Supporting "good enough" colour reproduction in non colour managed workflows

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Abstract

In this paper we propose a novel and coherent approach to control and adjust colour reproduction where strict end-to-end colour management cannot be achieved. We first recall the studies and findings that identified the need to reconsider colour management in certain workflows. We then present in detail the Print Mediator system, constituting a first attempt to implement this new approach.

Introduction

In some digital printing industry workflows the adoption of state of the art colour management approaches to solve the problem of colour reproduction across various displays and printers has failed. Often this is due to practical constraints, such as cost and a lack of required expertise (this will be discussed in more depth in the motivations section). This has been reported as relatively common in studies of graphic design for products and marketing where documents are created by design agencies but ultimately printed by separate print shops (cf.[1],[2]). In this paper we present a practical alternative to strict end-to-end colour management in the digital printing industry. This work is the outcome of several in-depth *work practice studies* (see [5][1] for an introduction to this research method) of print workflows conducted in order to better understand the barriers to adoption of colour management [2],[3],[4]. Our suggestion does not replace but rather complement existing colour management approaches which are themselves based on sound scientific groundings [12].

This paper is structured as follows. In the first section we briefly expose the findings of the work practice studies that motivate our approach. We highlight the causes for the failure of traditional colour management approaches that these studies identified in various settings and describe the current practices used by professionals in the absence of a colour managed workflow. We also explain how these studies have driven the design of our approach in complementing existing traditional colour management. The second section then presents the design of the *Print Mediator* system, being our first attempt to address the highlighted weaknesses. Here we describe in detail the features of the proposed system. In section 3 we discuss how Print Mediator differs from existing techniques and technologies and why we believe it proposes a novel and coherent approach to control and adjust colour reproduction where strict end-to-end colour management cannot be achieved. Finally we conclude by presenting some preliminary tests and indicating some future work to be done to further validate the proposed concept.

Motivations

Colour profiles and International Colour Consortium (ICC) protocols are meant to enable colour to be rendered consistently across devices. They embody formal colour management procedures. These protocols and techniques rely on rigorous mathematical models and have facilitated the design of very sophisticated and accurate colour reproduction technology. Whilst the use of colour management has proved its efficacy in certain application domains, Riordan [1] found that about two-thirds of design firms and publishers do not use colour management at all and that, where they do, the print shop personnel often do not trust the colour expertise of the designers, and discard any profiles included in the document. Our more recent field studies have confirmed these observations.

As discussed in [2] one of the weaknesses of colour managed workflows is that they need to be applied end-to-end; i.e. in order to work properly they rely on good practices at *all* steps of the document creation-to-printing process. From a printers' perspective, an additionally problematic feature is that while they understand colour profiles in files are often an artefact[2] of choices unwittingly made by designers, they have no clear way to recapture what the 'real' intent of the document was. Thus, when the lack of consistent industry standard colour management practices in everyday workflows results in problematic colour output this leads to an increased time-to-press and requires several print iterations before adequate print results are reached. Furthermore, such workflows require a high amount of communication and collaboration between print shops and customers to sort out colour problems. Interestingly, at a time when we see an emerging market for short-run, on-demand, web-based printing, where communication and collaboration between document creators and printers is meant to be minimised, this may stand as a considerable barrier to the growth of this market.

Rather than the underlying technical principles of colour management what is challenged here is its adoption in some workflows. For this reason, we felt that a deeper understanding of the professional practices in these settings was required in

[1] Work practice – or ethnographic – studies, are naturalistic, qualitative studies. The approach originates in anthropology and sociology. Randall et al. [5] give a detailed introduction to the use of this approach in computing as well as providing an introductory guide to carrying out these studies.

