Hardcopy

Prerequisites

An understanding of the nature of color and visual communication, and an appreciation of what makes an effective image.

Introduction

You have worked hard to analyze a problem and have developed really good models and great images or animations that communicate your solution to that problem, but those images and animations only run on your computer and are presented on your screen. Now you need to take that work and present it to a larger audience, and you don’t want to lose the control over the quality of your work when you take it to a medium beyond the screen. In this chapter we talk about the issues you will face when you do this.

Definitions

Hardcopy images are images that can be taken away from the computer and communicated to your audience without any computer mediation. There are several ways this can be done, but the basic idea is that any kind of medium that can carry an image is a candidate for hardcopy. Each of these media has its own issues in terms of its capability and how you must prepare your images for the medium. In this chapter we will discuss some of the more common hardcopy media and give you an idea of what you must do to use each effectively.

In general, we think of hardcopy as something we output from the computer to some sort of output device. That device may be actually attached to the computer, such as a printer or a film recorder, or it may be a devise to which we communicate data by network, disk, or CD-ROM. So part of the discussion of graphics hardcopy will include a description of the way data must be organized in order to communicate with external production processes.

Print: One version of printed hardcopy is created by a standard color printer that you can use with your computer system. Because these printers put color on paper, they are usually CMYK devices, as we talked about in the color chapter, but the printer driver will usually handle the conversion from RGB to CMYK for you. In order of increasing print quality, the technologies for color output are:

- inkjet, where small dots of colored ink are shot onto paper and you have to deal with dot spread and over-wetting paper as the ink is absorbed into the paper,
- wax transfer, where wax sticks of the appropriate colors are melted and a thin film of wax is put onto the paper, and
- dye sublimation, where sheets of dye-saturated material are used to transfer dyes to the paper.

These devices have various levels of resolution, but in general each has resolution somewhat less than a computer screen. All these technologies can also be used to produce overhead foils for those times when you have only an overhead projector to present your work to your audience.

Print can also mean producing documents by standard printing presses. This kind of print has some remarkably complex issues in reproducing color images. Because print is a transmissive or subtractive medium, you must convert your original RGB work to CMYK color before beginning to develop printed materials. You will also need to work with printing processes, so someone must make plates of your work for the press, and this involves creating separations as shown in Figure 16.1 (which was also shown in the chapter on color). Plate separations are created by masking the individual C, M, Y, and K color rasters with a screen that is laid across the image at a different angle for each color; the resulting print allows each of the color inks to lay on the paper.
with minimal interference with the other colors. A screen is shown in Figure 16.2, which is enlarged so much that you can see the angles of the screens for the C, M, Y, and K components. (You should look at a color image in print to see the tell-tale rosettes of standard separations.) There are other separation technologies, called stochastic separations, that dither individual dots of ink to provide more colored ink on the page and sharper images without interference, but these have not caught on with much of the printing world. Creating separations for color-critical images is something of an art form, and it is strongly suggested that you insist on high-quality color proofs of your work. You must also plan for a lower resolution in print than in your original image because the technologies of platemaking and presses do not allow presses to provide a very high resolution on paper.

Figure 16.1: separations for color printing

Figure 16.2: C, M, Y, and K screens in a color image, greatly enlarged
Film: sometimes you want to present the highest-quality images you can to an audience: the most saturated colors and the highest resolution. Sometimes you want to be sure you can present your work without relying on computer projection technology. In both cases, you want to consider standard photographic images from digital film recorders. These are devices that generate images using a very high-quality grayscale monitor, a color wheel, and a camera body and that work with whatever kind of film you want (usually slide film: Kodachrome, Ektachrome, or the like).

A film recorder is organized as shown in Figure 16.3. The grayscale monitor generates the images for each color separately, and that image is photographed through a color wheel that provides the color for the image. Because a grayscale monitor does not need to have a shadow mask to separate the phosphors for different colors, and because the monitor can be designed to have a long neck and small screen to allow for extremely tight control of the electron beam, it can have extraordinary resolution; 8K line resolution is pretty standard and you can get film recorders with up to 32K lines. This allows you to generate your image at resolutions that would be impossible on the screen.

Film is much less of a problem than print, because you can work directly with the image and do not need to deal with separations, and you work with the usual RGB color model. Recall that slides produce their image by having light projected through them, so they behave as if they were an emissive medium like the screen. Your only issue is to deal with the resolution of the camera or to accept the interpolations the film recorder will use if you don’t provide enough resolution.

Video: video is a very important medium for your work, because it is the only medium available to show the motion that is so important to communicate many of your ideas. At the same time, it can be one of the most limited media available to you — at least until video leaves the first half of the 20th century and really comes into the 21st century. We will focus on NTSC video here, but there are similar issues for PAL or SECAM video, and if you are reading this in one of the areas where PAL or SECAM are the standards, you should check to see how much the comments here apply to you.

