A NUMERICAL SYSTEM FOR THE ANALYSIS & PRE- VISUALIZATION OF A COLOR REPRODUCTION SYSTEM

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Abstract: The use of printed color guides as an aid in color separation photography is a procedure used by many color experts. Through the use of data base, rule base and numerical programming techniques the MECAS system described uses color guides to emulate the color expert and provide a color reproduction system that compensates for the printing variables in use.

Computer Aided Color Separation

The color scanner has gained popularity as a means of producing color separation negatives to the point that the color cameraman is in danger of extinction. This is unfortunate because there are many situations where camera made separations are both practical and necessary. For instance there are many shops that produce very high quality color work that are not large enough to support the overhead imposed by an electronic scanner. One option is to buy separations from a trade shop, but there are many problems associated with outside vendors. If the printer does not have average industry requirements he may not be able to find a supplier that will tailor make film for him. In instances such as this there is a need for a in house separator. Camera separations do not require large investments in equipment but they do rely heavily on talent. Unfortunately talent is not always available.

What is needed in this situation is a system that will enable the technician with average skills to have access to the decision making ability of an expert color cameraman. Such a system is called an "Expert System", and is a type of artificial intelligence program. Expert systems are becoming popular in many of the service industries.

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The system described in this paper is designed to work with a technician that has average skills and give him the benifit of an experts knowledge. It is not, however, a classic expert system. The MECAS (Machine Expert Color Analysis System) system is actually a hybrid computer program that contains a data base subprogram, a rule base (expert system) subprogram and simulation subprogram. Knowledge about the variables in a specific plant is gathered through a color guide produced under actual printing conditions. The program outputs parameters for a color reproduction system based on the variables of the operators plant. Interaction between the operator and the program is also possible.

The Use of Color Guides

The graphic arts industry today produces an enormous variety of product with many types of equipment on thousands of different substrates. Because of the different reproduction characteristics that are introduced when variables such as paper type, ink type and press type are changed no one color separation system alone will yield films suitable for all situations. The diferences encountered by changing just one printing variable, such as paper type, can be staggering. In order to compensate for these differences the color separator must alter the way in which he produces his films. Usually he will categorize these differences and produce a small number of different types of separations that will provide a good compromise in most situations. The error still present after using this method is usually corrected by hand work on the separations by skilled dot etchers or retouchers. This kind of correction is time consuming and limited in its potential. The end result of inadequate separation techniques that are uncorrectable by hand is always a loss of quality.

The use of printed color guides has long been established by color separators as a usefull tool in producing separation films that correct for the inadequacies of a set of particular printing conditions. The GATF* color guide is one in common use. The technique works well because it not only gives a visual representation of the errors present in the system that need compensation for, but also indicates when the corrective work has yielded the required goal. Another advantage is that it supports trial and error methods of correction. This is especially helpful in that

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it allows an individual to find a workable solution regardless of the degree of expertise he has at his disposal. At the hands of a lesser skilled individual the system will not necessarily yield an inferior result but may only take longer.

The Color Guide procedure

The procedure is simple and straightforward. Film standards are produced that allow solids and various tints of the three primary colors, overprints of pairs of the three primaries, a three color overprint, a four color overprint, black and white to print. These films are used to expose plates that will be used for the test. The plates are run with the particular press, ink and paper combination that is to be evaluated. The resultant "Color Guide" represents all of the printing variables used in its creation. The Color Guide is then color separated in the camera department using techniques that are thought to be correct for the printing conditions being evaluated. The differences in the densities or %dot areas between the films created by color separation and those used to expose the plates that printed the color guide represent the reproduction error that would result if this color separation system were used. Through good judgement and experimentation the color sepatator reduces these errors to within accepatable limits. Ideally the separation of the color guide should yield film identical to that used to print the color guide.

This proceedure while accurate and dependable is very costly and time consuming. It is with this in mind that the MECAS system was created. Before discussing the use of such a system it is first necessary to understand how the seasoned color separator tackles these problems.

The Human Expert

A camera operator with a sound technical background and a number of years experience can analyze a color guide and in time produce a separation system that will yield quality reproduction. His actions can be broken down into three basic sub-tasks: comparison, analysis and experimentation.

