Interactive Color Palette Tools

Barbara J. Meier Anne Morgan Spalter David B. Karelitz

Department of Computer Science Brown University

ABSTRACT

Color is fundamental in computer graphics imagery. But despite the importance of good color selection and the difficulty most people have making those color selections, current graphics applications provide only minimal tools for mixing and organizing colors, exploring color combinations, and soliciting historical, theoretical, or expert sources.

We developed a new tool set that addresses these needs. The tools are based on artists' methods, perceptual science, and a task analysis survey we conducted. With these tools, users can quickly experiment with color within the context of their compositions to arrive at deliberate, confident selections. We describe the tools' rationale, inner workings, and interfaces, and discuss important implementation issues.

Keywords Color, user interface, human factors, applications, graphic design. Additional keywords: palette, interactive palette tool.

1 INTRODUCTION

Color is one of the basic building blocks of image creation, yet many of the computer-based methods for selecting and working with colors remain unchanged from their invention two decades ago. While some advanced color tools have been created for specific tasks, such as color correction, there are virtually none to help users select a set of colors and work with them effectively.

The barriers to development of useful color tools are significant. Color is subjective—culture, prevailing fashions, and individual preference can all affect the perceived quality of a color decision [7, 17]. Since there is no agreed-upon syntax, as with text, a "color spellchecker" is not possible. In addition, color is an unusually interdisciplinary field and requires a challenging integration of concepts from areas as diverse as art, perceptual science, and psychology [1]. We have integrated core concepts from these fields to develop a new tool set, Interactive Palette Tools (IPTs), that can be used by both casual and expert users to aid the task of color selection. With these tools, users can quickly experiment with color within the context of their compositions to arrive at deliberate, confident selections.

The IPTs help users answer routinely-asked questions when using color, such as:

- What goes with this color?
- What is a good background or text color?
- What are two (or several) colors that look well together?
- How can I get a color that is a blend of this green and blue?
- How would my design look if I added some purple to it?
- How would my composition look if all the colors were more subdued or lighter?
- These colors are close to what I want; how I can I get some palettes similar to this one?
- Can I find a color like *brown* by searching for it by name?
- How can I arrange my swatches so that all the reds are near each other or all the dark colors are together?

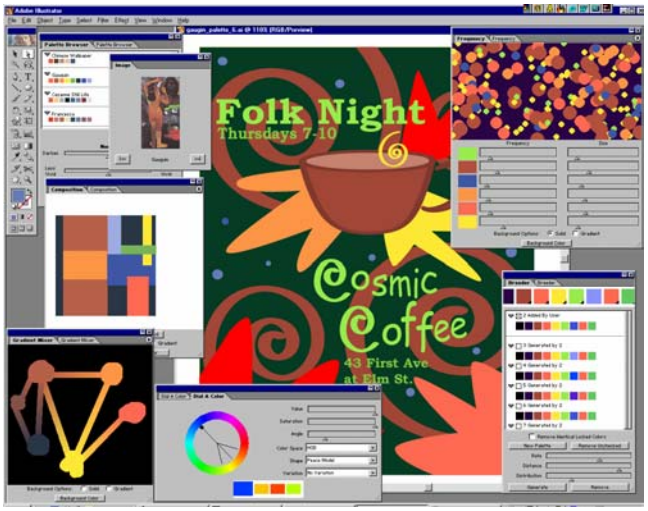

Figure 1: The IPTs in action during creation of an image.

We believe that image-makers, from occasional users to professional designers, can use color more effectively if these kinds of questions can be answered during the creation process. The IPTs are prototype plug-ins to Adobe Illustrator. Here we briefly introduce them and describe their functions; the details are presented in section 3.

The *Palette Browser IPT* provides predefined palettes*;* reference images on which the predefined palettes are based can be viewed with the *Image IPT*. In order to answer the question "what goes with this color?" palettes can be sorted by a theme color.

The *Composition IPT* helps a user decide how to use the colors from a predefined palette in a real composition. It provides a scratch area in which to experiment with color scale, location, and juxtaposition. In addition, users can scroll through examples of posters, web pages, and other targeted designs. The *Dial-a-Color IPT* generates palettes of two to six colors that look well together based on color harmony rules.

With the *Gradient Mixer*, artists mix colors on a virtual palette to create blends. The *Grouper* displays palettes in a user-selectable style such as in a color wheel or by increasing value. The *Palette Breeder* generates variations of existing palettes until the user finds an optimal one. Designers can explore the effect of how many times a color appears in a piece and in what quantity with the *Frequency Visualizer*. Finally, by using the *Name IPT,* users can look up colors by textual names such as "dark green."

While each IPT can work as a stand-alone widget, they are linked through shared color sets and reference imagery. An example of the IPTs in use is shown in Fig. 1.

In the following section, we discuss existing tools for manipulating color. Next we present the broad foundation for our tools, followed by an in-depth description and discussion of each tool. Finally, we show how the tools could be used choose colors for a poster and conclude with suggestions for continued work.

