Hiding patterns with daylight fluorescent inks

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Abstract

We propose a method for hiding patterns within printed images by making use of classical and of two daylight fluorescent magenta and yellow inks. Under the D65 illuminant we establish in the CIELAB space the gamut of a classical cmyk printer and the gamut of the same printer using a combination of classical inks with daylight fluorescent inks. These gamuts show that a significant part of the classical ink gamut can be reproduced by combining classical inks with daylight fluorescent inks. By printing parts of images with a combination of classical and daylight fluorescent inks instead of using classical inks only, we can hide security patterns within printed images. Under normal daylight, we do not see any difference between the parts printed with classical inks only and the parts printed with daylight fluorescent inks and classical inks. By changing the illumination, e.g. by viewing the printed image under a tungsten lamp or under a UV lamp, the daylight fluorescent inks change their colors and reveal the security pattern formed by combinations of classical inks and of daylight fluorescent inks.

Introduction

Daylight fluorescent colorants were first introduced in the middle of the last century for applications requiring high visibility such as road markers, safety jackets and warning devices. At the present time, they are widely used for special inks, highlighting markers, toys and optical brighteners.

The gamut of color printers can be extended by making use of daylight fluorescent colorants. In 1999, Hallmark Cards introduced a 6 ink offset printing system, known as the BigBox Color^{TM} system, combining classical inks and three daylight fluorescent inks. Guyler [1] compared the gamut of the BigBox printer with the gamut of classical *cmyk* offset printers by relying on Neugebauer primaries and on printed color patch measurements.

Another application of fluorescence is the authentication of security documents [2]. Bala [3] used the fluorescence of paper incorporating fluorescent brighteners in order to create images embedding security information that is invisible under normal daylight and revealed under UV illumination.

Security features relying on single invisible fluorescent inks are widely used in passports, bank notes and credit cards [2]. The hidden patterns are generally printed with a single invisible fluorescent ink, for example the yellow "VISA" text appearing on Visa credit cards under a UV light source. Hersch et al. proposed to enhance the security provided by invisible fluorescent inks by creating full color images viewable under UV light with three inks having their fluorescent emission in different parts of the visible wavelength range [4].

In the present contribution, we show how to embed into printed images security patterns by making use of two daylight fluorescent magenta m_f and yellow y_f inks. Parts of images are either printed with classical inks (with the ink set *cmyk*) or printed with combinations of classical inks with one or two daylight fluorescent inks (ink sets cm_fy_f, cmy_f, cm_fy). By applying a metameric color match under the D65 illuminant between the ink set comprising no daylight fluorescent ink and the ink sets comprising daylight fluorescent inks, we create images which look the same under normal daylight. By changing the illumination, for example by observing the image under a tungsten or a UV illumination, we reveal the security patterns formed by the parts of the image printed with daylight fluorescent inks.

Hiding security patterns by printing parts of images with combinations of classical inks and daylight fluorescent inks raises several challenges. First, we have to establish an exact relationship between a CIELAB color and the surface coverages of the contributing inks for the ink sets *cmyk*, cm_fy_f, cmy_f and cm_fy. In addition, the relationship should be established by making as less spectral measurements as possible. This can be achieved with the IS-CYNSN spectral prediction model [5] which is dedicated to the accurate prediction of spectral reflectances of halftones combining daylight fluorescent inks and classical inks. This model needs to be calibrated with a few calibration patch reflectances. In the case of the ink sets comprising 3 inks we need 35 calibration measurements and in the case of the ink set comprising 4 inks we need 97 calibration measurements. Finally, for printing color images, we have to establish in the CIELAB space a color mapping from the input *sRGB* display gamut to the printer gamut formed by the classical *cmyk* ink set.

Reflection spectra of the fluorescent inks and their superposition

In the following section, we show that it is possible to create new colorants either by superposing daylight fluorescent inks with classical inks or by superposing several daylight fluorescent inks. These new daylight fluorescent colorants are useful to create the fluorescent gamut.