[2] Files always contain colour information. Often this comes from default settings. Graphic designers are often unaware of what these are and how they may affect the colour reproduction when a document is printed.

order to understand the barriers preventing the adoption of colour management and to get some insights in how to better support it. We carried out our research through multi-sited ethnographic work practice studies in Europe, the US and Canada of print shops and graphic design houses [2,3,4]. We studied 6 print shops, which can be described as small to medium in size, general purpose, and with varying levels of sophistication in terms of colour understanding. However, none systematically implemented colour management. Similarly we studied 5 graphic designers with basically similar profiles – small to medium in size and varying understandings of colour. On the whole these were general purpose, however one was located in a university marketing department and another specialised in packaging. These designers had heard of but did not understand or implement colour management. Nevertheless both designers and print shops could achieve good or certainly 'good enough' colour results. Ethnographic workplace studies have been used in computer systems design in fields like Human-Computer Interaction (HCI) and Computer Supported Cooperative Work (CSCW) since the 1980s (cf. [6][7][8][9]). They are a social scientific method that involves the gathering of qualitative data, in situ, in field-sites, through observation (and note taking), unstructured interviews and video and audio recordings and the analysis of how work is organised as a recognisable social accomplishment. A better understanding of the application domain and the way technologies are used and understood collaboratively, within e.g. a workflow, can be helpful in reconfiguring those technologies or providing inspiration for technology innovation.

The study highlighted a serious miss-match between the concerns, activities and understandings of many designers and the way colour management controls are instantiated. Colour management technology can be thought of as a technical infrastructure supporting colour reproduction across different rendering devices of a workflow. Our studies indicated a knowledge and interest gap in the industry (i.e. colour management is too complicated for the average user to understand, and is furthermore not a central concern during the design activity). As such it would need to be controlled by a "colour engineer" with specific knowledge and concerns about administration of overall colour reproduction across the devices of the workflow [3]. In many small and medium sized teams and cross-organizational settings, having a skilled person dedicated to this function constitutes too much of an overhead and the responsibility for managing colour (i.e. working to get good enough colour rather than adhering to colour management, profiles etc.) is thus shared across the different actors and organisations producing the documents.

'Successful' colour management would ideally start with document designers. However, designers have a very different approach to colour compared to a colour management expert. They deal with colours primarily as they perceive them, on screen or on-print. Furthermore, they are aware of colour reproduction problems and operate with *tolerances* that relate to aesthetic concerns (does it look good, is the design harmonious), customer requirements (what is important, what will they accept, how much money can they spend) and also the lack of perceptual constancy between successive viewings (they do not always notice colour changes). For example, the green colour of the grass in a photo might be allowed to change as long as it appears somehow natural, while the green colour of a company logo would need to be pretty exact. In contrast to such a tangible and practical object related colour definition, colour management involves the manipulation of global colour space mappings, with very accurate and objective definitions but it is disconnected from specific instances of the design and from their requirements, tolerances and so forth. Designers do not master the underlying principles of colour management. They do not grasp the links between the colour management controls and the effects on their particular design. This often leads to inappropriate and incorrect use of colour management technology.

From our study we have identified a strong incompatibility between the way document designers interact with colour and the way colour management needs to be monitored. This does not mean, however, that document designers underestimate colour reproduction issues and the need for colour management. They rather engage in very ad hoc colour management practices based on a practical understanding of colour reproduction issues and ad hoc strategies to palliate them (see also [3][4]). They are often built on the basis of well established relationships and collaborations between designers and printers. These practices include printers providing specific swatch books to theirs customers, doing colour tests, or defining dedicated spot colours in printer libraries for a recurrent customer. Also, 'savvy' designers work systematically in a CMYK colour space during design to be "close to the printer". These practices can be seen as neither systematically optimal nor scientifically correct but they all have the advantage of offering to their users a more graspable (and realisable) way to handle colour in their work. The currently available more robust colour management solutions, in contrast, lack this graspable dimension. To improve their design and increase their adoption it is therefore important to carefully consider the observed current practices.