2 PREVIOUS WORK

Most existing computer-based color tools date back to paint programs from the early 1980s. Basic features include methods to select colors from a list of names or swatches, to create new swatches, and to save selections for use later. We expand on current tools using swatches and palettes as the basic building blocks for exploring how color selections behave in relative quantities, locations, juxtapositions, and frequencies.

Initially, colors were described with hardware-related, but unintuitive, RGB coordinates. In 1978, Alvy Ray Smith introduced the HSV color space [15] and more recently has proposed HWB, a Hue-Whiteness-Blackness space [16], both of which offer more intuitive ways of choosing colors. We believe that perceptually based spaces such as Munsell or CIELAB [6] may be easier to work with, and we use such spaces for creating swatch sets with our Dial-a-Color tool.

Some more sophisticated color pickers display choices in the form of a color wheel or slice, which is useful to artists and designers familiar with this presentation. However, almost none allow users to identify commonly used geometries that describe color relationships such as complements or triads. One exception is Hot Door's Harmony Color Picker, a plug-in for Adobe Photoshop. Although a move in the right direction, Harmony is limited in that it confines color selection to a planar slice of HSV space. Our Dial-a-Color IPT allows both non-planar combinations and a selection of color spaces with which to work.

The Gradient Mixer borrows ideas from Electronic Art's Studio 8 (no longer available). Studio 8 provided a mixing area in which colors could be hand-blended in a painterly fashion.

Several applications offer Pantone™-based or other standardized palettes, which are especially useful for translating designs to other media. Some provide palettes linked with designs, such as presentation graphics templates in Microsoft PowerPoint. Our color sets, based on graphic design and fine art, augment those already found in common applications. At the other end of the spectrum are systems that generate functional color sets for specific applications such as map-making [8, 18], or by using algorithmic or expert and intelligent systems such as [2, 11, 13], but these systems give the user little control. Our tools address the middle ground between the automated research systems and predetermined commercial solutions.

3 INTERACTIVE PALETTE TOOLS

3.1 Practical and Theoretical Basis

We based our tools on a task analysis survey, artists' theory and methods, and perceptual science. We describe the tools, our basis for their design, and our experimentation with regard to look and feel. We discuss some of the strengths and weaknesses of each tool.

3.1.1 Task Analysis Survey

During the early implementation phase of the IPTs, we conducted a Web-based survey of individuals who use color in their work or avocations [5]. To date we have over forty responses (many quite detailed) from fine artists, designers, illustrators, animators, computer artists, and color technicians. The respondents had an average of 12.75 years of experience working with color.

We asked respondents to describe how they use currently available tools with details about what is useful and what is not. We asked them to list their gripes about tool performance and missing functionality, and also to create wish lists of desired features. We refer to specific complaints and suggestions in the detailed descriptions of the IPTs in section 3.2.

3.1.2 Artists' Theory and Methods

In addition to the survey, we researched whether artists make color decisions by consulting art theory and instruction books, and if so, what aspects of these are helpful. Again in section 3.2, we discuss how the color wheel, palette organization, predefined palettes, thumbnail color studies, and methods for adjusting colors are used by artists and supported by the IPTs.

3.1.3 Perception

In contrast to the useful but often conditional or conflicting guidelines supplied by artistic theories and survey respondents, the results we used from perceptual sciences are relatively uncontroversial. The most basic result used in our IPTs is that colors are perceived differently depending on the context in which they are viewed. Although this has long been an important tenet of artistic color theory, it is also supported by scientific experimentation. A tool that displays colors in isolation or in groupings unrelated to one's image not only fails to provide all the necessary information but also can be significantly misleading. We addressed this by providing both solid and gradient background options in our IPTs, and by giving users control over swatch shape, position, and scale (the lack of which was a subject of complaint in our survey).

3.2 The Tools

3.2.1 Palette Browser

The IPTs are coordinated through a Palette Browser (Fig. 2) that displays named palettes. In our implementation, a drop-down arrow lets the user hide or show each associated palette. Large swatch sets are displayed on multiple lines.

Respondents to the survey mentioned using palette books such as [17] as a way to find color sets without having to create them from scratch. The Palette Browser is not a new idea, but existing versions are often tied to a particular task such as creating presentation slides. We enhanced our version with the nudger feature, the ability to sort palettes by a theme color, and the corresponding reference imagery available in the Image and Composition tools which are described below.

With the nudger, users can modify all colors in a palette simultaneously, making them lighter or darker, or more or less saturated. These calculations are made in HSB color space.

Swatches within a palette are displayed in the order in which they were defined unless sorted by a user-selected theme color. In this case, the closest match to the theme color is displayed first followed by the other colors in ascending hue order.

Our Browser shares a problem common to many grid-based representations in that swatches are displayed at a constant size, out of context, and against a constant background—all of which can be misleading to users. We envision the Browser to be a way to quickly find an approximate palette that can be manipulated in another IPT that is free of these limitations.