Comparison

When the camera operator is presented with a new color guide to evaluate he first relys on his past experience and compares the new guide to those he has evaluated in the past. This may be done by memory or may actually consist of a file of color guides with a list of the printing conditions used and a description of the color separtaion techniques decided upon for that particular giude. Even before subjecting the guide to a densitometer he will probably search through his files for guides printed on a similar paper. He will continue to narrow his search by selecting guides that were printed with a similar press, and finally a similar ink. In this way he limits the amount of search he needs to perform by eliminating guides that will probably be dissimilar and then ordering the good candidates in such a way that the guides with the highest probability of success are tried first. At this point he will compare densitometric measurements of the new guide with those in his files and select the closest match. If he finds a guide that is identical to the new guide he may assume that the photographic conditions used to separate for that set of printing variables will also work well with those used to print the new guide. If there is no perfect match he will take the closest match and use it as a starting point for his analysis.

Analysis

After selecting the closest match color guide from his files the camera operator will observe the differences between the new guide and the file guide. He will then make certain decisions as to how to separate the new guide based on his knowledge of the old guide and of the differences between the two. If the differences are of several different types he will usually proceed in one area of correction at a time. For instance if there are both tone scale and color correction errors it would be wise to correct for the tone scale errors first because the color correction error may be affected either negatively or positively after the correction has taken place. Based on his observations he will alter the conditions used to separate the file guide to compensate for the differences between the two guides one step at a time. After deciding what changes to make he will prepare film using those new conditions.

Experimentation

The first trial set of separations made will try to compensate for the most major differences between the file guide and the one being evaluated. After the film has been made and densitometric measurements have been made the new separation densities are compared to those that created the color guide. The differences represent the error still present in the new system. At this point the reproduction system is reevaluated as above and a new set of exposures are made. These two processes are repeated until an acceptable match is found. If no acceptable match is found it must be decided whether to change the printing conditions or rely on hand correction techniques.

The Machine Expert

Computers have been finding their way into the graphic arts industry for some time now. Much of the equipment in use today is controlled by microprocessors. Digital scanners and pagination systems are striking examples of the computers entry into the graphic arts. The MECAS system attempts to bring artificial intelligence techniques into practical use in the graphic arts through the use of an expert system to aid the cameraman in this decision making processes.

Hybrid Programming

The graphic arts expert is not a simple creature. He has to mix and balance some very old ideas and principle with state of the art technology. When attempting to emulate the skills of one of these experts one is confronted with a multifaceted task that has no one simple solution. One way of dealing with this situation is to rely on several diverse techniques that each do a part of the job very well and then integrate them into a system that allows each part to interact freely with the other. This brings about the concept of hybrid programming. A hybrid program is one that has several sub programs that are very different in structure and cannot be combined with each other but are made to communicate with one another. The MECAS system is such a program.

In order to emulate the three areas of thought processes emcompased in the above description of the human expert the program relys on three subprograms that individually do one part of the task very well. The comparison procedure described above is best handled by a data base program. Data base techniques are well known for their ability to store, sort and retrieve information, much like a human would in his mind or with the aid of a filing system on index cards. Rule based knowledge systems or "Expert Systems" have proven their ability to reason about a particular problem state using the same rules that a human expert would in trying to solve the problem. The analysis process that the human expert must go through will be handled by such techniques. Number crunching routines written in languages such as Basic, Fortran or Pascal have been utilized in solving complex systems of equations that can be used to simulate processes will substitute for the actual creation of film elements as described above. Information needed and generated by each subprogram is stored in files in a common format and easily exchanged between them. An executive program oversees the transfer of control to each subprogram and interacts with the user.

The MECAS system

The MECAS system is an interactive system that allows the user to input information describing the creation and results of a printed color guide. The system, in a variety of ways selected by the user, then generates a color reproduction system that will provide the highest quality reproduction attainable when using those particualar variables. The user may interact as much or as little as he wishes and has the opportunity to override machine decisions. There is also the provision to interact with the simulation subprogram and observe the results of changing one or more of the parameters of any given film element. All data generated is stored in the data-base subprogram that is also accessible separately. The flow chart in Figure 1 shows the complete system in how it approaches human emulation.