Daylight fluorescent inks contain organic molecules [6] that fluoresce by absorbing light at one wavelength range and reemitting it at longer wavelengths. Classical daylight fluorescent inks, such as the daylight fluorescent yellow ink and the daylight fluorescent magenta ink are mainly excited in the visible wavelength range at respectively 400 to 500 nm and at 500nm to 560nm. In addition, they have a near ultra-violet excitation band between 350 and 400nm [7]. Therefore, these daylight fluorescent inks no longer behave only like classical inks where part of the incident light is absorbed by the inks

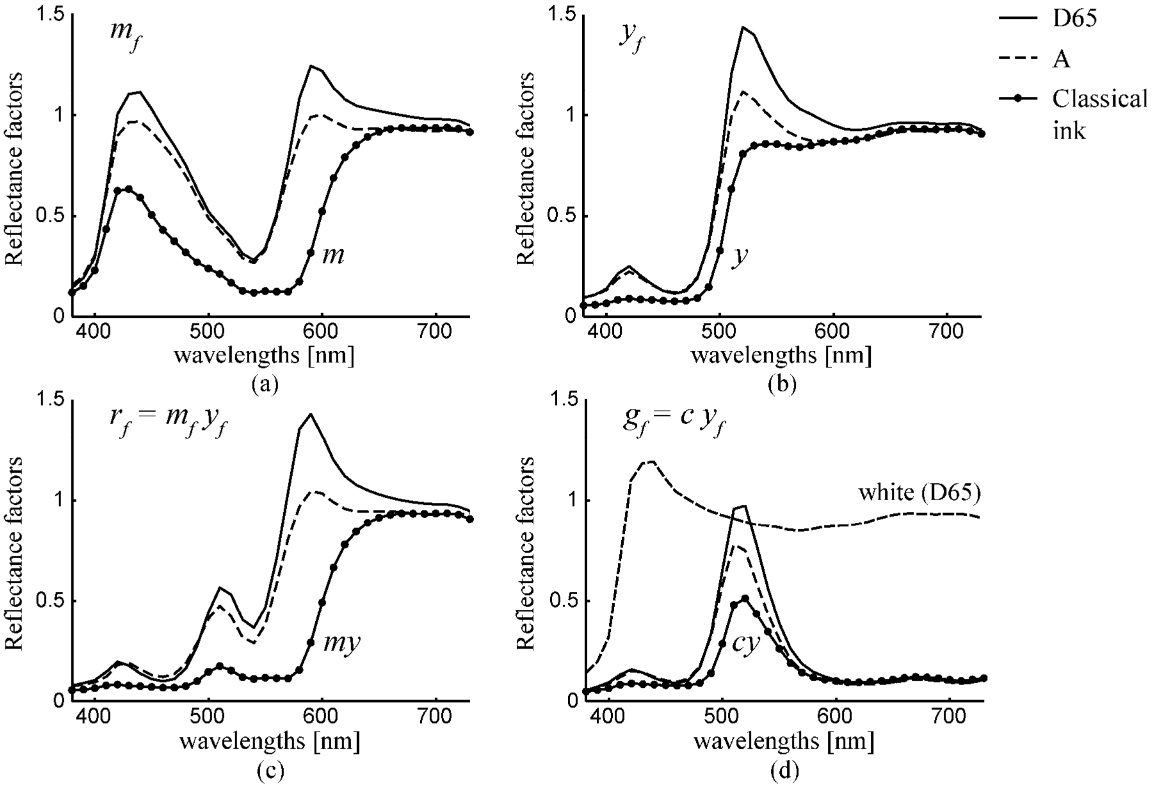

Figure 1. *Reflectance factors of the (a) daylight magenta fluo m_f colorant, (b) daylight yellow fluo y_f colorant, (c) daylight fluo red colorant (m_f superposed with y_f) and (d) daylight fluo green colorant (cyan superposed with y_f) under the D65 illuminant (solid lines) and the A illuminant (dashed lines), together with the classical colorant reflectances (pointed lines).*

They also behave additively, i.e. the fluorescent emission behaves like a color light source. The color appearance of daylight fluorescent colorants is fully characterized by the total spectral reflectance, which includes both light absorption and fluorescent emission [8]. Therefore, from now on, we use the term spectral reflectance to refer to the total spectral reflectance. To be more precise, we use the term reflectance factor expressing the ratio between the spectral flux emitted and reflected by the sample, captured by the spectrophotometer and the corresponding captured spectral flux reflected by a perfect white diffuser.