From the study two main directions have emerged to improve the colour reproduction in settings where strict colour management is not affordable. The first one is to rethink the interface between the colour management infrastructure and the document producers in order to help them in choosing the appropriate options and improve the quality of their documents through better colour specifications. The second one is to acknowledge that the communication between the designers and printers will remain central to solving the colour reproduction issues when documents have not been designed and handled properly using the colour management infrastructure. This communication is further challenged by productivity constraints and new printing business models. Therefore it requires adequate support to enable the collaborative solving of colour reproduction issues quickly and efficiently. Both dimensions are addressed by the Print Mediator system presented in the following section.

Proposed solution

The Print Mediator system (see figure 1) is a new type of print workflow tool to be deployed as web front-end of print shops. Designers can use it to review and improve the quality and print readiness of their document before submitting it to the printer. Printers can use it afterwards to review the submitted document including the annotations provided by the designer.

As represented by the doted lines in Figure 1, the system acts as a mediator at two levels:

- *Designer printer communication (vertical doted line).* The Print Mediator system facilitates the communication between document designers on one hand and printer operators on the other hand. Before submitting his 'job' (e.g. a PDF document) to the print shop the document designer will go through the Print Mediator system to foresee potential issues with printing. Print Mediator will assist him in either applying immediate colour corrections or communicating requirements to the printer. Immediate colour corrections might for example consist in adapting a particular element's colour specification. Requirements to the printer can be specified in free text, e.g. "this colour is our company colour; it must be matched accurately" or "This text must be easily readable; check contrast with background". On the print shop side, the operator or a pre-press agent will use Print Mediator to visualize the submitted document together with the designer requirements. It will help him to take into account these requirements when actually printing the document.
- *High level interface to colour (horizontal doted line).* Print Mediator does not only mediate between document designers and printer operators. It also mediates between human users and underlying technical components, in particular colour management and colour processing components. It provides a high level interface to these components enabling the user to associate the underlying operations with corresponding visual effects on the document objects. It furthermore translates the technical parameters used by the colour processing components, e.g. RGB values and profiles, into natural language [10]. This interface provides a more intuitive view of colour components to users so that they can use these components to correct colour problems.