Once the program is started the user is prompted to input information about the color guide to be evaluated. A complete description of all of the printing variables and the densitometric measurements of the printed color guide are input at this point. Once the information has been entered the program proceeds to a search routine. The data base of printed color guides already entered into the system is sorted and then searched for a perfect match. If a perfect match is found the parameters used to create the color reproduction system for that color guide are output, the data base is updated and a link is formed between the two guides. At this point the user has the option of exiting the program or interacting further to see the result of any changes he may want to make. If no perfect match is found the best match is presented to the user. There is an option at this point to either manually make changes in the reproduction system or rely on the program to make the changes. If the user wishes to interact with the simulator the program branches to the simulation subprogram in the interactive mode. If the program is given control the densitometric data of the best match guide is transfered to the simulation subprogram. At this point the program simulates the process of color separating the color guide. The result is a matrix of film densities that represent key aim points of each film element. These densities are compared to the densities of the film used to create the color guide. If the simulated densities are within acceptable limits the program outputs the changes necessary to the best match color guide reproduction system parameters. The user may override at this point and manually make changes or pass control back to the program. If program control is elected the program branches to the rule based subprogram. At this point the difference between the ideal film densities and the actual film densities is represented by an error matrix. This error matrix is analyzed by the inference machine using the rule base in the program. The rule base is a series or rules that were input by a human expert and represent the way in which he would anaylze such an error matrix. When a rule is found to apply to the situation an action subroutine is initiated. This subroutine acts on the file containing the simulated reproduction system variables and changes any one or more parameters used in the simulation. The control is then passed back to the simulation sub program and the changes are simulated. The simulated film densities are again compared to the ideal ones and a decision is made to either output the new parameters or go back to the rule based sub program. This process is repeated until an acceptable answer is found. If no acceptable answer is found after the entire rule base has been exhasted the user is asked to interact with either more input or a decision to abandon the analysis. When an answer is found acceptable to the user the data base is updated with the new information.

The Data-Base Subprogram

The data-base subprogram stores sorts and retrieves all data that is put into the system. Initially when the program is set up for a particular user the file structure is set up for his shop. Paper types are given code numbers, different