Figure 1 shows the measured spectral reflectance factors under both the D65 and the A illuminants of four daylight fluorescent colorants, the daylight fluorescent magenta ink m_f, the daylight fluorescent yellow ink y_f, the daylight fluorescent red colorant (m_f superposed with y_f) and the daylight fluorescent green colorant (cyan superposed with y_f) printed on a fluorescent paper containing optical brighteners (Canon MP-101). Figure 1 also shows the reflectances of the corresponding classical colorants under the D65 illuminant, i.e. colorants made of classical inks without fluorescent additives. Note that all measurements are carried out with a SpectroEye Xrite spectrophotometer, with a geometry (45°:0°), emulating the D65 and A illuminants.

In Figures 1a and 1b we observe that the emission peaks of the y_f and m_f ink are located in the visible spectrum at wavelengths corresponding to the desired color, i.e. for the daylight fluorescent yellow ink near 520 nm and for the daylight fluorescent magenta ink near 450nm and 590 nm, yielding both a strong brightness and saturation of these colors. When mixing two daylight fluorescent inks together, we also observe a strong fluorescent emission. For example, the red fluorescent colorant has a peak located at 580nm at reflectance factor of 1.45 (Figure 2c). This yields a very strong red. We observe that all daylight fluorescent colorants are more saturated and brighter than the corresponding classical colorants. For instance the daylight fluorescent green colorant (Figure 2d) has a narrow fluorescent peak between 500 and 540 nm which is much higher than the peak of the classical green ink. Under the A illuminant all daylight fluorescent colorants have less fluorescent emission and are therefore less saturated and brighter than under the D65 illuminant. This is due to the fact the A illuminant has less energy than the D65 illuminant in the excitation range of the daylight fluorescent m_f and y_f inks.

Hiding security patterns by printing colors either with or without daylight fluorescent inks

The previous section has shown that it is possible to create new interesting colorants by superposing classical inks with daylight fluorescent inks or by superposing several daylight fluorescent inks. With these new fluorescent colorants we establish a fluorescent gamut G_f. By comparing the G_f gamut with the classical ink G_{cmyk} gamut under a D65 illuminant, we determine the colors of the G_{cmyk} gamut