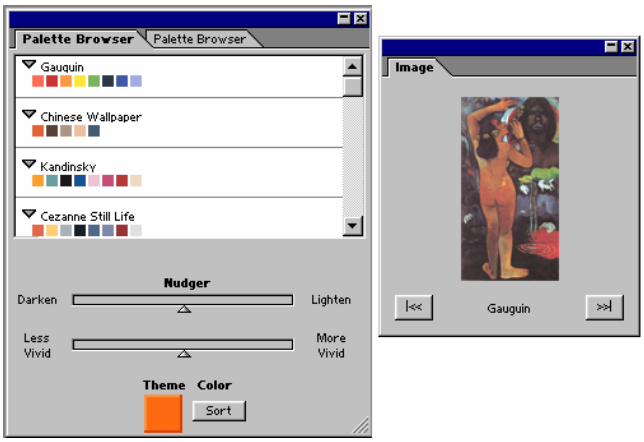

Figure 2: The Palette Browser (left) shows a list of predefined palettes based on art works. Users can browse through reference imagery associated with palettes in the Image IPT (right).

3.2.2 Image and Composition Tools

The Image IPT displays an image that uses a palette in the Palette Browser, such as the Gauguin painting shown in Fig. 2. Images are typically of art works, natural objects, or photographs. Users can search separately in the Image IPT to bring up related browser palettes.

Many survey respondents mentioned using reference imagery as a starting point for choosing colors since a composition provides much more information about color use than a palette displayed as a swatch grid can. In an image, users may view how colors appear in different size areas, quantities, and juxtapositions.

The Composition IPT takes this concept further by providing an editable image, which allows experimentation with relative sizes of color fields and their locations in a scratch area. Many art instruction books suggest that designers create color studies or thumbnails to quickly experiment with color effects [12]. Survey respondents mentioned making studies using both computers and traditional media, but complained about the overhead required to create a new document or the problems associated with translating colors between media. Our tool provides an easy and quick way to experiment without the burden of this overhead.

The tool provides compositions of rectangles abstracted from the reference imagery available in the Image IPT. Fig. 3 (left) shows an abstracted color composition for the Gauguin painting. The shapes can be clicked and dragged for moving. Rolling over a rectangle brings up "handles" at the corners and midpoints for scaling; making the handles invisible otherwise is important so that they do not visually clutter the composition. Selection of an object brings up a color picker for modifying the color. To provide perceptual context, background colors can be changed and displayed as a solid or gradient.

Other designs for specific types of art and graphic work are also presented, such as the poster design shown in Fig. 3 (right). Using arrows below the image, a designer can rapidly scroll through compositions associated with different palettes (with the outer arrows) or through different function-targeted compositions created with one palette (with the inner arrows). Some survey respondents discussed the difficulty of translating a predefined palette to an actual composition. This tool is meant to help bridge that gap, eliminating tedious trial and error.

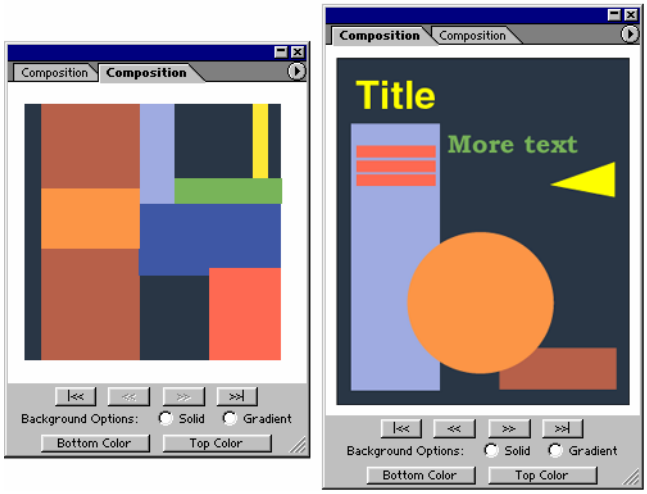

Figure 3: In the Composition IPT, users experiment with scale and relative location of colored fields. At left, the size and location of rectangles are abstracted from the painting in Fig. 2, and are moveable and scalable. Users can also browse targeted design ideas (right).

Choosing a drawing order for the rectangles was an implementation issue with this IPT. We experimented with drawing the selected object on top, but without a method for putting one object under another, which would have complicated the simple interface, the user would not be able to change the color of a background object without obscuring the other rectangles. We settled on a fixed drawing order, which works for most quick experiments.

At this point, the targeted designs are not editable, which might be a future improvement. Also, it could be helpful to assign different colors from the same palette to the various elements of these designs since a particular palette can be used in many ways. We also considered providing a way to assign colors randomly or to rotate through the palette, but we chose to offer only predetermined assignments that use color effectively which may not be the case with random assignments.