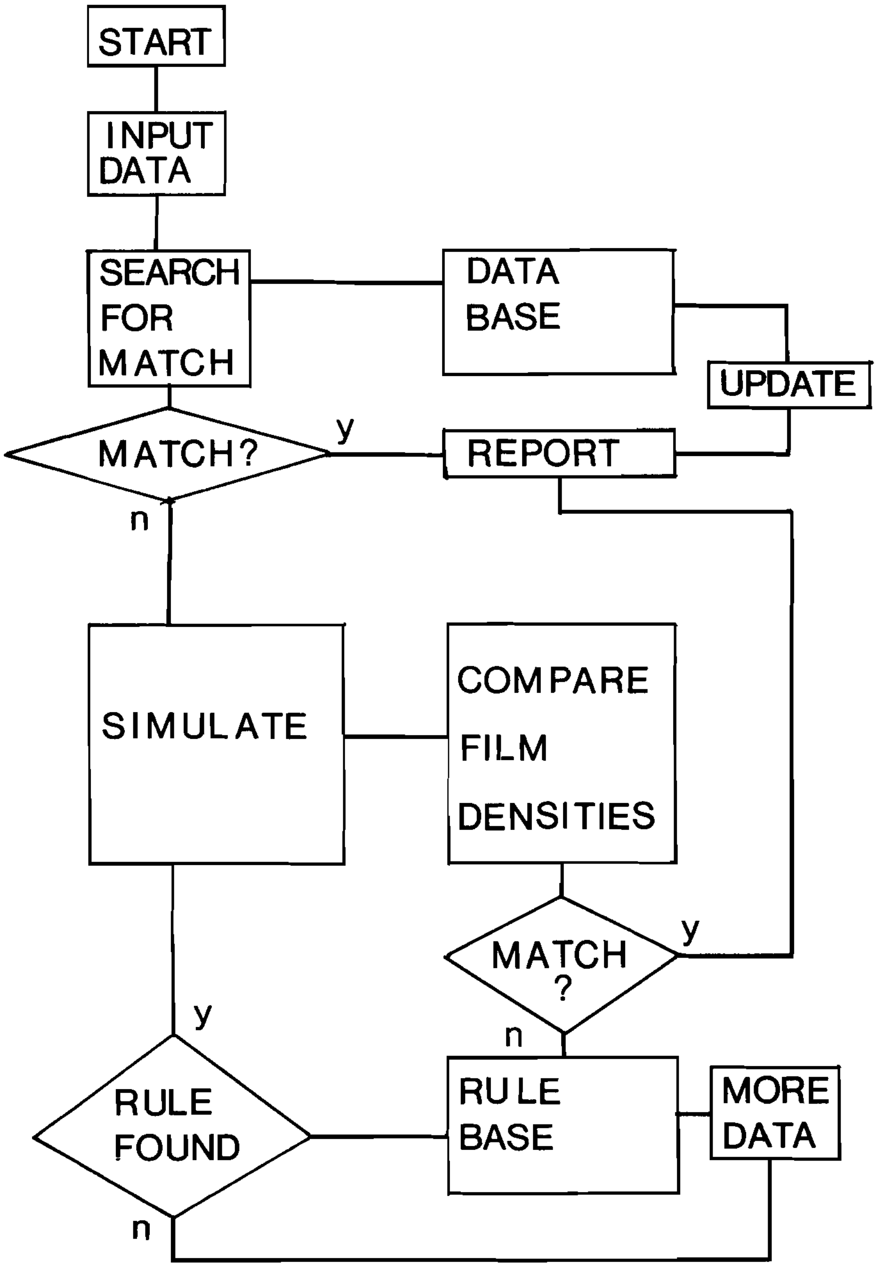

Figure 1. Flow Chart of the MECAS System

presses are categorized according to type, brand, size, number of colors, type of dryer etc. Ink type information is also gathered and coded. When actual data is to be input into the program the user is queried about his printing conditions with questions that are tailored to his shop. The program has default priorities built into it that ascertain which parameters produce the most variablity in the system in question. The user is allowed to override this default if he wishes.

Color Guide Input

When the user wishes to evaluate a particular color guide he is first asked to input information about the guide. The printing conditions used to print the guide are established first. This is accomplished through the use of questions asked of the user. The answers are input into the new file. Next the user is asked to input the reflective tricolor density readings of the color guide. These densities are stored in matrix form along with the printing conditions. Space is left in the file for the program to store the color separation parameters once they have been established. Space is also left for comments that may be input by the user that tell of special conditions that cannot be categorized.

File organization

The file structure used in the current version of MECAS is a sequential one. It is formatted as follows:

> [1st priority printing variable] [2nd priority printing variable]... [n^{th} priority printing variable] [guide number] [links to match guides] [color guide densities] [color reproduction system variables] [comments]

In this format the file color guide can be tested for applicability as a match to the guide being evaluated guide before the whole file is read into memory. This improves search time by limiting access to those files that are probably the better candidates for a match. If the file is chosen as one that will be searched for a match the file number and the printing variable index will be input into a stack. The match guide index is checked to make sure duplicate guides are not tested. When the entire data base has been exhausted the stack is sorted according to the established highest priority printing conditions. The highest priority file is input and the printing denseites are then checked for a match against the guide being evaluated. The goodness of match is recorded as a number and is placed in a stack and indexed to the color guide number. After the high priority guide files have been exhausted the best fit guide file is output to the user and the information is sent to the simulation program. In the event that no close match is found the rest of the data base will be searched for the closest match. If a good match is still not found the user will be asked to make a choice or a default file will be used.

Goodness of Match subroutine

A problem arises when a perfect match is not found and the best match has to be choosen. For instance, all the steps on one color scale might vary form a compared scale by + or - .03 . This would probably be considered a good match. Another scale may match in most steps by a greater degree but be off to a large degree in one or two steps. The differences of these two situations must be discernable by the program because of the large difference in the amount of correction needed to bring each system to the desired end. This is accomplished by measuring the error in a variety of ways:

Total error = sum of the absolute values of the differences in each step of the color scale.

Individual error = the absolute value of the error of any given point.

Color error = the number of colums in the density matrix which the cumulative error is within certain limits.

Tone scale error = the number of rows in the density matrix which the cumulative error is within certain limits.

Each type of error listed above has a different impact on the amount of correction needed to compensate for it. Color error is the hardest to correct, tone scale next, followed by individual error and finally total error. To quantify this effect each type of error is multiplied by a different power of ten that indicates it's severity and all of the errors are then added togeather. The resulting number indicates the amount of effective error that is present and determines the amount of correction necessary. The matrix with the lowest effective error in comparison with the matrix of the guide being tested is chosen as the closest match. Effective error is calculated by the formula in Figure 2.

$$(\text{color error} \times 10^{2}) + (\text{tone scale error} \times 10\ ) + (\text{individual error} \times 10^{0}) + (\text{total error} \times 10^{-1}) = \text{effective error} \qquad (2)$$

These variables can be extracted very easily if the color guide densities are arranged in the matrix format described in Appendix 1.

The Simulation Subprogram

The simulation section of the MECAS system eliminates the need for the color separator to make tests in the darkroom. It does this by simulating the creation of film elements numerically. Initially the subprogram is set up by making a series of test exposures and entering the results into the system. At this point the subprogram is capable of emulating the photographic processes of color separation. The input into the simulation subprogram is always a matrix of color guide densities. The subprogram is controlled either by the machine expert subprogram or by the operator in the interactive mode.

