Interactive Color Palette Tools

Barbara J. Meier, Anne Morgan Spalter, and David B. Karelitz
Brown University

The author's tool set extends graphics applications' ability to mix and organize colors; explore color combinations; and solicit historical, theoretical, or expert sources.

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

The barriers to developing useful color tools are significant. Color is subjective—culture, prevailing fashions, and individual preference can all affect the perceived quality of a color decision.[1,2] Because no agreed-on syntax exists, as with text, a "color spellchecker" isn't possible. In addition, color is an unusually interdisciplinary field and requires a challenging integration of concepts from diverse areas.[3]

When using color in compositions, users routinely ask questions, 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 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?

We believe that image-makers, from occasional users to professional designers, can use color more effectively if they can find the answers to these types of questions during the creation process. We have integrated core concepts from art, perceptual science, and psychology to develop a new toolset, Interactive Palette Tools (IPTs). (See the "Previous Work" sidebar for related work.) The IPTs address each of these questions with a prototype plug-in to Adobe Illustrator. While each IPT can work as a stand-alone widget, they are linked through shared color sets and reference imagery. (Figure 1 shows an example of the IPTs in use.) With these tools, users can quickly experiment with color within the context of their compositions to arrive at deliberate, confident selections.

Practical and theoretical basis

During the early implementation phase of the IPTs, we conducted a Web-based survey of individuals who work with color (see the *Color Task Analysis Survey* at http://www.cs.brown.edu/research/graphics/research/color/agreement.html). We received over 40 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 and is not useful. We asked them to list their complaints about tool performance and missing functionality, and also to create wish lists of desired features. 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 sources they find helpful.

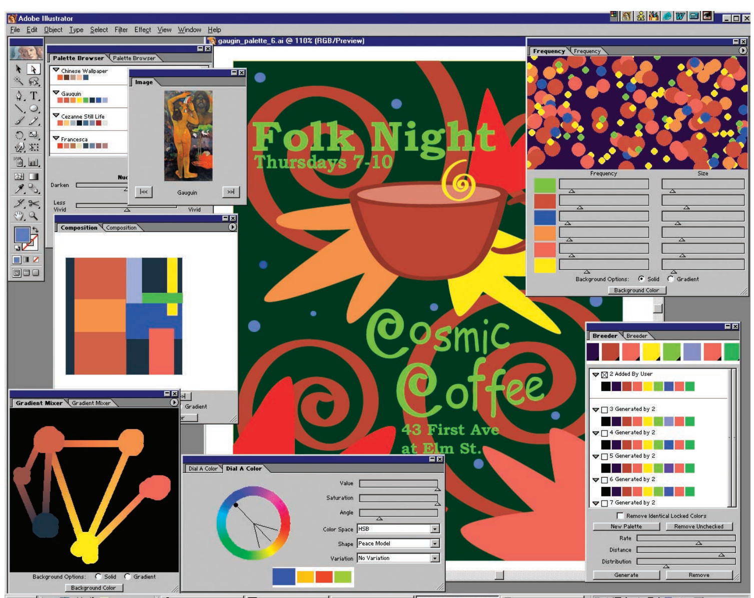
In contrast to the useful, but often conditional or conflicting guidelines supplied by artistic theories and survey respondents, the results we used from perceptual sciences are relatively uncontroversial. The most basic result used in our IPTs is that people perceive colors differently depending on the viewing context. Although

Published by the IEEE Computer Society

this has long been an important tenet of artistic color theory, scientific experimentation also supports this conclusion. A tool that displays colors in isolation or in groupings unrelated to an image will fail to provide all the necessary information to make a color choice, and it can also significantly mislead the user. We addressed this issue 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).

Interactive Palette Tools

We developed the following set of IPTs to address real-world needs.



1 **The IPTs in action during creation of an image.**

Gaugin Digital Image © The Museum of Modern Art/Licensed by SCALA/Art Resource

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, create new swatches, and 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, the industry described colors with hardware-related, but unintuitive, RGB coordinates. In 1978, Alvy Ray Smith introduced the hue-saturation-value (HSV) color space[1] and more recently proposed the hue-whiteness-blackness (HWB) space, which both offer more intuitive ways of choosing colors. We believe that perceptually based spaces such as Munsell or CIELAB[2] might be easier to work with, and we use such spaces for creating swatch sets with our dial-a-color tool.