3.2.3 Gradient Mixer

Artists can paint swatches onto a work area and create gradients between them with the Gradient Mixer. The swatches are painted any size using a circular brush shape; they are easily relocated by clicking and dragging on a "handle" that appears as a small circle when the mouse is rolled over the swatch (Fig. 4). Clicking on one swatch and dragging to another creates a gradient. The further apart the colors in physical space, the more detail appears in the gradient. Additional gradients can be created by dragging from anywhere on a gradient to anywhere on another gradient or swatch. If the gradient creation line is dragged to an empty area, a new swatch of the initially selected color is created without a gradient attached. This is useful for creating swatches based on blended colors. The color of a painted swatch can be changed by clicking on its handle which brings up a color picker. Attached gradients are then updated automatically.

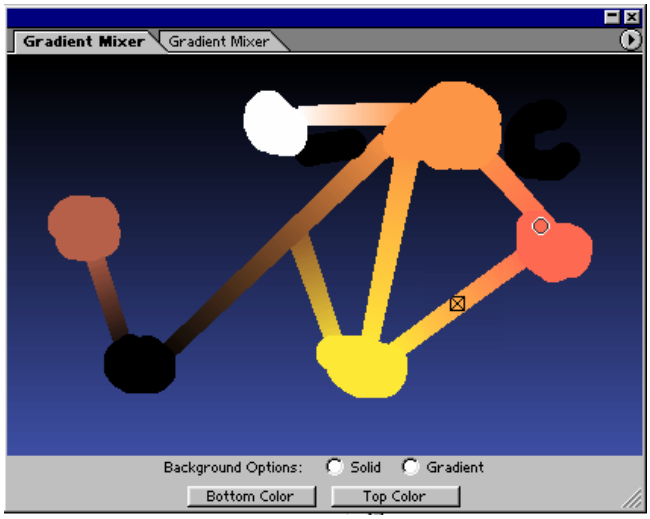

Figure 4: The Gradient Mixer provides functionality similar to that of a traditional painter's palette. The circle and delete box, which appear on rollover, are used to move swatches and delete gradients, respectively.

Unlike traditional artists' palettes, any given swatch and its associated gradients are simple to remove—one simply drags the swatch off the IPT window. Gradients can also be individually deleted, without affecting the swatches, by clicking on a small checkbox that appears when rolling over a given gradient. All gradients are updated to follow any swatch movement. A solid or gradated background is set with buttons at the bottom of the IPT. Colors created in the Gradient Mixer may be added to the Illustrator swatch set or used directly as the foreground color. The gradients made in this IPT can also be transferred to the Illustrator gradient tool. Like the Composition IPT, backgrounds can be changed and displayed as a solid or gradient.

Though simple in design, this tool is a major improvement on existing interfaces for creating palettes and mixing colors. Several survey respondents requested ways to mix colors similar to ways of mixing paint to obtain in-between colors. Others wanted to have more control over the visual representation of their virtual palette. In addition to creating gradients, this tool can be used to simply organize user-sized swatches in desired arrangements and sizes. Art instruction manuals affirm these desires; many even prescribe particular palette layouts in their painting demonstrations.

During implementation, we experimented with several ways of drawing swatches. An early version used circles, but we decided that the organic look of the swatches and the painterly feel of creating them were important to the interface. We finally chose to draw circles at each mouse hit, but also place extra circles in between to fill in gaps (where response to mouse movement lagged) to create solidly-filled blob shapes.

Our first method for creating gradients used modifier keys; however, this impinged on the direct interaction we wanted to achieve. In order to eliminate the modifier keys, we introduced "handles" for moving swatches. These are shown as small circles and are moved dynamically so as to be always onscreen even if part of a swatch is not.

Gradients are calculated by interpolating between colors in CIELAB color space. We also experimented with RGB and a cylindrical representation of CIELAB, interpolating around the hues instead of through them. We based our final on aesthetic appearance of the gradients, which seemed superior in CIELAB space. Gradients can be imported into the Illustrator gradient tool, but do not appear exactly the same because Illustrator uses a different color space. While swatches are being dragged, gradients are drawn with only a few steps; they resolve to more steps on mouse up.

The final interface issues we encountered concerned the drawing order of swatches and gradients. We chose to place the most recently drawn gradients on top, but below the lowermost swatch, so those swatches always appear on top of everything. The beginning and end of a gradient are determined by where the user clicked and dragged on the two swatches. If swatches are moved in particular ways, a portion of the gradients might be obscured when the swatches are drawn on top.

3.2.4 Dial-a-Color Tool

Probably the most fundamental color tool used by artists is the color wheel. Many versions have been proposed such as [9], but all display the spectral hues in a circle and show color relationships such as complements (opposites on the wheel) and analogous colors (adjacent on the wheel). Color theorists and painters both agree that color relationships are more important than the colors themselves and entire instructional books have been devoted to exploring this theory [12]. Our survey revealed that some artists use color relationship rules to the letter, others more intuitively.