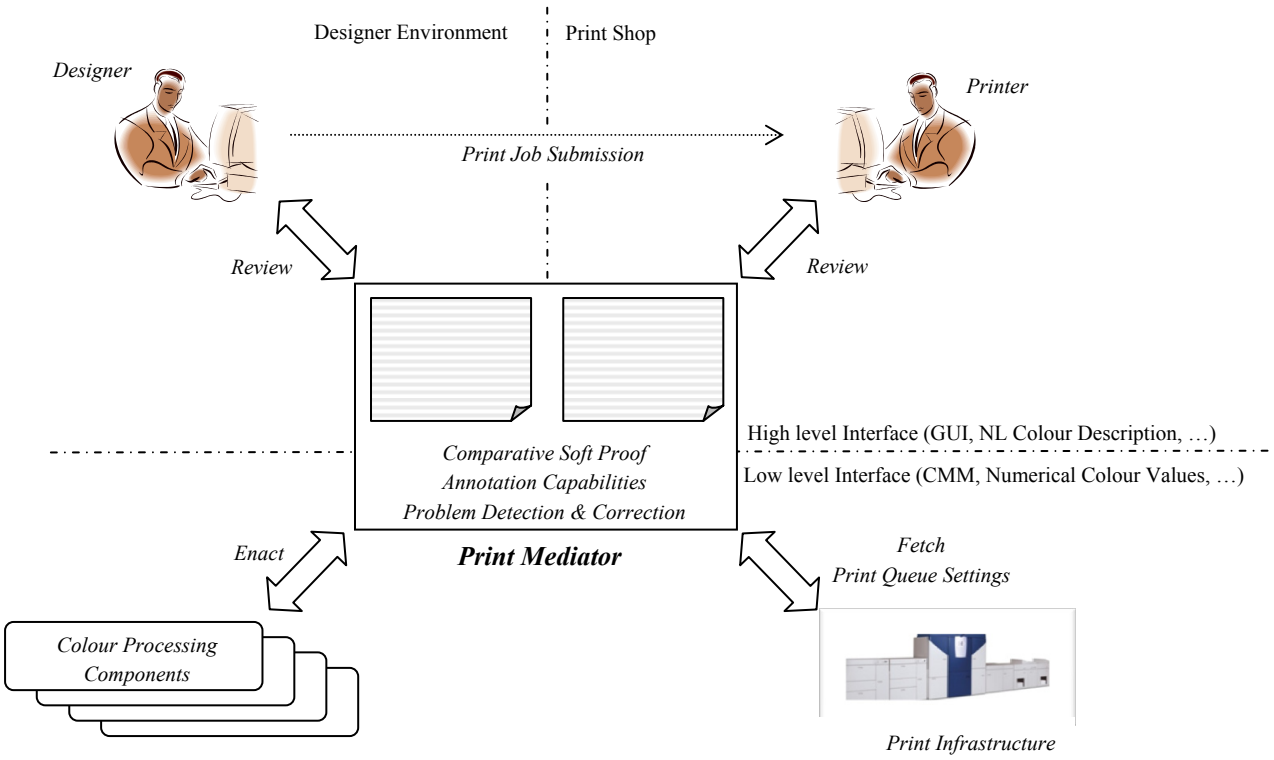

Figure 1 *Print mediator acts as mediating interface at two levels, firstly between the document designer and the print shop operator, and secondly between its human user and the underlying colour infrastructure.*

In the next section we describe the functional layers of the system that provide these two levels of mediation.

Functional Layers

Print Mediator is composed of the following three functional layers:

1. The *comparative soft proof* allows the user to visually assess colour differences between the original document and its simulated print out.
2. The *annotation capabilities*, allow the user – on top of the comparative soft proof – to indicate problematic areas and specify corresponding requirements with respect to printing.
3. The *interaction facilities with colour problem detection and correction components* first assist users in assessing colour differences by highlighting colour problems and explaining their causes. They then guide users in the use of colour processing components to correct these problems wherever possible.

In the following we present each layer in more detail.

Comparative Soft Proof

The traditional role of soft proofing is to accurately simulate the print out of a document in order to avoid performing an actual proof on the printing device. However, achieving an accurate soft proof requires a correct and regular calibration of the screen together with controlled viewing

conditions. This is – as discussed earlier – often difficult to achieve for a designer. With Print Mediator we propose an alternative approach, the comparative soft proof, which does not aim at giving an accurate simulation of the print out but rather at providing a review environment enabling a user to appreciate if and where the colour reproduction of his document will be problematic. It consists of a combined visualization, side by side, of the submitted document version and a document soft proof (based on the actual target device capabilities). The underlying assumption is that even if the user's screen is not calibrated the comparative soft proof will enable the user to detect major differences between the document he is submitting and the (simulated) printed version. Visible differences on important regions will trigger interactions and stimulate the user to articulate his expectations and requirements with respect to those regions.

Annotation Capabilities

When visually comparing the original document and the predicted print result, the Print Mediator system will allow the designer to interactively indicate those objects and areas within the document where the document transformations during printing introduce problematic changes. This feature clearly acknowledges the unique competency of the user to decide which objects and areas are critical in the colour reproduction of the document. Indeed, as discussed below, dedicated colour components may detect colour changes but only the user can evaluate if these changes are really problematic or not. The user can thus annotate areas and objects and specify the problem s/he observed and/or the correction s/he requires. These annotations assist a specification for each problematic area in terms of the nature of the problem (i.e. the colour is not compliant with the brand), its criticality, or the property of the object colour to preserve in order to maintain the original intent. The resulting annotations will be visible and accessible through the document display to both, designer and printer. Ultimately they will help to find a good overall compromise for the colour reproduction of the document. The user annotations are not contractual and do not correspond to a formal agreement over a proof. Thus nothing prevents using them in a non calibrated environment.