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 let users identify commonly used geometries that describe color relationships such as complements or triads. One exception is Hot Door's Harmony, 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 nonplanar combinations and a selection of color spaces with which to work.

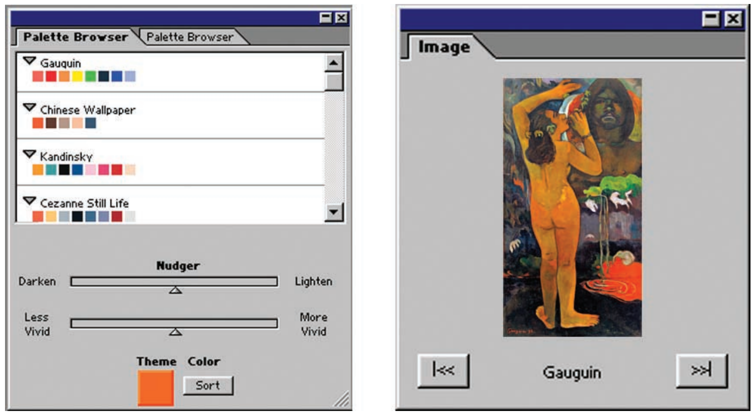
Our gradient mixer borrows ideas from Electronic Art's Studio 8 (which is no longer available). Studio 8 provided a mixing area in which users could hand blend in a painterly fashion.

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 in common applications.

At the other end of the spectrum, some systems generate functional color sets for specific applications such as map making,[3,4] or by using algorithmic or expert and intelligent systems,[5-7] but these systems give the user little control. Our tools address the middle ground between the automated research systems and predetermined commercial solutions.

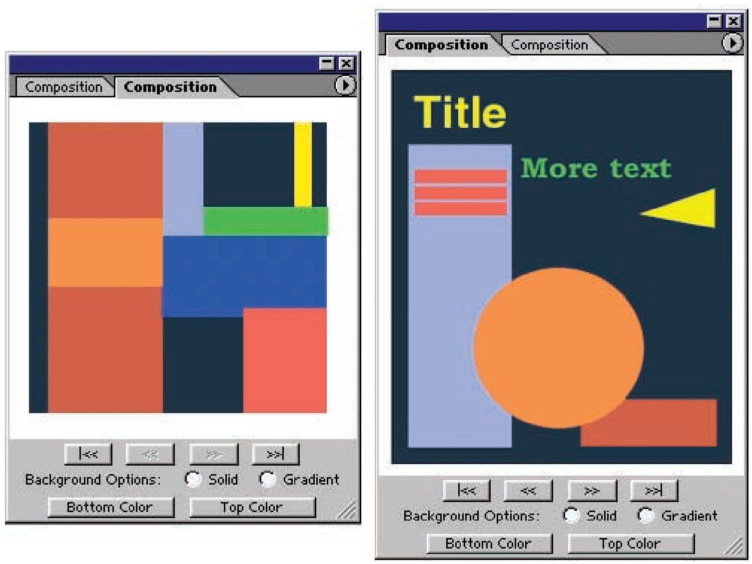
References

1. A.R. Smith, "Color Gamut Transform Pairs," *Proc. ACM Siggraph*, ACM Press, 1978, pp. 12-19.
2. M.D. Fairchild, *Color Appearance Models*, Addison-Wesley, 1998.
3. M.A. Harrower and C.A. Brewer, "ColorBrewer: An Online Tool for Selecting Color Schemes for Maps," *The Cartographic J.*, vol. 40, no. 1, pp. 27-37.
4. C. Ware, *Information Visualization: Perception for Design*, Morgan Kaufmann, 1999.
5. L. Bergman, B. Rogowitz, and L. Treinish, "A Rule-Based Tool for Assisting Colormap Selection," *Proc. Visualization*, IEEE CS Press, 1995, pp. 118-125.
6. L. Lavendel and T. Kohler, "The Story of a Color Advisor," *Proc. 6th Society for Imaging Science and Technology/Society for Information Display (IS&T/SID) Color Imaging Conf.*, *IS&T/SID*, 1998, pp. 228-232.
7. J. Mackinlay, "Automating the Design of Graphical Presentations of Relational Information," *ACM Trans. Graphics*, vol. 5, no. 2, Apr. 1986, p. 110.



