COLOR SEQUENCE IN FOUR-COLOR PRINTING

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Abstract: The importance of color sequence in four-color printing is investigated solely from the viewpoint of changes in color gamut due to the opacity of individual printed ink films. Discussion is also included on other factors to be considered in color sequence selection. The study eliminates trapping as a factor by using a dry-trap laboratory experiment. SWOP inks and paper and clear film are used in the experiment. The densitometric evaluation of the samples lead to the conclusion that black should always print on top of yellow. It is recommended that yellow, magenta, cyan, and black, or cyan, magenta, yellow, and black be adopted as a standard sequence for the publications industry.

Introduction

The ink sequence (or rotation or progression) which should be used in four-color process printing is often the subject of much debate. Consequently, sequence is rarely subject to standardization.

The lack of standard sequence did not exist in the early days of color printing - the sequence of yellow, magenta, cyan, and black was near universal, dictated in part by the semi-opaque yellow pigments then in use. The yellows of today generally use diarylide (formerly benzidine) pigments, which are much more transparent than the former lead-based pigments. Therefore, printers today have more flexibility in their choice of a sequence.

With four inks there are twenty four possible sequences. The last major Graphic Arts Technical Foundation (GATF) color survey (Field, 1972) identified seventeen sequences being used by survey participants. Further studies of web offset printers by Field and Ingram (1976)

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and by the Graphic Communications Association (GCA) Spectrum '82 research project, have confirmed this diversity. The results of these surveys are presented in Table I.

Table I

Survey Results - Color Sequence

Survey	GATF - All Printers		GATF - Web Offset		GCA Spectrum '82 - Web Offset	
Year	1971		1975		1982	
Number of Samples	123		78		16	
Sequences	KCMY	28	CMYK	40	KCMY	9
	YMCK	22	KCMY	13	CMYK	4
	YCMK	16	YMCK	11	YMCK	1
	Other*	57	Other	14	CKMY	1
					MKCY	1

*Fourteen sequences

Because of the different sample sizes and populations, the survey results are not strictly comparable. However, one general trend that is possible to discern is the increasing practice of running yellow last in the sequence. Another noticeable shift is the change in the major web offset color sequence from CMYK in 1975 to KCMY in 1982. The committee responsible for establishing specifications for web offset publications recently dropped the cyan, magenta, yellow and black sequence that was in force at the time of the 1975 GATF study, in favor of no specific sequence (Church 1981). This stance almost certainly contributed to the slip in popularity of the CMYK sequence in the Spectrum '82 study.

Given that a wide variety of color sequences are being used, a key question is: does sequence make any difference? The rather brief literature on color sequence (Williams, 1973, 1975; Scarlett, 1979; IARIGAI, 1982; Mead Corporation, 1982) suggest that sequence does matter, mostly as a variable to be used to avoid particular production problems. Little evidence is presented in the literature to document specific appearance changes that are due to sequence. This lack is not surprising given that press tests of color sequence are not only time consuming and expensive, but are also difficult to control.

Experimental

An experiment was devised to determine the influence of color sequence on the appearance of multi-color overlaps. The major part of the study was carried out in a laboratory using the Thwing-Albert 'Quickpeek' Color Proofing Kit. This device allows the transfer of a standard solid ink film thickness, which approximates normal printing thicknesses, on to any substrate. The inks used for the test were the standard SWOP (Specifications for Web Offset Publications) inks. The paper substrate used was 60 pound Appleton proofing stock. Clear film was also used as a substrate.

A rollout pattern was devised to give solids of yellow, magenta, cyan, black, red, green, blue, 3-color, and 4-color on the same sample. Prints were produced in the following sequences: KCMY; YMCK; CMYK; YCKM, using the inks and paper previously noted. Printed ink films were allowed to dry between printings.

An examination of the 'repeat' pattern of the Quickpeek roller revealed some dry trapping problems, i.e. less ink was transferring to the previously printed ink than to the unprinted paper. To achieve perfect trapping, additional rollouts were made of each of the inks on to separate sheets of clear film. These prints were each cut in half and combined in opposing sequences (e.g. yellow on magenta, and magenta on yellow). This technique, while another stage removed from actual printing, ensured perfect trapping and uniform densities.