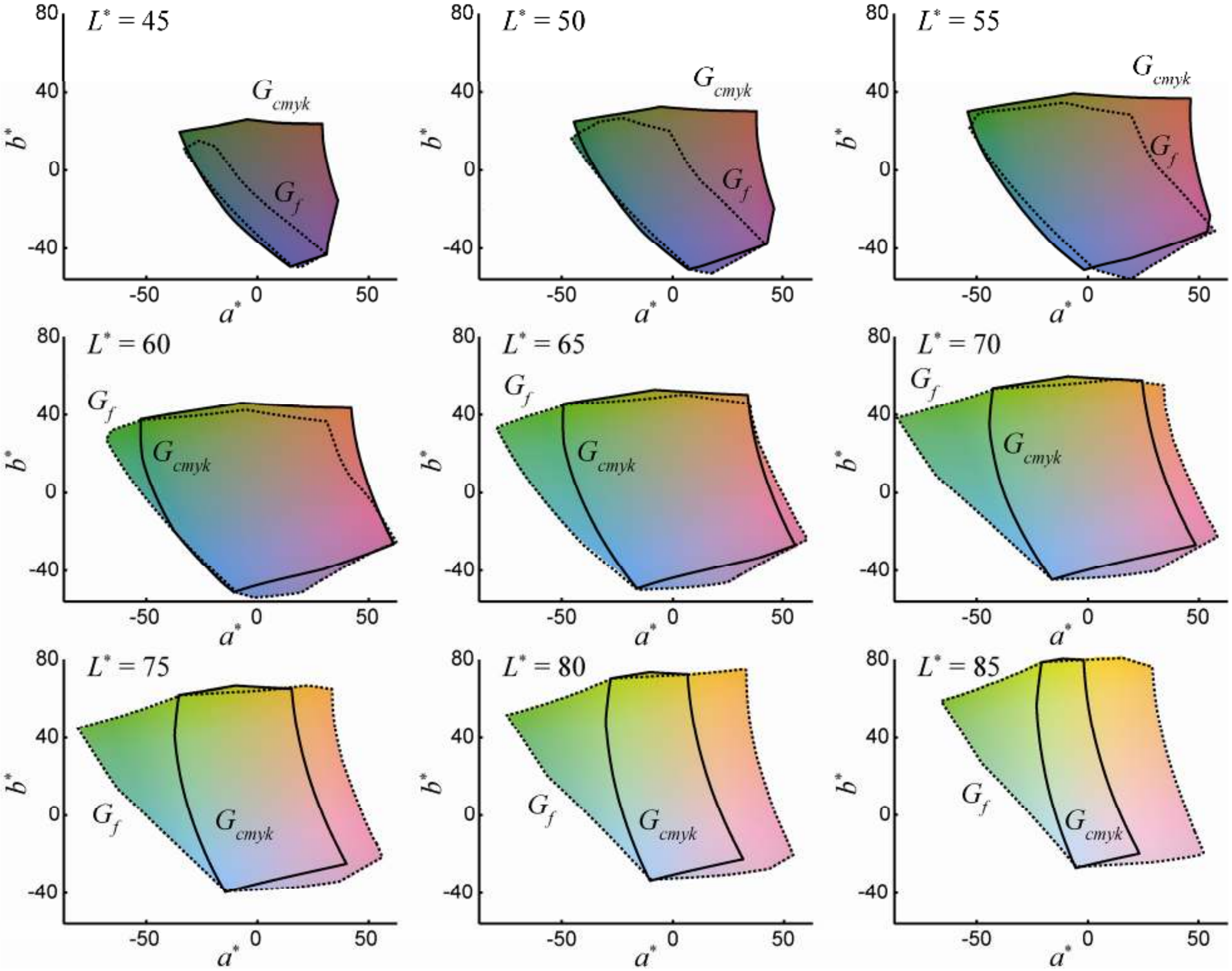

Figure 2. *Color gamut of the classical cmyk ink set G_{cmyk} (solid lines) and the fluorescent gamut G_f (dotted lines).*

which are metameric to the G_f gamut under normal daylight conditions. We print the hidden patterns whose colors are located within the G_f gamut with a fluorescent ink set so as to have an exact match with the gamut mapped original color under the D65 illuminant. These patterns will therefore be hidden under normal daylight.

The fluorescent gamut G_f is the conjunction of the three cm_fy_f, cm_fy and cmy_f ink set fluorescent sub-gamuts, i.e. one color of the global fluorescent gamut G_f is associated with one of these sub-gamuts and is printed with its corresponding 3 inks. We halftone the individual ink layers with a blue noise dispersed dither halftoning algorithm. This prevents the occurrence of artifacts at the boundaries between non fluorescent and fluorescent ink sets.

Figure 2 illustrates in the CIELAB space a comparison between the G_{cmyk} and the G_f gamut boundaries under the D65 illuminant. For lightnesses less than $L^*=55$, we observe that the G_f gamut is smaller than the G_{cmyk} gamut. This can be explained by the fact that the daylight fluorescent colorants are brighter than the corresponding classical colorants (see Figure 1). At a lightness between $L^* = 55$ and $L^* = 65$, there are not many differences between the classical ink gamut (G_{cmyk}) and the fluorescent gamut (G_f), i.e. only a small part of the G_{cmyk} gamut is outside the G_f gamut. For lightnesses higher than $L^* = 65$, the G_{cmyk} is included within the G_f gamut. We therefore observe that for bright CIELAB colors (having a lightness $L^*>50$), we are able to reproduce most of the classical *cmyk* colors by combining classical and daylight fluorescent inks.

For hiding security patterns within an image, we define a mask. The mask can represent any patterns such as for instance a security text. While generating a specific image, we print outside the mask the colors of the image with the G_{cmyk} gamut, i.e. with classical inks only. Inside the mask, if colors of the G_{cmyk} gamut are reproducible by colors of the G_f gamut, we print them with fluorescent colorants, i.e. combinations of classical and daylight fluorescent inks. In the contrary case, we use classical inks only.