(a) (b)

2 **(a) The palette browser shows a list of predefined palettes based on artworks. (b) Users can browse through reference imagery associated with palettes in the image IPT.**



(a) (b)

3 **In the composition IPT, users experiment with scale and relative location of colored fields. (a) We abstracted the size and location of rectangles from a Gauguin painting. These rectangles are movable and scalable. (b) Users can also browse targeted design ideas.**

This collection of tools will 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.

Palette browser

The IPTs are coordinated through a palette browser (see Figure 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.

Survey respondents indicated using palette books (such as Walch and Hope[2]) to find color sets without having to create them from scratch. The palette browser isn't 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, palette sorting by theme color, and corresponding reference imagery available in the image and composition tools.

With the nudger, users can modify all colors in a palette simultaneously, making them lighter or darker, or more or less saturated. We make these calculations in the hue-saturation-brightness (HSB) color space.

A palette displays swatches in the order in which the user defines them, unless the user chooses to sort the swatches by a user-selected theme color. In the latter case, the closest match to the theme color displays first, followed by the other colors in ascending hue order.

Our browser shares a problem common with many grid-based representations in that it displays swatches at a constant size, out of context, and against a constant background—all of which can mislead users. We envision the browser as a way to quickly find an approximate palette that users can manipulate in another IPT that is free of these limitations.

Image and composition tools

The image IPT displays an image that uses a palette in the palette browser. Images are typically of artworks, 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 because a composition provides more information about color use than a palette displayed as a swatch grid. In an image, users can view how colors appear in different size areas, quantities, and juxtapositions.

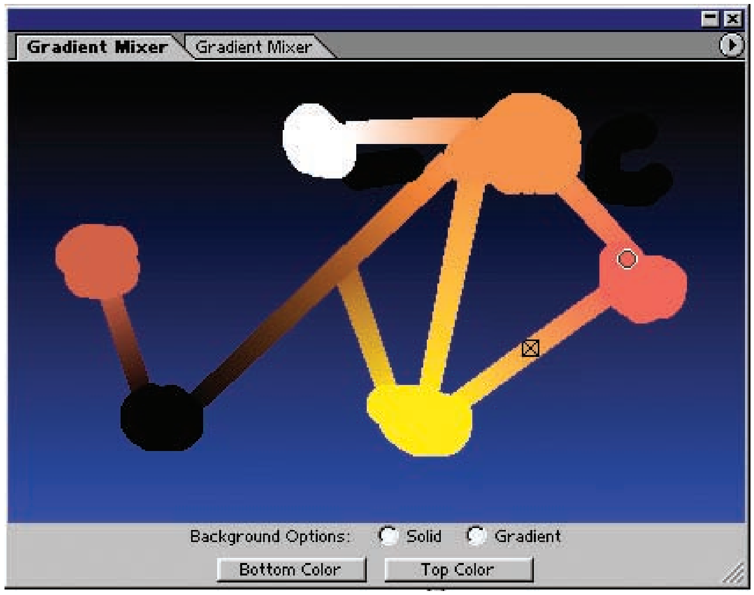
The composition IPT takes this concept further by providing an editable image, which allows experimentation with relative sizes of color fields and their locations in a scratch area. Many art instruction books suggest that designers create color studies or thumbnails to quickly experiment with color effects.[4] Survey respondents mentioned making studies using both computers and traditional media, but they 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. Figure 3a shows an abstracted color composition for a Gauguin painting. Users can move the shapes by clicking and dragging them. Rolling over a rectangle brings up handles at the corners and midpoints for scaling; making the handles otherwise invisible is important so that they don't visually clutter the composition. Selecting an object brings up a color picker for modifying the color. To provide perceptual context, users can change and display background colors as a solid or gradient.

