Mobile Displays

Technology and Applications

Edited by

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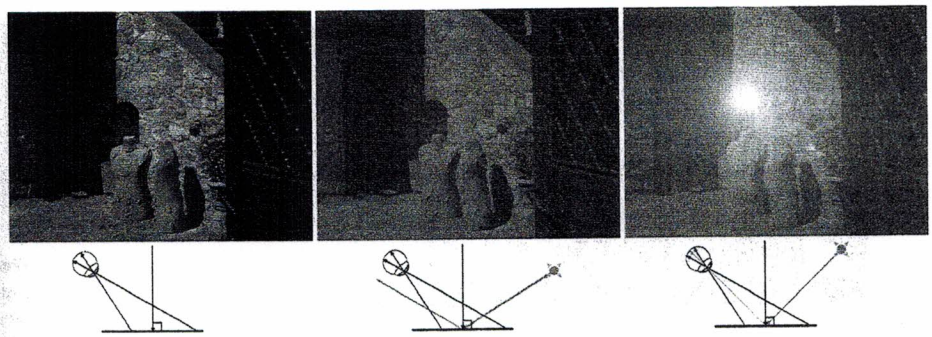
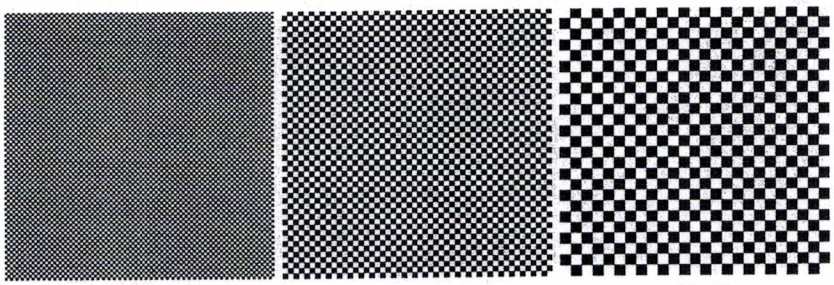


Figure 2.14 Diffuse and specular veiling glare are illustrated in this figure. The image on the left represents viewing a display in a dark or low ambient level environment. The middle image illustrates the diffuse reflection of ambient light degrading the contrast of the image produced by the display. Finally, the image on the right illustrates the combination of diffuse and specular reflections that can overwhelm the image produced by the display reducing its contrast sufficiently to obscure image features from view. The figures under each image represent the viewing geometry with the display lying flat and horizontal and with the viewer on the left and light source on the right. The specular angles are represented in yellow. (See Plate 2).

2.12 Dither: Trade Offs between Spatial Scale and Intensity

Pixels in an electronic display are capable of producing a finite number of intensities. Dither is a signal processing technique used to expand the apparent number of intensity levels in the rendered image. For example, if a display has intensity levels I_j and I_{j+1} the intensity $(I_j + I_{j+1})/2$ can be dithered in a region on the screen by setting half the pixels to level I_j and the other half to I_{j+1}. For dither to work well the spatial pixel pattern produced by this technique should not be visible. Dither depends upon the properties of the *csf*, at high spatial frequencies beyond the peak in the 4 to 8 cycles/deg range more contrast is required to see spatial variations. This is illustrated in Figure 2.15, below, with black and white checkerboards 3 spatial frequencies each increasing by an octave from left to right. Viewed from a distance these three checkerboards will appear to be identical accept for a small variation in brightness due to the printing process.



3x3 6x6 12x12

Figure 2.15 Three checkerboard patterns are shown at three different scales on a 300×300 grid. When viewed from a distance all three of these checkerboard patterns will look identical because the check contrast falls below the threshold for the spatial frequency of the checkerboard pattern.

In Figure 2.16, below, a gray scale ramp was rendered in five different resolutions. Ramp (c) contains 256 intensity levels and at 300 *ppi*. Ramps (a), (b), and (d) are the same ramp rendered with 16 intensity levels and additionally in ramp (a) the pixels are two octaves bigger, 75 *ppi*, than the pixels in the other