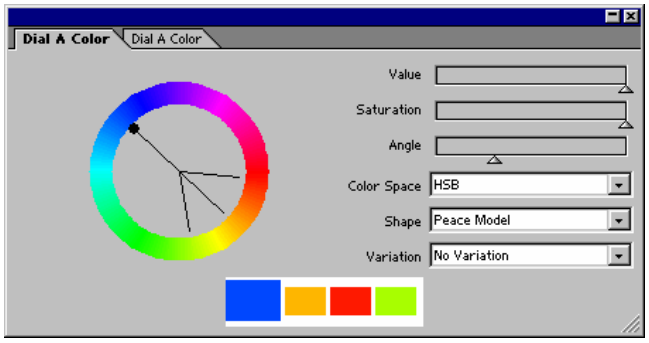

Figure 5: The Dial-a-Color IPT generates palettes based on harmony rules.

The Dial-a-Color IPT provides a method for generating palettes containing two to six colors based on geometric harmony relationships which are shown in Fig. 6. The user spins the pointer around the color wheel (Fig. 5) to select the hue (similar to Hot Door's Harmony). Ours differs from Harmony in that we offer sliders to globally control saturation and value of all the colors simultaneously or locally modify the saturation and value of individual colors. For all rules except complements, the user also controls the angle to choose colors closer together or further apart. The colors generated depend on whether the user has selected the perceptually based CIELAB color space or the HSB color space.

We also extend Harmony by offering color combinations that do not lie in a single plane of color space, perpendicular to the brightness or value axis. For example, one presents the complements at their specified value and saturation, but the

analogous colors at half that value and saturation. We chose this and a few other non-planar relationships by visually evaluating many combinations. Included in this version of the tool are a few that we thought created more consistently aesthetic palettes and were also different enough from palettes that could be generated in other ways. We realize our judgment is subjective, but given our collective artistic experience and the lack of similar or better algorithms for generating palettes, we chose to include this method. We could have allowed full control over the variations and not limited the relationships, but this would have required an interface to the 3D color spaces. In ongoing work, we are exploring ways to offer more options without burdening users with a full 3D interface. We are also trying to find more algorithmic ways for generating aesthetic combinations.

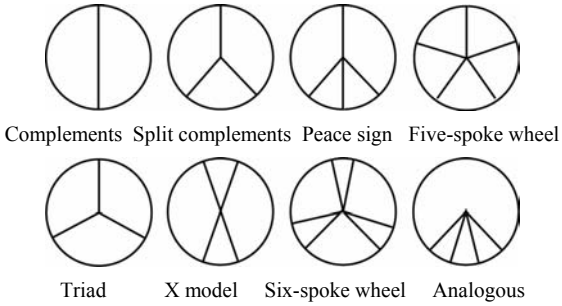

Figure 6: Dial-a-Color offers these color harmony relationships.

We found that non-planar relationships were especially important when using a perceptually based color space. In such a space, a planar slice perpendicular to the brightness axis gives colors of equal brightness so that even "light" colors like yellow are not brighter than "dark" colors like purple within the slice. Thus the harmony relationships appear quite different than those obtained using another color space such as HSB or another medium such as paint. Perception research [18] affirms that brightness contrast is important for distinguishing objects from one another. It can also create a more aesthetic combination of colors. When using the perceptually based spaces, a decision to vary the value or saturation is made deliberately, offering the user control of these parameters. In HSB, brightness contrast is inherent in the color space, which might make it easier for some users to find aesthetic combinations. Neither type of color space is better; we provide both to give users more options.

3.2.5 Frequency Visualizer

The Frequency Visualizer enables users to explore the role of color frequency in their compositions using an interface inspired by a sound mixing board. The Frequency IPT creates a random or orderly composition using up to six user-selected colors (Fig. 7). For each color, one slider specifies how often this color appears in the composition and another slider determines in what size areas. Four patterns are offered: random circles or squares of varying size, and rows of fixed-sized circles or squares. For the rows, the frequency of a color determines how many circles or squares are drawn of that color. Depending on the chosen pattern, the background may or may not be visible and can be set to solid or gradated colors chosen by the user. Colors may be changed individually using a color picker or palettes may be dropped in from the Dial-a-Color IPT.

Research in perception has shown that the size and shape of a color field, the frequency with which a color appears in a composition and the background color all affect our perception of a color. Likewise, artists know that for color, context is everything. Art instruction manuals recommend testing several combinations or using a scratch area to adjust colors before adding them to a work in progress [12]. Our goal for this IPT was to create an environment for quick experiments so users can learn the perceptual effects of color selections before committing them to a potentially complicated composition. Unlike the Composition IPT, this one does not concern itself with placement of color fields. They both create thumbnails or representations of color combinations.

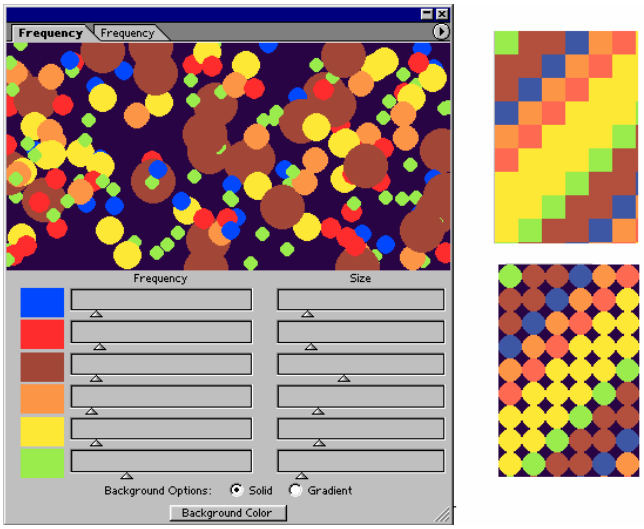

Figure 7: The Frequency Visualizer lets users explore the role of color frequency in their compositions. Users choose among random circles (left), space-filling squares (upper right), or orderly circles (lower right).