Guided Colour Problem Detection and Correction

With the comparative soft proof and the annotation capabilities described above the Print mediator system constitutes a review/communication tool between the different actors of a print workflow. To complete its functionality it still has to be connected to the colour management infrastructure. Indeed, the review activity can benefit from an interaction with colour management controls at two levels, problem detection and problem correction. Associating a visual colour difference with a particular colour management setting for instance allows one to understand its causes and enables problem detection. Using the colour processing components to improve the document colour reproduction, taking into account the user annotations, for example, allows problem correction. In consequence the third layer of the system links the user perspective with the colour processing capabilities. Colour is internally represented through numeric values associated for instance to colour profiles or spot colour names. In the end colour problems basically correspond to numerical differences between the original document and its print out. Such numerical differences are difficult to appreciate, in particular for non technical users such as document designers. This layer translates observed colour differences into natural language descriptions (from [10]), and, even more, provides a natural language interface to interact with colour processing components that translates user requirements into internal settings and colour values changes in order to correct the problems. This is implemented on one hand through a generic user interface framework based on a template-based text generation mechanism inspired from multilingual document authoring [11] and on the other hand through a set of colour problem detectors and correctors that integrate the colour processing components as plug-ins.

Within these three layers, the objects manipulated and constituting the core of the mediation are colour problems. In the next section we define more precisely the concept of colour problems in Print Mediator illustrating it with concrete known problems in colour reproduction.

Colour problems: Symptoms, Causes, and Solutions

When talking about colour problems, it is important to distinguish their *symptoms* and *causes* in order to apply appropriate *solutions*.

Symptoms

A symptom corresponds to the perception of a problem by a user. The symptom of a colour problem in digital printing workflows corresponds basically to a colour change within a document that is observed when comparing the printed version to the original version. Such a colour change might affect the whole document ("all reds become darker"), individual objects (the logo colour changes), or several objects and their relative colour ("the objects A and B appeared to have the same colour in the original but their colour differs in the printed version"). An observed symptom is always characterized as a numeric difference in the underlying colour values, but it is impossible to define a universal threshold that allows one to detect when a difference will constitute a real problem for the user. Evaluating what is a problem is indeed a subjective interpretation of a user. The way a problem concerning an individual object is perceived depends furthermore not only on the object's own colour change but also on the colour change of its background and/or surrounding objects, and on the object's size and location.

Causes

The causes of a colour change can be manifold. Each symptom can be produced by various causes, the set of possible causes being limited by the type of object that is concerned by the colour change, and the way its colour is specified. If the colour change affects the whole document the cause might be that the document has no associated colour profile and is thus interpreted using the default profile defined within the visualisation tool and at the printer respectively. If the colour change affects a photograph embedded within a document, similarly the photograph might lack an associated colour profile, and again a different default profile might be used at both sides. If the colour change affects a particular graphical element, a coloured block for instance, several causes are possible: either (1) this block is defined through a spot colour and this spot colour is mapped into process colours differently within the visualisation tool and or at the printer, or (2) the colour – spot colour or not – is out of the gamut of the printing device and is therefore changed applying gamut mapping

algorithms, or (3) - even if the colour is within the printer gamut - it might be changed applying gamut mapping algorithms to allow mapping other out-of-gamut colours into the printer gamut. Finally if the colour change affects sets of objects and their relationship in terms of colour, e.g. if several objects appeared to have the same colour in the original but do not in the printed version, this is caused by the fact that these objects were specified through different means (spot colours on one hand and process colours on the other hand) and will thus be processed and mapped to process colours differently when generating the printed version.

