1
Differences are in a weak sense of presence, but can be determined	2
Slightly significant sense of difference, but in an acceptable range	3
Significant sense of difference , the difference is not acceptable	4

Four test images were created for each of five images, each observation was repeated three times, and the average scores are shown in Table 4. The average scores of 10 observers represent the discrimination level for image color differences between image pairs, the bigger the average score, the larger the difference of images, and the smaller the differences in average scores, the smaller the difference between the two images.

TABLE 4:

THE EVALUATION DATAS OF SUBJECTIVE

Testing image	The Score of subjective evaluation			
	img1	img2	img3	img4
N1	1.17	1.47	1.9	2.63
N2	1.4	1.57	2.07	2.73
N3	1.1	1.57	2.07	4.13
N4	1.33	1.93	2.3	2.83
N5	0.97	1.4	1.97	2.4

Color differences between five source images and the corresponding 4 resulting images are calculated and shown in Table 5: small color difference indicates the difference between two images is small, and large color difference of images indicates big difference.

TABLE 5:
THE EVALUATION DATA OF OBJECTIVE

Testing image	The color difference data of image pairs (IPT)			
	img1	img2	img3	img4
N1	0.66	1.34	2.04	2.78
N2	0.43	0.87	1.32	1.78
N3	0.51	1.01	1.52	2.06
N4	0.66	1.34	2.04	2.78
N5	0.42	0.86	1.33	1.84

To further evaluate the performance of the proposed algorithm, S-CIELAB color difference values of test image pairs are listed in Table 6.

TABLE 6:
THE EVALUATION DATAS OF S-CIELAB

Testing image	The color difference of S-CIELAB			
	img1	img2	img3	img4
N1	2.16	4.27	6.61	9.15
N2	2.05	3.96	5.97	8.05
N3	3.78	7.00	9.75	12.67
N4	1.95	4.10	6.12	8.68
N5	2.49	4.93	7.52	10.11

By comparing above tables, it is clear, that color difference values from the new color difference algorithm and color difference values from S-CIELAB algorithm are showing the same trend: in the accordance with the image number img1, img2, img3, img4, color difference values are changing in an increasing order, and the trend of data is consistent with each other. The results of objective and subjective evaluations are more correlative, which means that the performance of the algorithm is better. Analysis results of the correlation are shown in Figure 4.

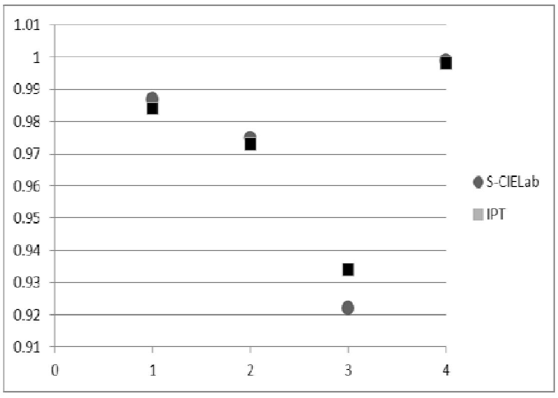


Fig.4 The Correlation Analysis Results of Subjective and Objective

From Figure 4 it can be found that the correlation of the results using two algorithms are basically the same, except for img3 the proposed algorithm performs relative better than that S-CIELAB. The result of color difference algorithm using S-CIELAB is generally larger than the proposed algorithm color difference. Most resulting color differences ΔE calculated by S-CIELAB are larger than 4, in that case, majority of the images are falling in category of "significant sense of difference, the difference is not acceptable", which is contrary to the judgments of subjective scoring. The average scores of subjective evaluation analyzed with visual levels as criteria show that color difference values calculated by the proposed algorithm are relative more consistent with the human visual than S-CIELAB results.

VI. CONCLUSION

The experimental results of the objective evaluation show that the color difference algorithm based on image contents has better results in terms of consistency with perceptual difference with human eyes than the traditional image difference algorithm. The proposed algorithm can be used to evaluate the performance of a number of distorted image processing algorithms, such as JPEG image compression methods, image blur algorithms, gamut mapping algorithms, etc. However, to achieve a better result and a more accurate consistency between the calculated color difference value and the human visual perception, a number of images with different characteristics should also be chosen, and a lot of visual psychophysical experiments should be carried out to establish an effective subjective evaluation data set. In order to establish a more reasonable model of visual image difference, further works will be focused on the improvement of space pre-processing functions based on human vision, and color difference calculation model with image pairs will be constantly adjusted.

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