We present designs of specific types of art and graphic work, such as the poster design in Figure 3b. 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 helps bridge that gap, eliminating tedious trial and error.

Choosing a drawing order for the rectangles was an implementation issue with the composition IPT. We experimented with drawing the selected object on top. However, without a method for putting one object under another—which would have complicated the simple interface—the user couldn't change the background object's color without obscuring the other rectangles. We settled on a fixed drawing order, which works for most quick experiments.

At this point, the targeted designs aren't 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 because 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. However, we chose to offer only predetermined assignments that use color effectively, which might not be the case with random assignments.



4 The gradient mixer provides functionality similar to that of a traditional painter's palette. The circle and delete box, which appear on rollover, move swatches and delete gradients, respectively.

Gradient mixer

Artists can paint swatches onto a work area and create gradients between them with the gradient mixer. Users paint swatches of any size using a circular brush shape. Users can easily relocate these swatches by clicking and dragging on a handle that appears as a small circle when the mouse is rolled over the swatch (see Figure 4). Clicking on one swatch and dragging to another creates a gradient. The further apart the colors in physical space, the more detail in the gradient. Users can create additional gradients by dragging from anywhere on a gradient to anywhere on another gradient or swatch. If we drag the gradient creation line to an empty area, the tool creates a new swatch of the initially selected color without a gradient attached. This is useful for creating swatches based on blended colors. We can change a painted swatch's color by clicking on its handle, which brings up a color picker. This automatically updates attached gradients.

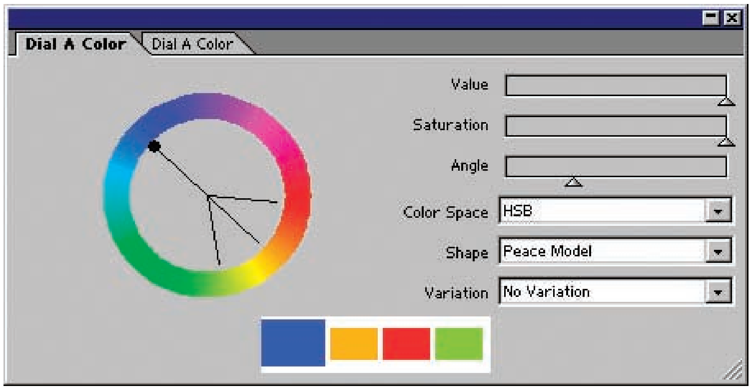
Unlike traditional artists' palettes, any given swatch and its associated gradients are easily removed by dragging the swatch off the IPT window. Users can individually delete gradients without affecting the swatches by clicking on a small checkbox that appears when rolling over a given gradient. All gradients are updated to follow any swatch movement. Users can add colors created in the gradient mixer to the Illustrator swatch set or use them directly as the foreground color. Like the composition IPT, users can choose between a solid or gradient background.

Although simple in design, the gradient mixer improves on existing interfaces for creating palettes and mixing colors. Several survey respondents requested ways to mix colors similar to ways we mix 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 help 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.

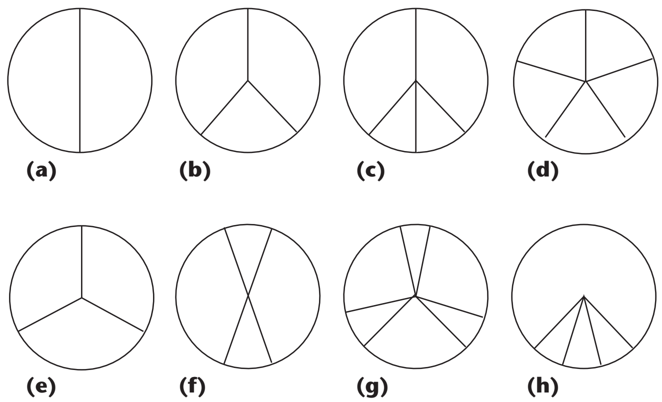
During implementation, we experimented with several ways of drawing swatches. An early version used circles, but we decided that the organic look of the swatches and the painterly feel of creating them were important to the interface. We finally chose to draw circles at each mouse hit and place extra circles in the gaps caused by lags in mouse response 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. To eliminate the modifier keys, we introduced handles for moving swatches. These appear as small circles and move dynamically so as to be always onscreen even if part of a swatch isn't.