The order in which the random shapes are drawn is important since the final appearance of the composition needs to reflect what the user specified. To achieve this, we use an algorithm that ensures colors will be drawn in a random order so that no color completely obscures another.

3.2.6 Palette Breeder

The Palette Breeder helps users who would like to see some variations on existing palettes. One or more input palettes are "bred" together to create ten new palettes that combine the colors and vary them randomly. The user may further select palettes from the new ones (or other sources) to be used as parents for the next round, and continue until satisfied. When a palette is selected in the Breeder, the colors are automatically updated in the actual composition, immediately showing the new decisions in context. We find this tool useful for exploring "what if?" scenarios. The variations are not ones that typical users would have created on their own, but offer fresh color ideas based on existing palettes. This is more useful than completely random palettes, which are usually not aesthetically compelling.

The Breeder, though inspired by genetic algorithms [14], is not a genetic algorithm because it has no formal evaluation function for judging the palettes generated. The artist performs the evaluation by selecting the parents for each generation. In our initial

implementation, "mutation" was replaced by adding a random offset to each of the RGB values. Random offsets were obtained from a normal distribution. Recombination was replaced with linear interpolation between the RGB values of the two colors.

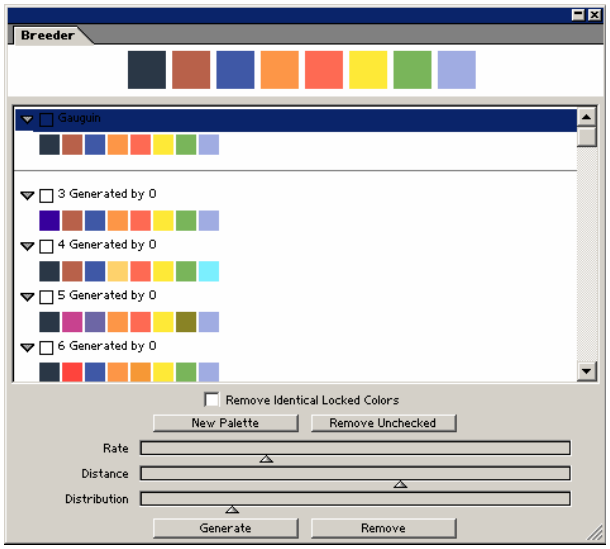

Figure 8: The Palette Breeder is for users who know what they like when they see it.

After the first design iteration of this tool, we found that we would like to "lock" some of the colors so they would not be changed in future generations. When creating new palettes, first we try to keep all locked colors, and then the remaining colors of the two parents are randomly shifted and combined as described above. If the parents have locks on identical colors, only one copy is propagated to the children.

We also discovered that we wanted more control over the random shift process. The "rate" slider sets a threshold for performing random shifts; for each color, if a random value is over the threshold, the color is mutated. The "distance" slider determines the bound of the offset that is added to a color; this can be used to control whether the new colors are very different or only a little different. Finally, the "distribution" slider determines whether the offsets added to colors are random or come from within a normal distribution. A random set will produce colors that shift different amounts while the normal distribution shifts colors closer to the same amount. We like the extra control offered by the sliders, but also realize that their use depends on some understanding of the algorithm. We would like to find a simpler interface without giving up the control. Since the Breeder can be used to create an overwhelming number of new palettes, users may use checkboxes to keep some palettes and delete all others.

3.2.7 Name IPT

Some designers like to use color names to choose colors [3]. The particular colors that match a name are subjective, but quickly finding a color based on a name can be a useful start especially given how cumbersome some color pickers are. The name IPT is particularly appropriate for rapidly calling up colors that are hard to locate in current color pickers, such as brown. Our Name IPT provides an alphabetical list of names with associated swatches. This tool is meant to complement other standardized color sets such as Pantone™. This is not a new innovation but was implemented to complete our suite of tools. A commercial implementation would probably have user-definable names and names obtained from a standard naming convention such as [10].

3.2.8 Grouper

Some respondents to our task analysis survey requested tools for visually organizing palettes on the computer. Traditional media artists often arrange their colors according to how they intend to use them. For example, they might make piles of their pastel sticks: blues and greens in one pile, reds and oranges in another pile. Painters might arrange lighter colors at one end and dark colors at the other end of their palettes. The swatch grid offered by Illustrator and other software simply records colors in the order in which they are created. As the perception research has shown, it would be difficult to decide, for example, which is the darker of two browns in such a grid when one is next to hot pink and the other next to light blue. We are not aware of any commercial software that can automatically arrange palettes in ways helpful to users and find this to be a significant hole in existing functionality.