Calculating the ink surface coverages with the IS-CYNSN spectral prediction model

The next challenge consists in establishing an exact relationship between the CIELAB colors and the ink surface coverages of the inks defining either the G_{cmyk} gamut or the G_f gamut. This relationship must be exact in order to print perfectly metameric colors. In addition, for establishing this relationship we would like to use as few calibration patch measurements as possible. This can be achieved by using a spectral prediction model that is optimized for predicting the spectral reflectance of halftones comprising daylight fluorescent inks.

Within halftones comprising classical and daylight fluorescent inks, due to the Yule-Nielsen effect [9] light scatters from one printed fluorescent colorant dot to a non-fluorescent colorant dot and vice versa. Therefore, different types of energy transfers occur. In this situation, the spectral Yule-Nielsen model [10] is not accurate for predicting the total spectral reflectances of halftones comprising daylight fluorescent inks. To illustrate the low prediction accuracies of the Yule-Nielsen model, we printed all combination of the c, m_f and y_f inks by varying the nominal ink surface coverage by steps of 25%, yielding $5^3=125$ halftones. We calibrate an ink spreading enhanced Yule-Nielsen model (IS-YNSN model) [11] and run the spectral prediction over all the 125 halftones. We obtain under the D65 illuminant a mean ΔE_{94} prediction error of 2.02, a 95% quantile prediction error of 4.19 and a maximal ΔE_{94} prediction error of 5.15. These prediction accuracies are not precise enough to build an exact relationship between CIELAB colors and the ink surface coverages of the inks for halftones comprising daylight fluorescent inks.

In order to obtain more accurate predictions, we use the ink spreading enhanced cellular Yule-Nielsen model, named IS-CYNSN [5]. The benefit of using the cellular IS-CYNSN model for predicting the spectral reflectance factors of halftones comprising daylight fluorescent inks is that this model predicts reflectances within smaller ink surface coverage spaces and therefore better accounts for the influence of non-fluorescent ink dots on fluorescent ink dots and vice-versa. In addition, the IS-CYNSN model accounts for ink spreading within the cellular subspaces, yielding very accurate spectral predictions. Finally, the IS-CYNSN model needs to be calibrated with only a limited number of spectral reflectance factor measurements. In the case of 3 inks, we only need 35 spectral reflectance factor measurements and in the case of 4 inks, we only need 97 spectral reflectance factor measurements.

In order to test the prediction accuracies of the IS-CYNSN model for the considered ink sets defining the G_{cmyk} and G_f printing gamuts, we print for each ink set all the ink combinations by varying the ink nominal surface coverages by steps of 25%, yielding $5^3 = 125$ halftones for the sets comprising three inks (cm_fy_f, cm_fy and cmy_f) and $5^4 = 625$ halftones for the set comprising 4 inks (*cmyk*). The halftones were measured under the D65 illuminant of the SpectroEye Xrite spectrophotometer with geometry (45°:0°). Table 1 gives the mean prediction error in terms of ΔE_{94} values, the maximal prediction error, the 95% quantile prediction error and the average rms reflectance prediction error.

These tests show remarkable prediction accuracies. The mean ΔE_{94} prediction error varies between 0.34 and 0.61 and the quantile 95 prediction error varies between 0.83 to 1.53. The IS-CYNSN spectral prediction model is therefore accurate enough to establish an exact relationship between CIELAB colors and the surface coverages of the inks of both the classical G_{cmyk} (ink set *cmyk*) and the fluorescent G_f gamuts.

In order to obtain a relationship between the ink surface coverages and the *sRGB* values of the image that is to be reproduced, we map all the *sRGB* CIELAB values by steps of 3% *R*, *G* and *B* into the G_{cmyk} gamut. This can be achieved by a standard gamut mapping algorithm (GMA) [12]. We obtain the ink surface coverages corresponding to the color mapped into the printer gamut with the IS-CYNSN model by minimizing the ΔE_{94} differences between the predicted color and the desired color. The minimization is carried out for each ink set. We store the fitted ink surface coverages plus the corresponding ΔE_{94} differences between desired and predicted colors. This yields four lookup tables mapping the *sRGB* values to the *cmyk*, cm_fy_f, cm_fy and cmy_f ink surface coverages with the corresponding ΔE_{94} differences. The minimizations are carried out with a computer executable procedure implementing Powell's function minimization [13]. Note that the IS-CYNSN models are calibrated for the D65 illuminant by measuring the calibration patches with that illuminant.