The 4-color solids of the paper prints were measured through the 'visual' filter of a reflection densitometer (see Table II). The clear film prints were combined in pairings necessary to produce the complete range of secondary color variations. These were each measured through red, green, and blue filters of a reflection densitometer. (A sheet of the Appleton paper was placed behind the films and the densitometer was zeroed on the paper covered by the layer of film.) These readings are presented in Table III.

Results

Table II

Color Sequence Versus 4-Color Density
(Paper Substrate)

Color Sequence	4-Color Solid D_{max}
CMYK	2.36
YMCK	2.31
YCKM	2.16
KCMY	1.87

Table III

Color Densities of Ink-On-Film Rollouts

Color Measured	Filters Blue	Filters Green	Filters Red
Yellow	0.93	0.06	0.03
Magenta	0.54	1.25	0.07
Cyan	0.04	0.22	1.06
Magenta on Yellow	1.62	1.31	0.10
Yellow on Magenta	1.41	0.98	0.09
Cyan on Yellow	0.92	0.30	1.09
Yellow on Cyan	0.96	0.29	1.03
Cyan on Magenta	0.60	1.42	1.14
Magenta on Cyan	0.61	1.51	1.12

The YMCK 'visual' density was 2.10 and the KCMY 'visual' density was 1.18.

The data from Table III are plotted on the GATF Color Hexagon (Cox, 1970) in Figure 1.

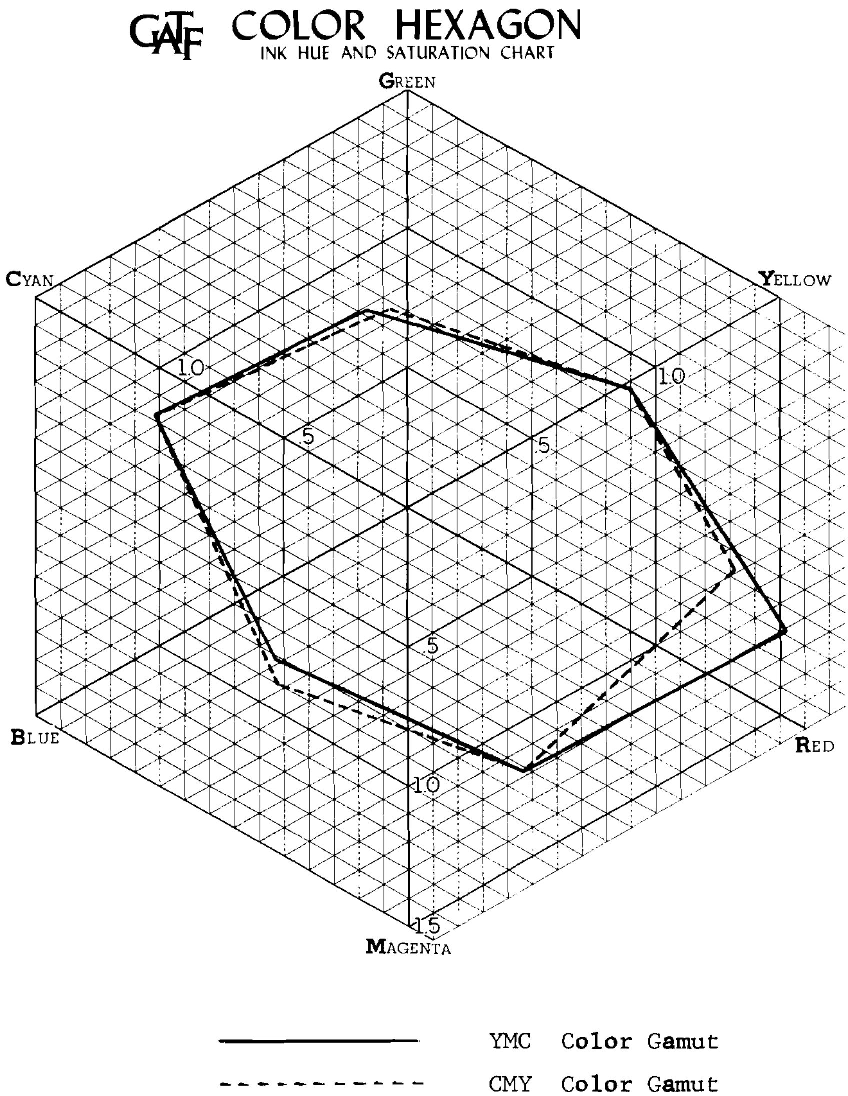

Figure 1 Color hexagon plots of ink-on-film rollouts in YMC and CMY sequences.