System Setup

A series of tests must be performed in the camera department and the results input into the system. The results of these tests show the subprogram how the photographic materials in use react to the variables in the camera department. Special color guides are used to make the tests. By knowing the reflective readings of the guide and the resulting film densities that are created, numerical routines can create formulas that emulate the actual photographic process.

The Color Guide for Setup

The special color guide used in the testing contains specific samples of colors that may present themselves in the simulation process. They are structured for use in generating data about the particular photographic conditions present in the operators cameraroom. Rather than a guide that has been created with standard films it is a guide that has standard colors present. All color patches in the guideare overprints of the three process colors. In each patch there is a different ratio of the three primaries as reflective tri-color densitometric readings. These particular densities are required by the mathematical system in use. The photographic conditionssuch as exposure times, developement times and filter numbers used in the tests are also input into the system.

The Mathematical Model

The mathematical model in use has been used in research laboratories as an aid to limit the number of experiments necessary to predict in a multivariable system what combination of these variables would yield some optimum result. (Box, Hunter and Hunter 1978) It is a three coordinate system that can be envisioned as a cube in space. Each dimension of the cube represents one of the three variables. Any point inside the cube will represent a combination of values for the three variables. The coordinates of this point are entered into an equation that yields the result of using these three values in the process. In the MECAS system the three variables used are the reflective red, green, and blue filter densities of the color guide. The output of the equation is the film density that will result when that patch is photographed. There is of course a separate equation for each film, filter combination. The coefficients for each equation are created by an subroutine that uses the tri-color densitometric readings taken from the special setup color guide. An algorithm of this subroutine appears in Appendix 2. The equation used to fit the data is shown in Figure 3. The variables X1, X_2, and X_3 are points on the three axis of the cube and Y is the film density. b_0 through b_{33} are constants determined durring setup.

$$Y = b_0 + b_1X_1 + b_2X_2 + b_3X_3 + b_{12}X_1X_2 + b_{13}X_1X_3 + b_{23}X_2X_3 + b_{11}X_1^2 + b_{22}X_2^2 + b_{33}X_3^2 \tag{3}$$

During program usage, when a color guide is evaluated, each step of the color guide, represented as tri-color densitometric readings is input into the formula above for each film element created, resulting in a new matrix for each film element. The densities of the color correction masks are subtracted from the densities of the separation negatives to simulate the masking effect. These matricies are then subject to another mathematical routine that in combination with the exposure and developement information create polynomials that represent characteristic curves of the film elements. It is these curves that are manipulated by the Machine Expert subprogram to institute changes in the reproduction system. The curves are then converted back into the density matricies that are used for comparison to ideal densities.

The Interactive Mode

The operator if he so chooses may simulate changes to the individual film elements manually by entering the interactive mode in the simulation subprogram. For instance if he is curious as to what would happen if he increased one of his mask contrasts or changed the mask exposure to a split filter exposure he could do so by entering the changes into the system and observing the results not only as the changed film densities of the mask but also the final film densities of the color guide. He would do so by entering the appropriate changes in response to prompts by the system. These changes would then be inplemented by the program through alteration of the polynimials that represent the film elements which in turn will alter the simulated film densities of the color guide. He also has the option of visually observing the change through the plotting routine. This routine will output a tone reproduction curve for the particular film element wanted. It will also produce 4 quadrant graphs showing the transfer of densities from element to element.

The Rule Based System

Rule based systems or "Expert Systems" as they are commonly known have had great sucess over the past few years. One program is in use today for medical diagnosis (Shortleffe 1975). The basic expert system consists of a knowledge base and an inference engine.

The Knowledge Base

The knowledge base is a collection of rules about a particular problem solving technique. These rules are input into the system by a human expert and represent the knowledge he has on a particular subject. The rules when input have to follow an exact format so that they may be interpreted by the inference engine. The format used in MECAS is shown in Figure 4.

<condition a> <condition b> <condition n> = <action n>

(4)

If each of the conditions of the rule are true then the action is implemented. If one or more of the conditions are not true then no action takes place. Each condition represents a piece of knowledge about the color guide and/or some information derived from the color guide or a constant related to the users shop conditions. When the rule is input into the system the conditions are also entered in a special format that the program understands. The condition format for the MECAS system is shown in Figure 5.