The tool calculates gradients 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 method on the aesthetic appearance of the gradients, which seemed superior in CIELAB space. Gradients can be imported into the Illustrator gradient tool but don't 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.



5 **Dial-a-color offers palettes based on color harmony relationships.**



6 **The dial-a-color IPT generates palettes based on harmony rules: (a) Complements, (b) split complements, (c) peace sign, (d) five-spoke wheel, (e) triad, (f) X model, (g) six-spoke wheel, and (h) analogous.**

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. Where the user clicked and dragged on the two swatches determines the beginning and end of a gradient. If users move swatches in particular ways, a portion of the gradients might be obscured when the swatches are drawn on top.

Dial-a-color

Probably the most fundamental color tool used by artists is the color wheel. Researchers and artists have proposed many versions,[5] 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 agree that color relationships are more important than the colors themselves, and entire instructional books have been devoted to exploring this theory.[4] Our survey revealed that some artists use color relationship rules to the letter; others, more intuitively.

The dial-a-color IPT provides a method for generating palettes containing two to six colors based on geometric harmony relationships, which Figure 5 shows. The user spins the pointer around the color wheel (see Figure 6) to select the hue (similar to Hot Door's Harmony, an Adobe Photoshop plug-in). 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 controls the angle to choose colors closer together or farther 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 don't lie in a single plane of color space, perpendicular to the brightness or value axis. For example, one combination 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 nonplanar relationships by visually evaluating many combinations. In the current version of the tool, we included a few combinations that we thought created more consistently aesthetic palettes and that were 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're exploring ways to offer more options without burdening users with a full 3D interface. We're also trying to find more algorithmic ways for generating aesthetic combinations.

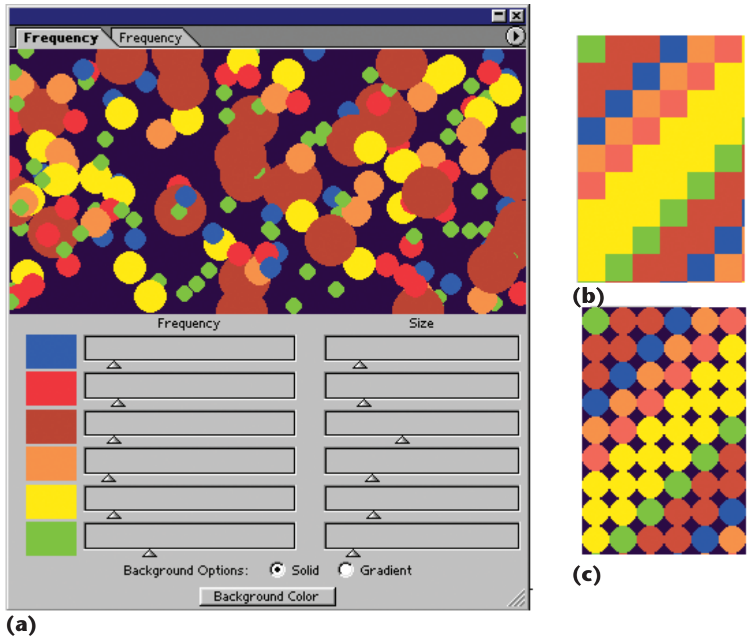
We found that nonplanar relationships were especially important when using a perceptually based color space. In such a space, a planar slice perpendicular to the brightness axis gives colors of equal brightness so that even light colors like yellow aren't brighter than dark colors like purple within the slice. Thus, the harmony relationships appear different than those obtained using another color space such as HSB or another medium such as paint. Perception research[6] affirms that brightness contrast is important for distinguishing objects from one another. It can also create a more aesthetic combination of colors. For the perceptually based spaces, the user controls the value or saturation deliberately. 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.