Conclusions

The color of an overprint will shift toward the hue of the top-down color (see Figure 1), indicating that probably none of the process inks are perfectly transparent. Colorimetric measurements would be needed to determine the magnitude of this problem, but visual judgements and densitometric measurements suggest that the position of yellow in the sequence has the strongest effect on the appearance of overprints (especially red overprints).

The sequence KCMY versus YMCK will result in about a 0.40 lowered Dmax, hence negatively affecting tone reproduction and therefore the quality of the reproduction. This would be even worse with better trapping (as suggested by the 0.90 Dmax shift with the film rollouts). Aside from this loss of density, the 4-color solid takes on a yellowish cast when yellow is printed last. It is generally not possible to adjust the magenta, cyan, and black to correct this problem - only poor trapping of yellow or changing the position of yellow in the sequence will shift the color of the 4-color solid toward neutral.

The gray balance requirements of a set of separations will shift according to sequence. For some jobs this statement will be more obvious than for other jobs. For high key subjects, where most dots are below 50 percent with minimum overlap, sequence change (all other factors being held constant) is not likely to have much influence. However, jobs with normal-to-heavy color saturation will change in appearance with sequence.

Some experimental errors in this study would include the multiple internal reflection of light between the sheets of clear film, and gloss differences of the printed ink films. These effects serve to further separate the experimental results from a specific press interaction. However, they detract little, if any, from the accuracy of the comparison between sequences.

Recommendations

Apart from the ink opacity considerations that have been examined in this paper, there are a large number of other factors that contribute to the choice of a color sequence (see Appendix). Consequently, it is difficult to recommend one particular sequence which will satisfy all circumstances.

The International Association of Research Institutes for the Graphic Arts Industry (IARIGAI, 1982) have proposed that the German (FOGRA) and Swiss (UGRA) recommendations be adopted. They are: 4-color press, KCMY; 2-color press, CMKY; 1-color press, CMYK. At the least, IARIGAI recommends always keeping cyan, magenta, and yellow in that sequence with black as a "floating" color to be moved to any position necessary for practical reasons. The merit in a consistent CMY sequence (as for any other consistent relationship between these colors) is standardized gray balance.

The research presented in this paper would suggest that yellow should never go last down, should not be printed on top of magenta, and probably should not be printed on top of cyan. However, the results (on film) represent what would be obtained under conditions of perfect trapping. In practice, trapping is less than perfect, and, for the CMY sequence, will result in greens that are less yellow, reds that are less yellow, and blacks that are of higher density (see the paper print results) than would exist with perfect trapping.

The only strong recommendation the author makes is that black follow yellow in the sequence. The loss of Dmax in printing yellow over black aggravates the problem of print contrast and tone reproduction. Also, the yellow cast over neutrals when yellow is last down is objectionable, and cannot be corrected by adjustments to either of the other colors.

Therefore, the sequence YMCK, which was used successfully for many years, would be quite satisfactory. The 1975 SWOP sequence of CMYK would also fit the criteria of black after yellow and would not be in opposition to the IARIGAI recommendations. An individual printer could adopt a variant of the black-after-yellow recommendation, but it is important that after a sequence is adopted, it becomes a house standard for all but the rarest circumstances. In cases where there must be standardization of manufacturing conditions among a large number of printers and color separators (such as the publications industry), a standard sequence is essential to quality results. The U. S. publications industry should re-adopt one of their two previous standards - YMCK or CMYK.

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Appendix

Choice Factors For Color Sequence

The literature on color sequence choice has documented a variety of factors which help determine the color sequence to be used under given conditions. These factors, together with others that have been accumulated by the author, can be grouped under the headings listed below.

Optical Factors
These factors are established by the optical properties of the printed ink films.

1. Opacity The research described in this paper has primarily dealt with opacity of printed ink films. The color of overprints will shift toward the color of the top-down ink if that ink is at all opaque. Also, the density of the 4-color solid (and, hence the contrast of the printing) will be reduced if non-transparent colors are printed over black, compared to printing black over that color. This is especially noticeable when yellow is the last down color.