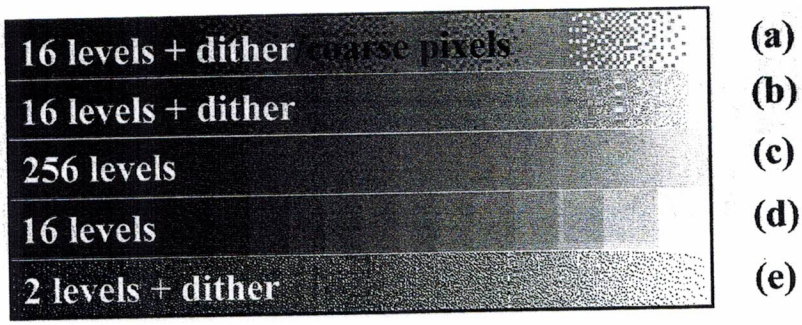


Figure 2.16 A continuous grayscale ramp is sampled at 256 levels and displayed as ramp (c); no sampling artifact is visible. If this signal is rendered on a display with 16 gray levels the image signal must scaled and if the scaling is performed without dither ramp (d) results with noticeable banding artifacts. If the 16 gray levels are dithered by signal processing performed with the scaling operation, then ramp (b) results with few noticeable artifacts relative to ramp (c). If the display is spatially coarse with 16 levels, then ramp (a) results. If the display has binary gray levels, i.e. black and white, then ramp (e) results. All five ramps will look the same viewed from a large distance. The sampling and rendering process creates the visible differences shown in this illustration.

ramps. Ramp (e) contains only 2 intensity levels, black and white. From a distance these five strips look more or less identical. As the observer moves away from the page the pixels subtend smaller visual angles and the contrast required to see individual pixels increases so the dithering becomes less apparent.

Ramp (d) reveals another sampling artifact that can occur due to scaling, the tone-scale banding artifact. A signal with n intensity levels cannot be rendered on a display with m levels, where $n > m$, without re-sampling the signal to fit the display. The number of intensity levels in the signal must be down sampled to match the number of intensity levels than can be displayed. If the down sampling reassigns all of the intensities between two display levels to one display level, then the banding artifact seen in ramp (d) can occur. This artifact is also apparent in Figure 2.6 and for the same reason. Had signal processing been employed when the tone scale resolution in Figure 2.6 was reduced the banding artifact could have been suppressed. This is illustrated in Figure 2.17,

Figure 2.17 The center image from Figure 2.6 is shown re-sampled in tone scale resolution from 24 bits to 3 bits in both images in this figure. The re-sampling on the right was combined with dithering, a non-linear signal processing step to reduce the visibility of the banding artifacts that are visible in the image on the left. (See Plate 3).

below. Signal processing to produce intermediate tone scale values, dithering, can be used to either reduce or increase the resolution of the control signal required to render the image signal onto the display. If the image signal is at a lower resolution than the display, signal processing must be used to scale the signal to match the resolution of the display. This kind of processing is required

Plate 1 The center image
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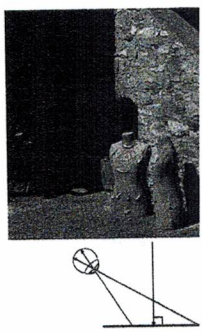

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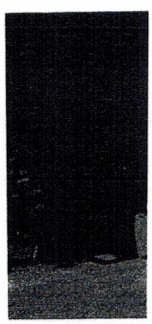

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routinely when a standard television signal at NTSC resolution is reconstructed on a 1080p HDTV display. In this case, if the scaling method simply replicates pixels, banding artifacts and jaggies will almost certainly appear in the image rendered on the higher resolution display. The signal processing used in the scaling step may take advantage of the limitations of human vision to employ techniques based upon the tuning characteristics of the eye to hide artifacts generated by the scaling process from the viewer.

The artifacts in Figures 2.16 and 2.17 depend upon the contrast between adjoining levels within the gray scale and the slope of the gradient on the screen. Even these bands will disappear from view with increasing viewing distance; this phenomenon underscores the importance of the *csf* in determining artifact visibility. Ramp (b) does not exhibit the same banding artifact that is amply apparent in ramp (d) because the dithering algorithm attempts to match the intensity level in the full resolution signal by mixing the intensity levels between bin boundaries within small regions of the ramp to achieve an average the appropriate average intensity in the region. It is also apparent from ramp (b) that the dithering was not always successful.

The jaggies, banding and dither are only apparent when the spatial scale of the pixels and contrast at the pixel boundaries rises above the threshold of visibility. This point is illustrated with another signal processing technique, anti-aliasing, used to smooth slanted edges in drawings and in text. In Figure 2.18, below, the left most triangle demonstrates the jaggies. The pixels filling the stair steps in

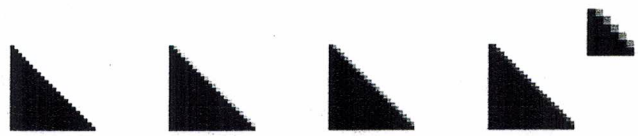

Figure 2.18 The slanted edges in this figure have been coarsely anti-aliased by darkening the pixels filling the stair step edge with a slightly darker than white pixel going from left to right. By holding this page at increasing distance from the eye the edges starting on the right will appear smooth. As the distance increases all of the slanted edges will eventually appear smooth. The upper right triangle is a 2x magnification of the edge to emphasize the anti-aliasing technique by making it more visible.

this triangle are white. The pixels filling the stair steps in the triangles to the right have been set to increasingly darker values relative to the background. The small triangle at the very right is a 2x magnification of the slanted edge. By viewing this figure from slightly different distances the edges can all be made to look smooth, that this occurs at different distances is due to the contrast of the lighter pixels 'filling' the stair steps.