<variable1 index or numerical value> <variable2 index or numerical value> <logic function>

(5)

All of the color guide densities and the results of computations made using them are contained in a variable matrix. The variables are refered to by an index code that represents the position of the data in the matrix. To represent a condition the first variable is input as a number that represents a cell in the variable matrix. If a constant is needed it is prefixed with a code that indicates that the next number input will be a constant rather than a variable. The second variable follows the same structure. The logic function is input as a code that represents one of 5 possible locical functions: (=),(<),(>),(<=),or (>=). If after the two variables are compared their relationship is equal to the logic function stated the condition is labled true and the next condition is tested in the same manner. If it is found to be not true then the rule is abandoned. The example in Figure 6 shows the translation of a typical rule.

English rule= If the cyan middle tone to shadow ratio is less than the magenta middle tone to shadow ratio and the cyan highlight density is 1.25 then decrease exposure by 15%.

The cyan midtone to shadow ratio is stored at <1,3,123>

The magenta midtone to shadow ratio is stored at <1,3,133>

rules one at a time every time the program passes to the machine expert mode would make the system impractacle. This situation is called "saturation" (Davis 1980). The MECAS system uses two techniques to eliminate saturation.

Rule Base Structure

A common feature of rule based systems that is also apparent in MECAS is that the conditions that make up individual rules are usually shared by many other rules. This means that if all of the rules in the rule base file are to be tested then the same condition may be tested countless times only to yield the same result. This is an extremely wasteful procedure, but a necessary one until the introduction of the hierarchically structured rule base (Leith 1983). This type of rule base structure allows rules to share individual conditions and allows these conditions the need to be tested only once. Figure 7 illustrates four rules organized in a traditional structure. Each condition in turn is evaluated to ascertain whether the rule is true. Conditions 1a, 2a and 3a are identical, as are 2b, 3b and 4b, etc. To test these 4 rules all 16 conditions must be evaluated even though there are only 9 different conditions. The same set of rules organized in a hierarchical structure appear in Figure 8. Using this method common conditions are represented only once and on one level of the structure. Links between conditions that make up the individual rules are represented by links to other levels. The final links in each branch lead to the action part of the rule. First the top level of conditions are evaluated. The conditions that are true allow the link to proceed to the conditions in the next lower level. If a condition is found to be not true then the evaluation of that branch is terminated because the rules represented by that branch have to be false. This structure necessitates a maximum of 9 evaluations. The advantage can be seen further if for instance condition (c) is false. In the structure shown in Figure 7, 13 evaluations would take place. The structure in Figure 8, however, only 10 evaluations are needed because the links to conditions after (c) are terminated. The MECAS system utilizes a subroutine when rules are entered into the system that automatically structures them hierarchically. An explanation of this procedure is, however beyond the scope of this paper.