There are some important issues in dealing with video. The first is resolution: the resolution of NTSC video is much lower than even a minimal computer resolution. NTSC standards call for 525 interlaced horizontal scan lines, of which 480 are visible, so your planned resolution should be about 640 by 480. However, many television sets have adjustment issues so you should not ever work right against the edge of this space. The interlaced scan means that only half of the horizontal lines will be displayed every 1/30 second, so you should avoid using single-pixel horizontal...
elements to avoid flicker; many television sets have poorly-converged color, so you should also avoid using single-pixel vertical elements to they will not bleed into each other. In fact, you will have the best results for video if you design your work assuming that you have only half the resolution noted above.

A second issue in video is the color gamut. Instead of being composed of RGB components, the NTSC television standard is made up of significant compromises to account for limited broadcasting bandwidth and the need to be compatible with black-and-white television (the NTSC standard dates from the late 1930s, before the wide-spread advent of color television or the advent of modern electronics and other technology). The NTSC color standard is a three-component model called the YIQ standard, but the three components are entirely focused on video issues. The Y component is the luminance (or brightness), and it gets most of the bandwidth of the signal. The I component is an orange-to-blue component, and it gets a little more than 1/3 of bandwidth of the Y component. The Q component is a purple-to-green component, and it gets a little more than 1/3 of the I component. The best color you can get in video always seems to be under-saturated, because that is part of the compromise of dealing with the technology available. To be more precise, the following table shows the bandwidth and the horizontal resolution for each of the components of the video image:

<table>
<thead>
<tr>
<th>Component</th>
<th>Bandwidth</th>
<th>Resolution/scanline</th>
</tr>
</thead>
<tbody>
<tr>
<td>Y</td>
<td>4.0 Mhz</td>
<td>267</td>
</tr>
<tr>
<td>I</td>
<td>1.5 Mhz</td>
<td>96</td>
</tr>
<tr>
<td>Q</td>
<td>0.6 Mhz</td>
<td>35</td>
</tr>
</tbody>
</table>

In order to get the best possible horizontal resolution from your image, then, you need to be sure that the elements that vary across the line have differing luminance, and you should focus more on the orange-to-blue component than on the purple-to-green component. If you want to understand how your colors vary in YIQ, the following conversion matrix should help you evaluate your image for video:

\[
\begin{bmatrix}
Y \\ I \\ Q
\end{bmatrix} = \begin{bmatrix}
0.299 & 0.587 & 0.114 \\
0.596 & -0.275 & -0.321 \\
0.212 & -0.528 & 0.311
\end{bmatrix}\begin{bmatrix}
R \\ G \\ B
\end{bmatrix}
\]

The question of video is complicated by the various digital video formats, such as QuickTime and MPEG, that require computer mediation to be played back. Digital video is RGB, so it does not have many of the problems of NTSC until it is actually played on a television screen, and there are television sets that will handle increasingly-high quality video. In fact, MPEG II is the video standard for DVD, and there are self-contained DVD players, so this provides one alternative to doing your own conversion to NTSC.

In the longer term, television will be moving to native digital formats and the HDTV standards will support direct RGB color and higher-resolution, non-interlaced images, so we look forward to this discussion becoming antiquated. For the time being, however, you may need to put up with creating images that will make your colleagues ask, “That looks terrible! Why are you doing that?” Figure 16.4 is a photograph of a video image that shows the problems with color and resolution. If they understand that you’re going to video, however, they’ll understand.
Creating a digital video from an animation is straightforward with the right tools. If you are creating an animation, for example, you may generate a single frame of the animation in a window on the screen and then use a function such as the OpenGL `glReadPixels` function to save the contents of the window to an array, which can then be written to an image file, possibly with a name that represents the frame number of that image in the overall animation. After you have completed running your set of animation segments, and have created the set of individual frames, you may import them into any of a number of tools that will allow you to save them as a digital movie in QuickTime or MPEG format. Many of these tools will also allow you to add a sound track, do transitions from one animation sequence to another, or add subtitles or other text information to the movie.

**3D object prototyping:** there are times when having an image of an object simply isn’t enough, when you need to be able to run your fingers over the object to understand its shape, when you need to hold two objects together to see how they fit, or when you need to see how something is shaped so you can see how it could be manufactured. This kind of 3D object prototyping is sometimes called “3D printing” and is done by special tools. You can view the resulting object as a prototype of a later manufactured object, or you can view it as a solid representation of your graphic image. Figure 16.5 shows photographs of the (3,4)-torus as created by several of these 3D printing techniques, as noted in the figure caption. The contact information for each of the companies whose products were used for these hardcopies is given at the end of the chapter. There are, of course, other older technologies for 3D hardcopy that involve creating a tool path for a cutting tool in a numerical milling machine and similar techniques, but these go beyond the prototyping level.