2.13 Three Display Screens with Text Imagery

Figure 2.19, below, shows microscope images at 50x magnification of three different display screens. Individual pixels are indicated in the figure by the white rectangles. All three screens have square pixels consisting of RGB vertical sub-pixel stripes. On all three screens the sub-pixels can be independently manipulated by the control electronics. Each screen is rendering dark text on a white background. The display on the left is a CRT television and the pixel tessellation rule is called the delta triad. Alternating columns of pixels are staggered by half a pixel height relative to the adjoining column. The image on a CRT is created when the electron beam raster sweeps across the screen. A portion of one of the letters is shown in this image. A unique feature of a CRT display is that a pixel region defined by the shadow mask need not be entirely activated by the electron beam as it sweeps the screen. This is exactly what has happened to the screen pixel on the right that is darkened below its negative diagonal and not above it to form part of a letter character on the screen. Scattering within the phosphor layer also adds to the edge softening effect. These features of a CRT tend to reduce the visibility of the jaggies by naturally anti-aliasing edges within the image.

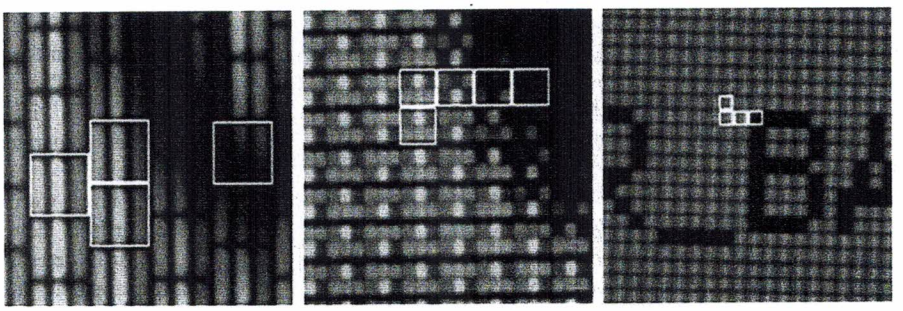

Figure 2.19 Three micrographs are shown of different display screens at ~50x magnification. The left screen is a shadow mask 36-inch diagonal CRT television with a 4:3 aspect ratio, the middle image is a 46-inch diagonal LCD television with a 16:9 aspect ratio, and the right screen is a 15-inch diagonal laptop computer screen with a 15:10 aspect ratio. The white squares are indicating the location of RGB triads on each screen. The spatial resolution of these screens is increasing from left to right. (See Plate 4).

The LCD laptop screen shown on the right has the smallest pixels and highest pitch of the three screens. A 6-point font text image is shown on this screen without anti-aliasing; at this magnification jaggies are quite visible. The combination of the viewing distance, typically 0.5 m, and fine pixel pitch, approximately 105 *ppi*, makes jaggies difficult to see with the unaided eye on this screen so anti-aliasing at this font size would not improve image quality; anti-aliasing at the pixel level would tend to thicken the stroke width within these text letters making them less legible. The text algorithm that controls how letters will be rendered on the screen does not employ anti-aliasing with text smaller than eight points. At eight points and above anti-aliasing can be applied without distorting the letters making them appear thicker or less legible, some computer operating systems anti-alias at the sub-pixel level introducing a small chromatic effect that is below the threshold of visibility at this scale. Text below six points on this screen is illegible.

The middle screen is a 1920×1080 LCD high definition television screen. A single pixel on this screen consists of six sub-pixels, two reds, two greens, and two blues, all of which can be independently controlled. On this screen a very sophisticated anti-aliasing that includes sub-pixel addressing is being applied to soften the edge on the much larger fonts being displayed on this screen. The row of four highlighted pixels reveals how the signal forming a stroke within a letter transitioned from white on the left to black on the right. Within this row of pixels the features of sub-pixel anti-aliasing algorithm are notable. To the unaided eye the letter appeared to be smooth and uniform from the typical viewing distance to this screen of several meters.