Solutions

Solutions for colour problems are again manifold and correspond to the options to correct a given perceived symptom with its possible causes. Missing profiles can be specified, and colour definitions changed. Where several objects are concerned their colour specification can be unified or modified consistently. What cannot be "solved" are out-of-gamut colours ; the only way to do this would be to either change the input colour specification, selecting instead an in-gamut colour, or to change the output device, selecting another one with a larger gamut. If the individual solutions might be simple, the problem with applying solutions, i.e. modifications, is that each individual solution may have side effects. For instance, assigning a profile to the document will change the rendering of all its components. Changing the colour specification of one particular object might change its colour relationship with other objects, i.e. create problems with inter-object harmony. Thus solutions may influence other observed symptoms and even create new problems. Therefore it is important to solve observed problems in a particular order, prioritizing them. It is important to identify which are the most important issues and where the corresponding solutions will have the broadest side effects, because these are the ones that should be tackled first.

Above we have given a number of examples for existing colour problems. In Print Mediator they are handled through corresponding problem detector and corrector plug-ins. A problem detector will be associated to a symptom-cause relationship. It will assist the user by detecting possible problems that have always to be confirmed by the user. A corrector will provide access to a corresponding solution. The next section will illustrate an example of a colour problem being managed through the use of our current Print Mediator prototype.

An Example

Once a designer has finished designing a document and estimates that it is print ready s/he will go to her/his print shops web site to submit the document for printing. To check that the document will print as expected s/he will first open it through Print Mediator. Figure 2 illustrates in more detail the interaction process described in this section along with the different interaction steps.