Frequency visualizer

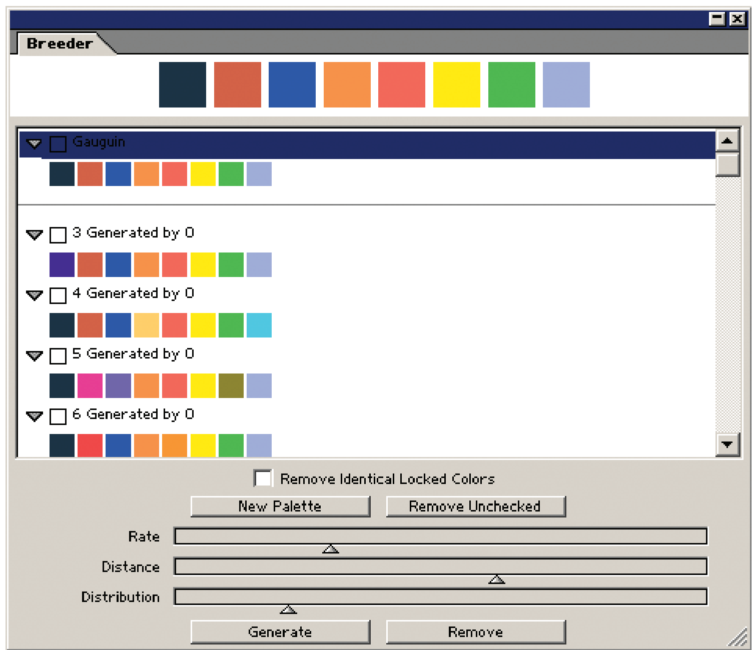
The frequency visualizer lets users explore the role of color frequency in their compositions, using an interface inspired by a sound mixing board. The frequency IPT creates a random or orderly composition using up to six user-selected colors (see Figure 7). For each color, one slider specifies how often this color appears in the composition, and another slider determines in what size areas. We offer four patterns: random circles or squares of varying size, and rows of fixed-sized circles or squares. For the rows, a color's frequency determines how many circles or squares are drawn of that color. Depending on the chosen pattern, the background might not be visible and can be set to solid or graduated colors the user chooses. Users can change colors individually using a color picker or drop in palettes from the dial-a-color IPT.

Research in perception has shown that a color field's size and shape, 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.[4] Our goal for the dial-a-color 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 tool doesn't concern itself with color field placement. Both tools create thumbnails or representations of color combinations.

The order in which the tool renders the random shapes is important because the final appearance of the composition must reflect what the user specified. To achieve this, we use an algorithm that ensures shapes will be rendered in a random order so that no color completely obscures another.



7 The frequency visualizer lets users explore the role of color frequency in their compositions. Users choose among (a) random circles, (b) space-filling squares, or (c) orderly circles.



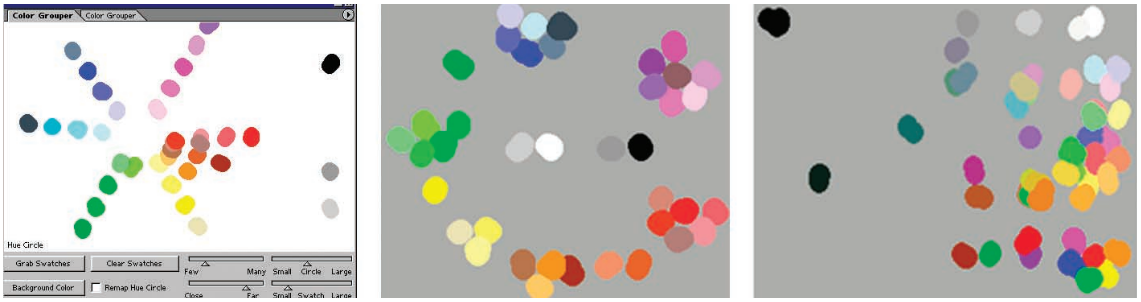
8 The palette breeder is for users who know what they like when they see it.