The laptop screen has the highest resolution because it is used nearest to the eye at a distance of approximately 0.5 m putting the resolution at the observers eye at approximately 15 lp/deg. TV screens are viewed at a greater distance than computer monitors or handheld devices so the pixels can be bigger. The rule applied during television screen design is to match the resolution of the eye of a typical viewer, 20/20 vision, at the design eye point or approximately 30 lp/deg. The BBC survey [7] found that resolution available at the viewing distances that were reported ranged from 20 to 40 lp/deg.

Hand held displays built into cell phones and PDAs are viewed from very short distances. A young user may view the display from as close as 6 or 7 inches. Older users tend not to view at such close range due to presbyopia, the loss with age of the ability to focus at short range. In Figure 2.20 the relationship between viewing distance and pixel pitch is shown for fixed resolutions at the observer's viewing distance. The green band corresponds to pixel densities between 75 and 175 *ppi*, the red band corresponds to user viewing distances. A display with 150 *ppi* will never fall below 10 *lp*/deg within this range of viewing distances.

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2.14 Color

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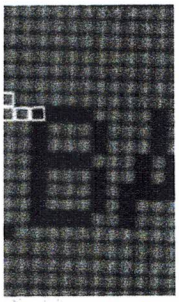

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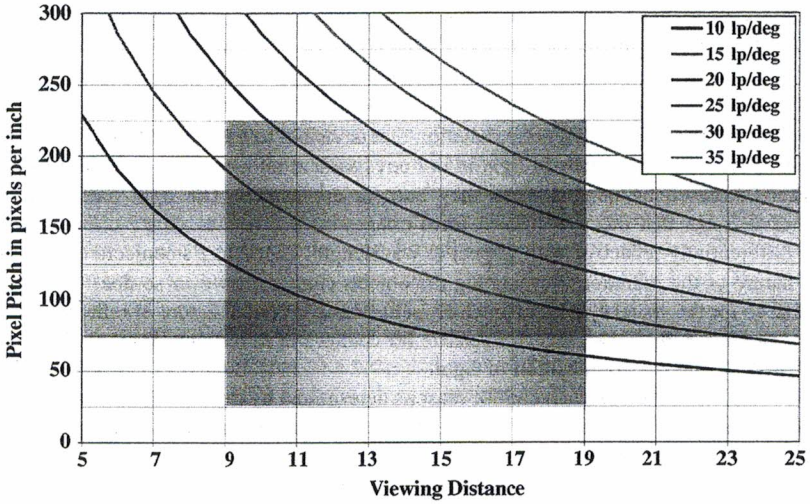

Figure 2.20 The pixel pitch required as a function of viewing distance to produce a fixed resolution measured in lp/deg at the observer's eye is shown in this figure. The green band corresponds to the range of resolutions found in PDAs and cell phones and the red band corresponds to the range of user viewing distances.

2.14 Color

Consumers prefer color displays to monochrome or limited color displays. Very few products succeed in the marketplace today that do not provide color imagery. Why do we see color, what value does color have for communicating information? Helmholtz conjectured that 'Colours have their greatest significance for us in so far as they are properties of bodies and can be used as marks of identification of bodies' [14, p 286].

Colors help us to identify objects and find them quickly in a cluttered scene. The color of food or the pallor of a face can suggest that the food should not be ingested because it could be spoiled or that the person with the sickly pallor might be ill and best avoided. It is reasonable to suppose that color must be a property of the objects viewed. Color results from light interacting with objects, by being absorbed and reflected by them, but it also results from the way the nervous system encodes and processes the light imaged onto the retina.

Isaac Newton, in his experiments with light, concluded that color is a perceptual and not a physical property of light. Newton's conclusion is based upon the observation that a mixture of different bands of the spectrum can look as if it is the same color as an entirely different and unique band of the spectrum. Based upon this observation he wrote,

> The homogeneal Light and Rays which appear red, or rather make Objects appear so, I call Rubrifick or Red-making; those which make Objects appear yellow, green, blue, and violet, I call Yellow-making,Green-making,Blue-making,Violet-making, and so of the rest. And if at any time I speak of Light and Rays as coloured or endued with Colours, I would be understood to speak not philosophically and properly, but grossly, and accordingly to such Conceptions as vulgar People in seeing all these Experiments would be apt to frame. For the Rays to speak properly are not coloured. In them there is nothing else than a certain Power and Disposition to stir up a Sensation of this or that Colour. For as Sound in a Bell or musical String, or other sounding Body, is nothing but a trembling Motion, and in the Air nothing but that Motion propagated from the Object, and in the Sensorium 'tis a Sense of that Motion under the Form of Sound; so Colours in the Object are nothing but a Disposition to reflect this or that sort of Rays more copiously than the rest; in the