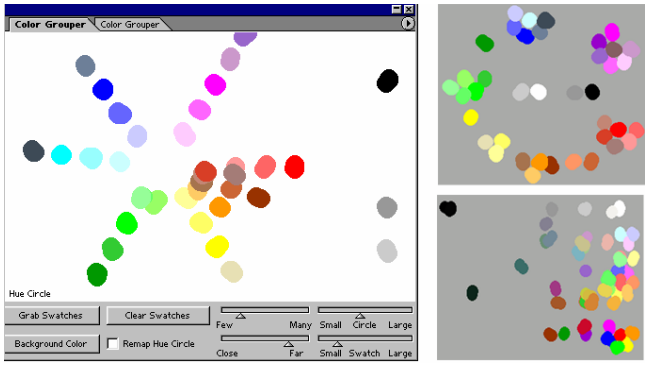

Figure 9: Artists can visually organize palettes with the Grouper. At left, colors are grouped in a color wheel. Along the spokes, higher value colors are closer to the center. At top right, swatches are remapped to be evenly spaced around the color wheel and are organized in clusters. At bottom right, colors are displayed in clusters in a grid with value on the horizontal axis and saturation on the vertical axis. Background colors are user-settable.

The Grouper IPT enables a user to organize a palette in several ways. At the highest level, the user chooses a color wheel or a grid organization. In the color wheel display (Fig. 9, left) swatches are grouped according to their hue (like the piles of pastels). Each of these groups is displayed in color wheel order. Neutral swatches are displayed to the side. The swatches are drawn as blobs; the user controls how closely they will be clustered within each group. The artist may further choose to order each hue grouping by value which is indicated by the distance from the center of the color wheel. Finally, the artist can use a slider to choose whether to create a few groups with more swatches in each or many groups that contain only a few swatches. When displayed in the circle, the swatches can be shown in their "correct" color wheel position or distributed evenly around the circle. The correct color wheel positions can help show color relationships as described in the Dial-a-Color section, but if the palette does not have much hue breadth, then the evenly distributed display will optimize screen space (Fig. 9, upper right). The other main style of grouping is by saturation and value. In this case, swatches are displayed in a grid: the vertical dimension is saturation and the horizontal is value (Fig. 9, lower

right). Again, the artist controls whether a few large groups or many sparse groups are displayed.

4 INTERACTION EXAMPLE

In this section, we present an interaction example to show how the IPTs could be used to choose colors for a graphic design, in this case, a coffee house poster. The IPT figures (Fig. 2-5, 7, 8) show the state of the IPTs while being used in this example. We begin with a grayscale design and think about possible color schemes: coffee suggests rich browns and "cosmic" suggests night sky colors like dark blue and light yellow. The graphic design contains explosive and nebula-like spiral elements. With these considerations, we find several palettes that contain a fiery red color by choosing this as a theme color in the Palette Browser (Fig. 2). We randomly apply these to our design for quick ideas (Fig. 10) and also look at the associated reference paintings in the Image IPT (Fig. 2) to get a sense of how these palettes were used originally. We like the Feininger and Gauguin palettes, but, not surprisingly, the random assignment of colors isn't working. In the Composition IPT (Fig. 3, left) we experiment for a few seconds to see how these colors could be used for the poster. We browse the targeted designs (Fig. 3, right) and decide that the Gauguin palette offers the best combination of colors: night sky colors, fiery explosive colors, and rich coffee colors. Based on our quick thumbnail study in the Composition IPT, we assign colors to the design more deliberately (Fig. 11, far left). This task is tedious and we are glad we were able to quickly get a sense of how it would look before getting to this point.

Figure 10: We try several palettes with random color assignment. Reference paintings from the Image IPT are displayed at lower left corners.

We decide the explosive elements should all be fiery colors, but this palette only contains a couple yellows and oranges. Using the Gradient Mixer, we create new colors (Fig. 4). We need several shades of orange, yellow, and red and some darker coffee ones also. After creating a few gradients, we add a few in-between colors to our palette and assign them to the design elements (Fig. 11, near left).

At this point, we're getting close, but the poster looks flat. We realize that most of our colors are analogous colors, i.e. they lie near each other on the color wheel. We remember that complementary colors can create depth so using the "peace sign" model in the Dial-A-Color IPT, we orient the three close-together spokes to point to the warm analogous colors. The remaining spoke points to their complement, which is blue (Fig. 5). We now realize we already had blue in our Gauguin palette, but we also know that sometimes we have to find the answer through a different route even if it is in plain sight! Just for experimentation's sake, we import our palette into the Palette Breeder and lock all the colors except for blue. We create ten new palettes with different blues and quickly apply these to our composition. We could also have just kept editing the one blue in our palette using sliders, but we have found that the occasional random experiment can really broaden our view and keep us from picking the same colors over and over. We choose one of the blues and experiment with applying it to different elements in the design, but nothing seems to be working. We like the blue outline on the explosions, but imagine the blue would be on the inside at the hottest point as on a lit match. The blue spirals compete too much with other elements (Fig. 11, right). To try out more ideas, we plug our palette into the Frequency Visualizer (Fig. 7). We adjust the sliders to mimic our composition and then start playing with the blue size and frequency. Eureka! We like the look of the small blue dots so much that we choose to add them to our design and we're finished (Fig. 1).