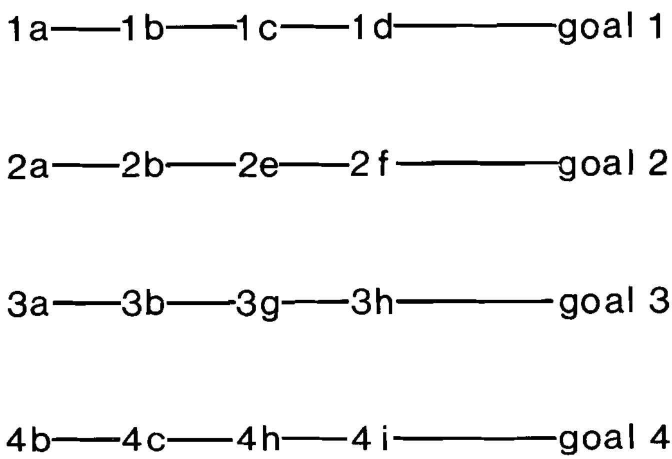

Figure 6. Rules Base Represented in Conventional Structure

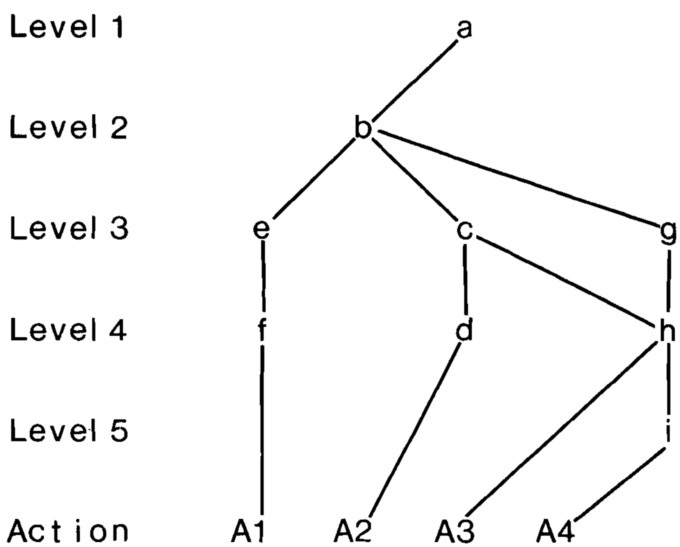

Figure 8. Rule Base Represented in Hierichical Structure

The logical function (=) is represented by the code 1

The cyan highlight density is stored at <1,1,1>

The code for a constant is 999

The density of 1.25 is input as 1.25

The action of decreasing exposure by 15% is <42,.15>

The rule would be stored as the following code:
{<1,3,123><1,2,133><1>}
{<1,1,1><999><1.25><1>} = {42, .15}
(6)

When the rule is input into the system it is done so in response to questions asked by the program. In this way the complexities of the format structure are transparent to the user.

The Inference Engine

The rule base alone cannot apply a rule to a problem. A mechanism for implementing the rule is necessary. The inference engine is a subroutine that checks the individual conditions of rules and indicates whether the rule is true or false. It also in the case of MECAS initiates the implementation of the action of a rule when it is true. The subroutine inputs a condition of a rule, finds the indicated variables in the variable martix, and compares the relationship of the two variables to the logic fuction indicated in the condition. If the condition is true the next condition is tested. If all of the conditions of a rule are found to be true the program jumps to a subroutine that implements the action specified by the rule. This subroutine changes variables in the simulation subprogram.

The Concept of Saturation

A problem occurs with rule based systems such as the one used for MECAS because usually there are massive amounts of rules necessary to implement the system. In order to find out which rules apply to the present problem they must all be tested. The amount of time required to test all of the

Metarules

Another technique used to make rule based systems more efficient is to use metaknowledge (Davis 1980). Metaknowledge is knowledge about knowledge. Metarules are rules about rules. If at the highest level of the rule base there are certain rules that limit the access to the rest of the rule base then it is possible to test only those rules which are most applicable to solving the current problem. For instance if the first rules tried can determine if the color guide being evaluated has tone scale error then the action of these rules can be to give rules that deal with correcting tone scale error a high priority and disable rules that deal with color correction. This is accomplished by having a series of rules that ask questions that will determine if there is tone scale error. The action part of these rules is not used to correct the errors but to branch to the rules that do.

Conclusion

The MECAS system when used as an extension of existing talent will adjust color separation techniques to compensate for different printing conditions. It is designed to run on a popular personal computer with 512K bytes of RAM and a 10 megabyte hard disk. Systems such as this one are readily available and inexpensive.

Future plans for the system include a version that will be interfacable to a color scanner. This type of programming will greatly reduce the efforts necessary to adjust the machine for different printing conditions. This type of programming coupled with statistical image analysis would also have some merrit.

Unfortunately the code for the program is too lengthy to include in this paper. For those interested this paper should provide enough information to create a simple version. Most of the techniques used are standard programming practices. The data base subprogram can be implimented by using any one of the better versions on the market. The math used in the simulation subprogram is readily available in the literature. For those interested, a copy of the conplete program will be made available in the near future.

Appendix 1.

Error Calculation

	CYN	GRN	YEL	RED	MAG	BLU	3C	4C	K	WH
HL	0, 0	0, 1	0, 2	0, 3	0, 4	0, 5	0, 6	0, 7	0, 8	0, 9
MT	1, 0	1, 1	1, 2	1, 3	1, 4	1, 5	1, 6	1, 7	1, 8	1, 9
SH	2, 0	2, 1	2, 2	2, 3	2, 4	2, 5	2, 6	2, 7	2, 8	2, 9

Total error can be calculated as follows:

```
Rem Errormat is matrix of errors
For I=0 to 2
     For J=0 to 9
     Let E=E + Abs Errormat(I,J)
     Next J
Next I
```

Individual error can be calculated as:

```
Ex=errormat(n,n)
```

Color error can be calculated as:

```
For J = 0 to 2
     For I = 0 to 9
     Let Color_error(J) = Color_error(J) + errormat(I,J)
     Next I
Next J
```

Tone Scale Error can be calculated as:

```
For I = 0 to 9
     For J = 0 to 2
     Let Tone_error(J) = Tone_error(J) + errormat(I,J)
     Next J
Next I
```

Appendix 2.