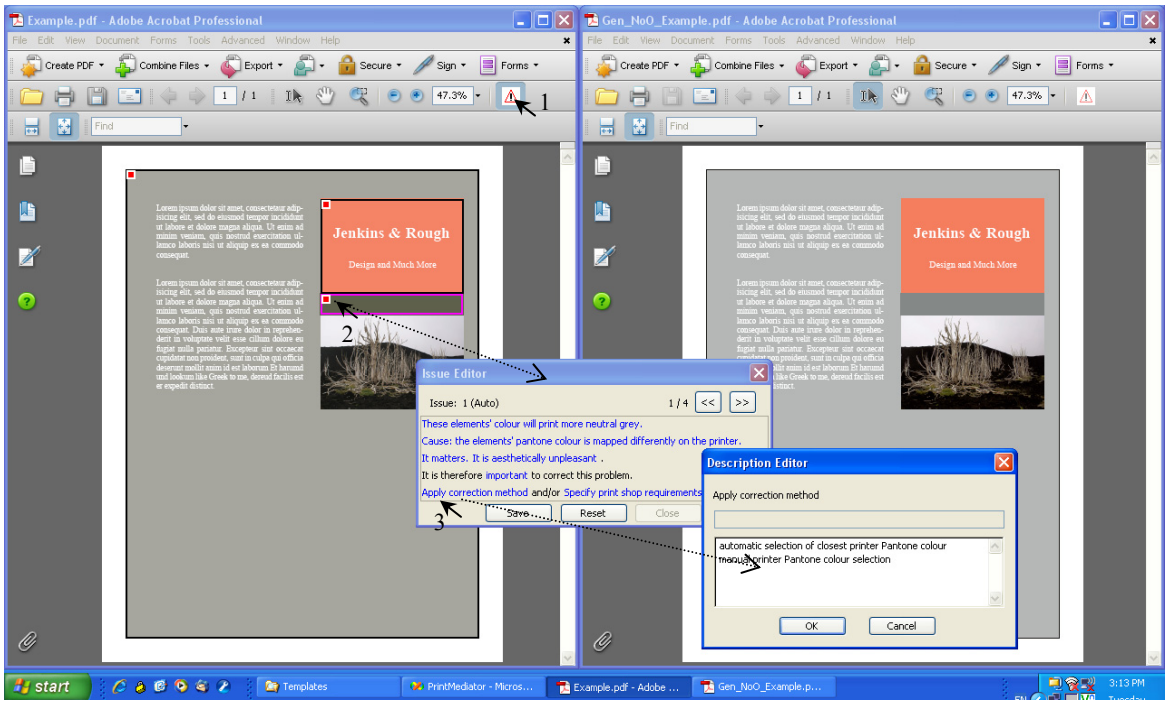

Figure 2 *The user has launched Print Mediator to check that his document will print as expected. Print Mediator is implemented as an Acrobat Plug-in. It initially activates the Comparative Soft Proof showing side by side the original document (left) and the soft proof (right). In this example several objects within the document change colour significantly. To display detected possible problems and concerned regions the user clicks on the Beware sign (1). To access the description of the possible problem s/he clicks on the corresponding region (2); this will open a corresponding problem specific dialog box. Here it explains that the selected region changes colour because it is defined by a spot colour that will be mapped differently on the printer. The user can further specify the problem description, in particular its importance and the reason for its relevance. The selected problem can in our case be solved launching any out of two integrated problem correctors (3)*

Print Mediator will first provide the user with the comparative soft proof view, simulating the print out as if it was processed through the client's usual print queue. The user can notice that - with respect to what was shown on her screen previously - some parts of the document will change colour when printed. In the background Print Mediator has automatically launched its set of integrated problem detectors. The user can display the corresponding regions to review the problems detected and suggested by the system. The user can also visually identify - through the Comparative Soft Proof - problematic regions that were not necessarily detected by the system. In this case s/he can select and annotate them manually.

Currently the Print Mediator prototype integrates two problem detectors. The first one is a colour difference detector. This detector maps object colours as specified in the original version and computed in the printed version respectively to the Lab colour space in order to compare them. For the user the colour change is translated into natural language and expressed in terms of Lightness, Hue and Saturation changes. The second detector detects sets of objects that were of similar colour in the original but will be different in the printed version. In our example (see figure 2) the first detector detects several significant colour differences.

On the display each of the suggested problematic regions is highlighted by a surrounding rectangle; selecting it opens a dialog box allowing the user to validate the problem as a problem for them, or to ignore it. When validating a problem the user also specifies its importance for the document intent and either tries to solve it through integrated corrector components or specifies free text requirements for the print shop.

Related Work

Whilst a lot of research has been done in the colour management community to develop more sophisticated models and colour reproduction techniques very little has been done concerning a better design of print workflow applications. On the market, mainly two types of applications supporting designers and printers work can be compared with Print Mediator: collaborative document annotation and Pre-Flight.

Concerning the designer-printer communication, several existing systems support collaborative document annotation for reviewing purposes, but without integrating these annotations with color-related problem detection and solving capabilities. An example is the INSITE Creative Workflow System proposed by Kodak that manages content creation and approval for ad agencies, publishers, and creative individuals. It includes a range of tools for collaborative reviewing and proofing. It allows selecting and textually annotating regions in PDF documents. But these annotations are limited to textual descriptions handled like post-it notes on a paper document and exclusively used as a basis for a collaborative document review and approval. In our approach in contrast annotations concern color issues and are integrated with problem detection and correction mechanisms. The Kodak system also integrates a differential view of two versions of a document. But its aim is to quickly verify if previously requested changes were made and *not* to highlight problematic areas and solve corresponding problems.

With respect to problem detection and correction, so called Pre-Flight tools, do not provide a printer-specific view of a document but rather allow one to check that a document respects a set of constraints corresponding to a particular document standard. The standard itself might be related to printing but aim to eliminate common problems in advance, guaranteeing for instance that all fonts used are included in the document. In some cases Pre-flight tools might also provide automatic corrections or transformations to comply with the target standard, but usually they simply flag up detected problems without linking to possible solutions. In any case the user is not included in the loop in the sense that there is no need to prioritize issues, to make any compromises, or to indicate which problems are really critical for the intent of the document.

Print Mediator can not only cover a gap in the workflow application offering but also offer an integration platform for existing colour processing components. Indeed many of them can be seen as problem detector and correctors.