There are several kinds of technologies for creating these prototype objects, but most work by building up a solid model in layers, with each layer controlled by a computation of the boundary of the solid at each horizontal cutting plane. These boundaries are computed from information on the faces that bound the object as represented in information presented to the production device. The current technologies for doing such production include the following:

- The Helisys LOM (Laminated Object Manufacturing) system lays down single sheets of adhesive-backed paper and cuts the outline of each layer with a laser. The portion of the sheets that is outside the object is scored so that the scrap to be removed (carefully!) with simple tools, and the final object is lacquered to make it stronger. It is not possible to build objects that have thin openings to the outside because the scrap cannot be removed from the internal volumes. LOM objects are vulnerable to damage on edges that are at the very top or bottom of the layers, but in general they are quite sturdy. Figure 16.5a shows the torus
created with the LOM system; note the rectangular grid on the surface made by the edges of the scrap scoring, the moiré pattern formed by the burned edges of the individual layers of paper in the object, and the shiny surface made when the object is lacquered.

![Figure 16.5a: the torus created by the LOM system](image)

- The Z-Corp Z-402 system lays down a thin layer of starch powder and puts a liquid binder (in the most recent release, the binder can have several different colors) on the part of the powder that is to be retained by the layer. The resulting object is quite fragile but is treated with a penetrating liquid such as liquid wax or a SuperGlue to stabilize it. Objects built with a wax treatment are somewhat fragile, but objects built with SuperGlue are very strong. Because the parts of the original object that are not treated with binder are a simple powder, it is possible to create objects with small openings and internal voids with this technology. Figure 16.5b shows the torus created with the LOM system; note the very matte surface that is created by the basic powder composition of the object.

![Figure 16.5b: the torus created with the LOM system](image)
• The 3D Systems ThermaJet system builds a part by injecting a layer of liquid wax for each layer of the object. Such parts must include a support structure for any regions that overhang the object’s base or another part of the object, and this support can either be designed when the object is designed or provided automatically by the ThermaJet. Because the object is made of wax it is not stable in heat and is not very strong. The need for a support structure makes it difficult to include voids with small openings to the outside. Also because of the support structure, the bottom part of an object needs to be finished by removing the structure and smoothing the surface from which this was removed. Figure 16.5c shows the torus as created by the ThermaJet system; note the slightly shiny surface of the wax in the object.

Figure 16.5c: the torus created by the 3D Systems ThermaJet system

• The 3D Systems stereolithography system creates an object by building up thin layers of a polymer liquid and hardening the part of that layer that is to be retained by scanning it with a laser beam. As was the case with the ThermaJet system, this requires a very solid support structure for parts of the object, particularly because there is a small contraction of the polymer material when it is treated with the laser. The support structure must be removed from the object after it is completed, so there is some finishing work needed to get fully-developed surfaces. The polymer liquid can readily be drained from any interior spaces if there is an opening to the outside, so this technology handles this kind of object quite well. The polymer is very strong after it is hardened in a treatment after the shaping is complete, so objects created with this technology are very sturdy. Figure 16.5d shows the torus as created by the stereolithography system.
One thing all these 3d prototyping technologies have in common is that they all take data files in the
STL file format in order to control their operations. This is a very simple file format that is easy to
generate from your graphics program. The STL file for the (3.4)-torus is 2,459,957 bytes long
and the first and last portions of the file are shown below. The file is organized by facets, and with
each facet you have an optional normal and a list of the vertices of the facet; if you create your
model in a way that will let you generate the explicit coordinates of your vertices, you can simply
write the contents of the STL file instead of calling the graphics output functions.

```
solid
  facet normal -0.055466 0.024069 0.000000
  outer loop
    vertex -5.000010 -0.000013 -1.732045
    vertex -5.069491 -0.160129 -1.688424
    vertex -5.000009 -0.000013 -1.385635
  endloop
  endfacet
  facet normal -0.055277 0.019635 0.002301
  outer loop
    vertex -5.069491 -0.160129 -1.688424
    vertex -5.000009 -0.000013 -1.385635
    vertex -5.054917 -0.159669 -1.342321
  endloop
endfacet
...
  facet normal -0.055466 -0.024069 0.000000
  outer loop
    vertex -5.000009 0.000014 1.385635
    vertex -5.069491 0.160130 1.688424
    vertex -5.000010 0.000014 1.732045
  endloop
endfacet
endsolid
```
A word to the wise...

The quick summary of this chapter is to know what your eventual medium will be, and to design for that medium when you plan your image or visualization. And be prepared to experiment as you work on your design, because some of these hardcopy media simply take experience that no notes or text can ever give you.

Contacts:

Below are contacts for the three 3D hardcopy sources shown above:

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