Palette breeder

The palette breeder lets users see some variations on existing palettes (see Figure 8). One or more input palettes are bred together to create 10 new palettes that combine the colors and vary them randomly. The user can further select palettes from the new ones (or other sources) to use as parents for the next round and continue until satisfied. When users select a palette 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 aren't ones that typical users would have created on their own, but they offer fresh color ideas based on existing palettes. This is more useful than completely random palettes, which usually aren't aesthetically compelling.

The breeder, although inspired by genetic algorithms,[7] isn't 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, we replaced mutation by adding a random offset (obtained from a normal distribution) to each of the RGB values. We replaced recombination with linear interpolation between the RGB values of the two colors.

After the first design iteration of this tool, we found that we wanted to lock some of the colors so that they



(a) (b) (c)

9 Artists can visually organize palettes with the grouper. (a) Colors are grouped in a color wheel. Along the spokes, higher value colors are closer to the center. (b) Swatches are remapped to be evenly spaced around the color wheel and are organized in clusters. (c) Colors are displayed in clusters in a grid with value on the horizontal axis and saturation on the vertical axis. Users can set the background colors.

couldn't be changed in future generations. When creating new palettes, first we try to keep all locked colors, and then the tool randomly shifts and combines the remaining colors of the two parents, as we described earlier. If the parents have locks on identical colors, only one copy is propagated to the children.

We also 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 tool mutates the color. The *distance slider* determines the bound of the offset that is added to a color; the offset controls whether the new colors are very different or only slightly 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 want to find a simpler interface without giving up the control. Because we can use the breeder to create an overwhelming number of new palettes, users can use check boxes to keep some palettes and delete all others.

Name

Some designers like to use color names to choose colors.[8] 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 difficult-to-locate colors in current color pickers, such as brown.

Our name IPT provides an alphabetical list of names with associated swatches. This tool complements other standardized color sets such as Pantone. This isn't a new innovation, but we implemented it to complete our suite of tools. A commercial implementation would probably have user-definable names and names obtained from a standard naming convention.[9]

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 records colors in the order in which users create them. As perception research shows, 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 aren't 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.

The grouper IPT lets a user 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 (see Figure 9a), we grouped swatches according to their hue (like the piles of pastels). Each group is displayed in color wheel order. Neutral swatches are displayed to the side. The tool draws the swatches as blobs; the user controls how closely they will be clustered within each group. The artist might 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 appear in their correct color wheel position or distributed evenly around the circle. The correct color wheel positions help show color relationships—as we described in the dial-a-color section—but if the palette doesn't have much hue breadth, then the evenly distributed display will optimize screen space (see Figure 9b).

The other main style of grouping is by saturation and value. In this case, swatches are displayed in a grid (see Figure 9c). Again, the artist controls whether to display a few large groups or many sparse groups.

Interaction example

With an interaction example, we can show how to use the IPTs to choose colors for a graphic design, in this case, a coffeehouse poster. Figures 2 through 4 and

Gaugin Digital Image © The Museum of Modern Art/Licensed by SCALA/Art Resource

10 **We try several palettes with random color assignment. The lower left corners show reference paintings from the image IPT.**

(a) **(b)** **(c)** **(d)**

11 **(a) We make more deliberate color assignments. (b) We import more fiery colors from the gradient mixer, and we further fine-tune the palette. (c-d) We try two ways of adding blue.**

6 through 8 show the state of the IPTs as we used them in this example.

We begin with a gray-scale design and then explore possible color schemes—coffee suggests rich browns, and the cosmic theme suggests night sky colors such as 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 (see Figure 2). We randomly apply these to our design for quick ideas (see Figure 10) and also look at the associated reference paintings in the image IPT (see Figure 2) to get a sense of how artists used these palettes originally.