Simulation Mathematical Model

This subroutine requires that certain tests be made with the shop photographic conditions and a special color guide. The color guide is comprised of 13 patches that represent as many combinations of specific tri-color densitometric readings. The readings from each of the three color filters must be exactly one of three predetermined levels of density. These levels are determined empirically to assure linearity within the system. They are represented by (-),(0), and(+) where (-) is the lowest test density,(0) is the middle test density and(+) is the highest test density. Each patch of the color guide is required to have certain combinations of the above densities. They are as follows:

Patch #	Coordinates X_1	X_2	X_3
1	+	+	0
2	+	-	0
3	-	+	0
4	-	-	0
5	+	0	+
6	+	0	-
7	-	0	+
8	-	0	-
9	0	+	+
10	0	+	-
11	0	-	+
12	0	-	-
13	0	0	0
14	0	0	0
15	0	0	0

The patch that represents (0,0,0) is presented 3 times to center weight the cube. It is also the only neutral patch in the guide. When photographed the resulting densities of each patch are input into a series of equations as Y(n) where n refers to the patch as described in the above chart. The following equations yield the final formula:

$$B_{1a} = Y_1 + Y_2 + Y_5 + Y_6$$
$$B_{1b} = Y_3 + Y_4 + Y_7 + Y_8$$
$$B_{2a} = Y_1 + Y_3 + Y_9 + Y_{10}$$
$$B_{2b} = Y_2 + Y_4 + Y_{11} + Y_{12}$$
$$B_{3a} = Y_5 + Y_7 + Y_9 + Y_{11}$$
$$B_{3b} = Y_6 + Y_8 + Y_{10} + Y_{12}$$
$$B_{1c} = Y_9 + Y_{12}$$
$$B_{1d} = Y_{10} + Y_{11}$$
$$B_{2c} = Y_5 + Y_8$$
$$B_{2d} = Y_6 + Y_7$$
$$B_{3c} = Y_1 + Y_4$$
$$B_{3d} = Y_2 + Y_3$$

then:

$$b_0 = (Y_{13} + Y_{14} + Y_{15}) / 13$$
$$b_1 = (B_{1a} - B_{1b}) / 8$$
$$b_2 = (B_{2a} - B_{2b}) / 8$$
$$b_3 = (B_{3a} - B_{3b}) / 8$$
$$b_{12} = (B_{3c} - B_{3d}) / 4$$
$$b_{13} = (B_{2c} - B_{2d}) / 4$$
$$b_{23} = (B_{1c} - B_{1d}) / 4$$
$$b_{11} = (B_{1a} + B_{1b} - B_{1c} - B_{1d} - 4b_0) / 8$$
$$b_{22} = (B_{2a} + B_{2b} - B_{2c} - B_{2d} - 4b_0) / 8$$
$$b_{33} = (B_{3c} + B_{3b} - B_{3c} - B_{3d} - 4b_0) / 8$$

gives:

$$Y = b_0 + b_1X_1 + b_2X_2 + b_3X_3 + b_{12}X_1X_2 + b_{13}X_1X_3 + b_{23}X_2X_3 + b_{11}X_1^2 + b_{22}X_2^2 + b_{33}X_3^2$$

The above process is repeated for each film element and the coefficients are stored. When the simulation subprogram determines a film density for a given color guide patch the coordinates of the patch are substituted for X_1, X_2, and X_3. The densities of the color guide patch must be translated first into the appropriate coordinates. For instance the point half way between $X_1(0)$ and $X_1(+)$ would be $X_1(.5)$. The following algorithm converts density into coordinates:

Where Cmid is the (0) density, Chi is the (=) density, Clow is the (-) density and den is the input density and X is the coordinate.

Let(Mid - Clow) = (Chi - Cmid)
X= (den - Cmid) / (Chi - Cmid)

References

Box, G. P., Hunter, G. H., Hunter, J. S
1978. "Statistics for Experimenters," John Wiley & Sons, NY 1978. pp. 291 - 432.

Davis, R.
1980. "Meta-Rules: Reasoning about Control," Artif. Intel. vol. 15, pp. 179-220.

Lieth, P.
1983. "Hierarchicaly Structured Production Rules," Comp. Jrnl., vol. 26, no. 1, pp. 1-5.

Shortliffe, E. H.
1975. "Mycin: A Rule Based Computer Program for Advising Physicians Regarding Antimicrobal Therapy Selection," Doctoral Thesis, Stanford University.