Concerning problem detection, various tools provide complementary functionalities to visually detect or indicate possible printer related problems to the user but without integrating corresponding problem solving capabilities. Examples are *soft proofing* and *gamut alarms*. With respect to a selected printer soft proofing allows users to appreciate how the document print out will look like, while gamut alarms and corresponding views rather indicate those regions within the document where the colors used are outside of the printer gamut. Both, soft proofing and gamut alarms provide functionality of interest to Print Mediator and are already or will soon be integrated into the system respectively. Soft proofing is available in lots of existing document and image editing programs, e.g. Adobe Acrobat©, Photoshop©. As explained previously we have adapted the soft proofing functionality to Print Mediator proposing the *comparative soft proofing* mechanism, showing side-by-side the original and the soft proof view, furthermore highlighting differences between the original version and the soft proof version. In Print Mediator the user can also directly interact with the comparative soft proof view, correcting or annotating problematic regions. Similarly to soft proofing, gamut alarms and corresponding views are available in various document and image editing programs like for instance in Photoshop©. The detection of out-of-gamut regions is a typical problem detector to be integrated in Print Mediator. But with Print Mediator the problematic regions will not only be indicated but automatically annotated and enable the user to act upon in order to solve the detected out-of-gamut problem.

With respect to colour problem correction, there are tools that provide solutions to particular problems, for instance taking into account aesthetic considerations. An example is the *natural language colour editing* tool [10]. This tool allows a user to express in natural language the required colour changes for an image, i.e. which colours should change and in which direction the change should go to make the image more pleasing. This mechanism will be integrated into Print Mediator as a problem corrector.

Conclusion

In this paper we have presented a new concept of application targeting the improvement of colour reproduction in non colour managed print workflows. This application supports both the communication between document designers and printers and the mediation between the workflow participants and the underlying colour processing infrastructure. In both cases the user's role is central: users control what is done to the document. Thus the success of this application depends on its adoption and its efficient use. The proposed concept has been motivated and designed from in-depth observations and studies of existing work practices; still some validation of the underlying hypotheses is required. This can be articulated more precisely through the four following questions:

1. Does the Comparative Soft Proof allow users to visualize and work with colour differences in an un-calibrated and un-controlled environment?
2. Does the review environment provided by Print Mediator motivate designers to annotate or solve apparent or highlighted colour problems?
3. Do the annotations provide useful information to the printer?
4. Do the modifications applied either at submission time through the application or later, on the printer side, and based on the designer annotations increase the perceived colour quality of the document (i.e. fitting better with intent)?

We have conducted a first experiment towards this validation. We asked to people with different profiles (5 graphic designers, 6 printers, and 21 non professionals separated in two groups with different viewing conditions) to review a set of 12 PDF documents corresponding to real print jobs. The users were reviewing these documents using only the Comparative Soft Proof layer with no support for colour problem detection and correction and they were asked to describe the colour differences they could see on screen. We have used a naturalistic approach to conduct this experiment. People were asked to show the areas where there saw some differences and to describe these differences aloud with minimal guidance and intervention from the test organizer. All their interactions with the various documents have been video recorded. From the analysis of the recording we have identified for each individual: (1) which objects or areas were perceived to show a variation of colour, (2) what was their articulation of those differences in ordinary language and (3) what was their visual strategy for identifying these differences? The overall findings are promising: users perceived colour differences in a generally coherent way no matter the viewing environment and the user profile. Thus the answer to the first question is positive. The analysis of the ways in which users described the differences and the strategies they applied to identify differences revealed more variation and complexity but not in a way that counteracts the idea behind print mediator.

The experiment also highlighted critical aspects to consider in the design for a successful user interaction. In the near future, we will therefore refine and continue to develop our prototype in order to organize more realistic tests with a more fully featured system that will allow us to complete the answers to the remaining questions and to fully validate the proposed concept.

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