We like the Feininger and Gauguin palettes, but not surprisingly, the random assignment of colors doesn't work. In the composition IPT (see Figure 3a), we experiment to see how we can use these colors for the poster. We browse the targeted designs (see Figure 3b) 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 (see Figure 11a). Because this task is tedious, it's convenient to quickly get a sense of how the final poster would look before getting to this point.

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 (see Figure 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 (see Figure 11b).

At this point, we're getting close, but the poster looks flat. We realize that most of our colors are analogous colors—that is, they lie near each other on the color wheel. We remember that complementary colors can create depth, so by 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 (see Figure 6).

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 the sake of experimentation, we import our palette into the palette breeder and lock all the colors except for blue. We create 10 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 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 work. We like the blue outline on the explosions (see Figure 11c), but imagine the blue would be on the inside at the hottest point, such as on a lit match. The blue spirals compete too much with other elements (see Figure 11d). To try out more ideas, we plug our palette into the frequency visualizer (see Figure 7). We adjust the sliders to mimic our composition and then start playing with the blue size and frequency.

Finally, we like the look of the small blue dots so much that we choose to add them to our design, and we're finished (see Figure 1).

Discussion and conclusions

We realize that some 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 aren't generally undertaken in everyday usage.

In our experience with using the tools, we found that most people use a subset of the tools tailored to their work style or project needs. We developed many tools, some with overlapping functionality, to accommodate these different styles. Some IPTs solve problems that a good designer could solve—for example, finding the complement to orange or finding the best blue. But for less experienced users or when expert users are stuck, the IPTs provide a quick visual problem-solving approach. It's nearly always easier to evaluate and modify an existing solution than create one from scratch.

Our prototype implementation has limited real-world usefulness at this time. For example, we can't drag-and-drop swatches between IPTs due to limitations of the Illustrator plug-in architecture. We hope to resolve this limitation in updated versions.

In our implementation, we want 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've 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 types of users. ■

Acknowledgments

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

References

1. J. Gage, *Color and Culture: Practice and Meaning from Antiquity to Abstraction*, Univ. of Calif. Press, 1993.
2. M. Walch and A. Hope, *Living Colors: The Definitive Guide to Color Palettes Through the Ages*, Chronicle Books, 1995.
3. G.K. Werner et al., eds., *Color Vision: Perspectives from Different Disciplines*, Walter de Gruyter, 1998.
4. C. Le Clair, *Color in Contemporary Painting*, Watson-Guptill, 1991.
5. J. Itten, *The Elements of Color*, Van Nostrand Reinhold, 1970.
6. C. Ware, *Information Visualization: Perception for Design*, Morgan Kaufmann, 1999.
7. K. Sims, "Artificial Evolution for Computer Graphics," *Proc. ACM Siggraph*, ACM Press, 1991, pp. 319-329.
8. J. Bourges, *Color Bytes*, Chromatics Press, 1997.
9. K.L. Kelly and D.B. Judd, *Color: Universal Language and Dictionary of Names*, Nat'l Bureau of Standards Special Publication 440, Dec. 1976.

Barbara J. Meier *teaches computer animation at Brown University. Her research interests include nonphotorealistic rendering and creating tools for artists that build on artists' preferred working methods. Meier has a BA and MS in computer science from Brown University, and she studied animation and illustration at the Rhode Island School of Design, Art Center College of Design in Pasadena, and the Museum School in Boston.*

Anne Morgan Spalter *is a researcher and artist in residence in the Brown University Computer Graphics Group. Her research interests include the use of computers in the visual arts and the design of educational software. Spalter has a BA in mathematics and visual art from Brown University and an MFA in painting from the Rhode Island School of Design.*

David B. Karelitz *is a member of the technical staff at Sandia National Laboratories. His research interests include combining scientific visualization and artistic tools in immersive and desktop environments. Karelitz has a BA and an MS in computer science from Brown University.*

Readers may contact Meier and Spalter at the Dept. of Computer Science, Box 1910, Brown Univ., Providence, RI 02912; {bjm, ams}@cs.brown.edu. Karelitz can be reached at Sandia Nat'l Laboratories, PO Box 5800-1360, Albuquerque, NM 87185; DBKAREL@sandia.gov.