2. Gloss Some colors (notably yellow) have a higher gloss than other process colors. Running such colors last in the sequence can improve the gloss of the finished print.

3. Bronzing Certain inks (notably black but sometimes cyan and magenta) have toners as part of their formulation. Under some circumstances these toners can migrate to the surface of the printed ink film and change its appearance. This problem can be minimized by printing the ink earlier in the sequence.

Production Problem Factors
These factors occur when press, ink, substrate, and plate are combined under production conditions. When the results are not satisfactory, a press operator may alter color sequence in order to minimize a given problem and hence improve the appearance of the final print. The kind of problems that the operator seeks to minimize are listed below.

1. Trapping The ability to transfer one ink to a previously printed ink depends on a variety of factors (Jorgensen, 1982). Sequence will affect this transfer, or trapping, if the inks are not run in their correct tack

sequence. The first down ink should be the highest tack with each succeeding ink slightly lower tack.

2. Doubling Under some circumstances, a form of dot gain called doubling can cause printing problems. This is especially true when very heavy ink films are being run. To minimize the effect of this factor, the most critical color (for example, magenta in a catalog job containing many skin tones or black in a magazine with considerable textual matter) could be run on the last unit.

3. Mechanical Problems A particular printing unit may be causing slur or misregister due to mechanical problems with that unit. Until repairs are made, the noticeability of the problem may be minimized by running yellow, the least visually discernable color, on the defective unit.

4. Printback On long runs with heavy ink films, the gradual contamination of one ink by the preceding ink is sometimes observed. This contamination could take the form of magenta contaminating yellow and turning it towards orange. The printback problem can be minimized by printing lighter colors before darker colors, for example, yellow before black will not result in any noticeable contamination, but the reverse could result in serious contamination.

5. Backtrap Mottle A variety of factors can contribute to the phenomena known as backtrap mottle (Mead Corporation, 1982). Large solids composed of approximately 100 percent cyan and 70 percent magenta seem most likely to show backtrap mottle. Changing color sequence so that the heavy form overprints the light form can help eliminate the problem.

6. Ink Coverage Inks with heavy coverage can often cause distortion of thin substrates. Consequently, to facilitate register, it may be desirable in some cases to print this ink last in a four-color sequence. This argument is often advanced for printing yellow last, which some claim (Scarlett, 1979) is the heaviest coverage color. Other related arguments for printing yellow last include reducing moire patterns (GATF, 1971), minimizing noticeable set-off (Williams, 1975), improving rub resistance (Scarlett, 1979) and, presuming black is printed first and yellow last, reducing the tendency to emulsify the black ink (Scarlett, 1979). Other yellow-last arguments such as covering an ink that has a tendency to bronze, and improving gloss, have already been mentioned.

Williams (1973, 1975) claims that yellow is printed at a heavier film thickness than the other process colors, and consequently causes trapping and dot gain problems when yellow is printed first. This should not occur under normal printing conditions - identical ink film thicknesses in the research reported in this paper resulted in densities of yellow--0.93, magenta--1.25, cyan--1.06, values that are generally in balance with average printed ink film densities. Scarlett (1979) also claims yellow is more difficult to trap on and hence should be printed last. With proper ink tack differentials there does not seem to be any reason why good trapping on yellow cannot be achieved.

7. Gray Balance The SWOP (AAAA/ABP/MPA, 1981) guidelines suggest selecting color sequence to achieve gray balance (and to achieve maximum trapping*). This is tantamount to saying that if the separations are wrong, correct them on press. Gray balance should be established in a set of separation films for a given set of printing/proofing conditions which would include color sequence. If a number of color separators produce films (and proofs) gray balanced for different color sequences, it will be impossible for a printer, using one color sequence, to have any hope of matching all proofs.

Other Factors

Other reasons advanced for the use of one sequence over another are usually related to printing four colors on a one-color press. They include: ease of washup (print light colors before darker colors); running the critical color last; and habit.

*To maximize trapping for two given colors (say, yellow and cyan) does not mean that trapping for other overprints (yellow and magenta, and cyan and magenta) are also maximized, consequently leaving the recommendation quite vague.