Table 1. Prediction accuracies of the IS-CYNSN model for 625 *cmyk*, 125 cm_fy_f, 125 cm_fy_f, 125 cmy_f test samples printed with a Canon pro 9500 ink jet printer and measured under the D65 illuminant.

	ΔE_{94}			*rms*
Test set	avg	95%	max	avg
cmyk	0.34	0.83	1.44	0.00334
cm_fy_f	0.61	1.53	3.32	0.00649
cm_fy	0.34	0.90	1.02	0.00324
cmy_f	0.54	1.36	1.80	0.00443

For generating an image incorporating a hidden pattern we test if the mapped *sRGB* colors within the mask can be reproduced by one of the fluorescent ink sets. This is the case when the corresponding entry in one of the cm_fy_f, cm_fy and cmy_f lookup tables shows a negligible ΔE_{94} difference between desired gamut mapped color and the color predicted with the fitted ink surface coverages. In order to maximize the amount of fluorescent ink, we test the ink sets in the order cm_fy_f, cm_fy, cmy_f. If no fluorescent ink set provides the desired color, it is printed with the classical *cmyk* ink set. Gamut mapped colors outside the mask are printed with the classical *cmyk* ink set.

Results

The printed images shown in this section embed the repetitive hidden "VALID" text pattern. Lookup tables mapping the *sRGB* values to the ink surface coverages have been generated for the D65 illuminant. Thus, these patterns are hidden under normal daylight viewing condition but revealed under both the A or the UV illuminations. Images

(a) (b) (c)

Figure 4. *Printed Iceland landscape incorporating the "VALID" pattern viewed under (a) normal daylight, (b) under UV illumination and (c) under A illumination. Please observe the images in the electronic version of the paper.*

were printed with the Canon Pro 9500 printer with the native Canon *cmyk* inks and with the daylight fluorescent yellow and magenta inks (Farbel Castel ink references 154907 and 154928). Pictures of the prints have been taken with a Canon PowerShot S95 camera under normal daylight conditions, under UV-A black light and under a tungsten lamp (A illuminant).

Figure 3 illustrates the printed Japanese girl image embedding the "VALID" hidden pattern, photographed both under normal daylight (left image) and under UV light (right image). Under normal daylight conditions it is not possible to distinguish the text "VALID" formed by combinations of classical and daylight fluorescent inks. This is due to the fact that we have a perfect metameric color match between the inner and outer part of the "VALID" mask. Under UV illumination, the text "VALID" is visible in almost all parts of the image, except in the hair. Since the hair is dark, it is not possible to reproduce it with daylight fluorescent colorants.

(a) (b)

Figure 3. *Printed Japanese girl image incorporating the "VALID" pattern, (a) viewed under normal daylight and (b) viewed under UV illumination.*

Figure 4 illustrates a printed Iceland landscape embedding the "VALID" hidden pattern. While under normal daylight it is not possible to distinguish the hidden pattern, under both A and UV illuminations, it is revealed. Since the A illuminant has less energy than the D65 in the excitation range of the daylight fluorescent inks, there is less fluorescent emission and therefore the "VALID" mask content appears darker than when seen under the D65 illuminant. This reveals the hidden patterns under the A illuminant (Figure 4c).

Conclusion

We propose a method for hiding security patterns within images by making use of the two daylight fluorescent magenta and yellow inks. The patterns are printed with combinations of these two daylight fluorescent inks and classical inks while the rest of the image is printed with classical inks only. Since the ink surface coverages are calculated with a highly accurate spectral prediction model calibrated under the D65 illuminant, the embedded security patterns are completely hidden under normal daylight.

The verification is performed by putting the security images under a tungsten lamp or under a UV black light and by visually verifying that the security patterns are revealed. With classical inks it is not possible to hide patterns that are revealed both under UV and A illuminations. Therefore, these security images are difficult to reproduce. The security provided by these hidden patterns can be further enhanced by establishing a model predicting the fluorescent emission of the daylight fluorescent inks under UV light. By comparing the image captured under a UV illuminant and the predicted fluorescent emission image, one may obtain a further confirmation of the authenticity of the document.

In the future, we intend to verify if the metameric index can be used as a metric for expressing the pattern hiding capabilities of different substrates under different daylight illuminants.

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