Figure 11: We make more deliberate color assignments (far left). More fiery colors are imported from the Gradient Mixer in (near left) and we further fine-tune the palette. We try two ways of adding blue (right).

5 DISCUSSION AND CONCLUSIONS

We have presented a collection of tools that help designers choose and use colors effectively. They enhance the process of working with color and help users feel more confident that they have explored the possibilities thoughtfully instead of making uninformed guesses. We realize that some of the methods used in our tools could be simulated with existing software. For instance, a user could create a gradient in a document and then choose a color from it. However, we found that tedious setup processes for working with color are in general not undertaken in everyday usage.

In our experience using the tools, we found that most people use a subset of the tools either tailored to their working style or to the needs of the project. We developed many tools, some with overlapping functionality, to accommodate these different styles. Some IPTs solve problems that a good designer would be able to solve just by thinking about them (e.g. from the interaction example, finding the complement to orange or finding the best blue). But for less experienced users and for when expert users are stuck, the IPTs provide a quick visual problem-solving approach. It is nearly always easier to evaluate and modify an existing solution than to create one from scratch.

The prototypical nature of our implementation limits its real-world usefulness at this time. For example, we are not able to drag-and-drop swatches between IPTs due to limitations of the Illustrator plug-in architecture. We hope this limitation will be resolved in updated versions.

In our implementation, we would like to remove the limits on the number of colors or swatch sets on which the IPTs can operate at once. We envision new IPTs, based, for example, on perceptual depth cues or textures. We also believe tools for picking colors from a 3D color space could be improved.

In our IPTs we provide tools based on methods used in traditional media and we have begun to explore the potential for color tools that are only possible on the computer. We believe the type of exploration promoted by our tools will become an integral part of the creative process for all kinds of users.

6 ACKNOWLEDGEMENTS

We thank Adobe Systems Inc. for supporting this work and Maureen Stone for her insightful comments on an early draft.

7 REFERENCES

[1] Werner G. K. Backhaus, Reinhold Kliegl, and John S. Werner, ed. *Color Vision: Perspectives from Different Disciplines*, Walter de Gruyter, 1998.

[2] L. Bergman, B. Rogowitz, and L. Treinish. "A Rule-based Tool for Assisting Colormap Selection," in Proc. of Visualization '95, pp. 118-125, October 1995.

[3] Jean Bourges. *Color Bytes*, Chromatics Press, Inc., 1997.

[4] M. E. Chevreul. *The Principles of Harmony and Contrast of Colors and Their Applications to the Arts*, Schiffer Publishing Co., 1987

[5] Color Task Analysis Survey. http://www.cs.brown.edu/research/graphics/research/color/agreement.html.

[6] Mark D. Fairchild, *Color Appearance Models*, Addison-Wesley, 1998.

[7] John Gage. *Color and Culture: Practice and Meaning from Antiquity to Abstraction*, University of California Press, 1993.

[8] Mark A. Harrower and Cynthia A. Brewer, ColorBrewer: An Online Tool for Selecting Color Schemes for Maps, *The Cartographic Journal,* in press.

[9] Johannes Itten. *The Elements of Color*, Van Nostrand Reinhold Co., 1970.

[10] Kenneth L Kelly and Deanne B. Judd, *Color: Universal Language and Dictionary of Names*. National Bureau of Standards Special Publication 440, December 1976.

[11] L. Lavendel and T. Kohler. "The Story of a Color Advisor," in Proc. of the Sixth IS&T/SID Color Imaging Conference, pp. 228-232, November 1998.

[12] Charles Le Clair. *Color in Contemporary Painting*, Watson-Guptill, 1991.

[13] Jock Mackinlay. "Automating the Design of Graphical Presentations of Relational Information," *ACM Transactions on Graphics* 5:2, p.110, April 1986.

[14] Karl Sims. "Artificial Evolution for Computer Graphics," in Proc. of ACM SIGGRAPH '91, pp. 319-329, July 1991.

[15] Alvy Ray Smith. "Color Gamut Transform Pairs," in Proc. of ACM SIGGRAPH '78, pp. 12-19, August 1978.

[16] Alvy Ray Smith and Eric Ray Lyons. "HWB-A More Intuitive Hue-Based Color Model," *The Journal of Graphics Tools*, 1:1, pp. 3-17, 1996.

[17] Margaret Walch and Augustine Hope. *Living Colors: The Definitive Guide to Color Palettes Through the Ages*, Chronicle Books, 1995.

[18] Colin Ware. *Information Visualization: Perception for Design*, Morgan Kaufmann, 1999.