Image Resolution vs. Bit-Depth

The perceptual trade-off in a two dimensional image array

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When selecting a Spatial Light Modulator (SLM) for a particular application the user is often faced with decisions on various requirements. One of these requirements, resolution, can often be directly traded for another, bit-depth. This paper describes the methodology that can be implemented for making this choice as well as provides some examples to illustrate the trade space.

Background

It has long been known by the printing industry that increased X/Y resolution can be used to give the perception of increased bit-depth. This has historically been done via the use of dithering techniques. Newspapers use tiny dots of black ink to create images that have gray levels. When the dots are tightly packed the region appears very dark, when the region is sparsely packed with dots it has the appearance of a lighter shade of gray. The human eye will integrate the information from several dots or pixels into a group or super-pixel that has the appearance of gray-levels. This ability to provide gray scale information with a binary printing process allows the newspaper to provide gray scale and even color images without upgrading the printing process. The tradeoff is resolution. If a reader views a newspaper at very close range, it will be apparent to them that the image contains only limited amount of information. All of the high-resolution information is eliminated by the reader's eye in order to generate the gray scale quality.

Application to Projection Display

The integration feature of human perception can be used to improve the appearance of projection image displays. Many displays use binary picture elements (pixels) closely spaced to provide gray or color levels. The designers of these systems trade-off the resolution of the display device with the gray level of the display. A high-resolution binary display device can be used to project a gray scale image of lower resolution. This human perception quality applies to the Spatial Light Modulator (SLM's) used to modulate the light being projected. When an SLM displays an image containing only black and white pixels the human eye will integrate groups of pixels into super-pixels to create the perception of gray-level. Thus the effect of gray-levels can be obtained at the loss of the X/Y resolution needed for the super-pixels. For this reason, a low X/Y resolution SLM that displays multiple gray-levels will appeal to the human eye just as well as a high X/Y resolution binary SLM.

The trade-off between X/Y resolution and bit-depth can be identified in terms of the number of pixels used to create the super-pixel effect. For example, a 4x4 super-pixel should give the approximate appearance of 16 levels of gray, but at a resolution reduced by the same factor of 4x4. Table 1 illustrates various choices of super-pixel dimensions versus the relative bit-depth.

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It should be noted that Table 1 is really an oversimplification of the human perception process. Smart dithering algorithms will maintain more of the resolution than that listed in the table. Conversely, the dithering process will probably not reach an apparent bit-depth of 8-bits because at some point the human perception will no longer blend more pixels into a single super-pixel. These points are illustrated by the example images shown on the following pages. The resolutions range from 1024x1024 to 256x256. The images are shown in full 8-bit depth and in a reduced 1-bit dithered version.

Super-pixel Size	Apparent Gray-levels	Apparent Bit-Depth	Apparent Resolution
2x2	4	2	512x512
3x3	9	3+	171x171
4x4	16	4	256x256
5x5	25	4+	102x102
6x6	36	5+	85x85
7x7	49	5+	73x73
8x8	64	6	64x64
9x9	81	6+	57x57
10x10	100	6+	51x51
11x11	121	6+	47x47
12x12	144	7+	43x43
13x13	169	7+	39x39
14x14	196	7+	37x37
15x15	225	7+	34x34
16x16	256	8	32x32

Table 1 - The impact of the super-pixel dimension on perceived gray-level and perceived resolution from a binary 1024x1024 SLM image.

The image in Figure 1 is a 1024 X 1024 pixel image with theoretically 256 gray levels of information at each pixel. Note that this fact is somewhat distorted by the printing process. The image in Figure 1 is derived from an original 2048 X 2048 image with 256 gray levels. The resulting pixels are enlarged so that the size of the entire image is the same as the original image. The process of reducing the resolution of the image but enlarging the pixels necessarily reduces the clarity of the underlying object. However, because of proper gray scale clues, this process can be repeated several times before significant degradation is observed.

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Figure 1 - Original 1024x1024x8-bit image of the International Space Station (Photo courtesy of NASA).

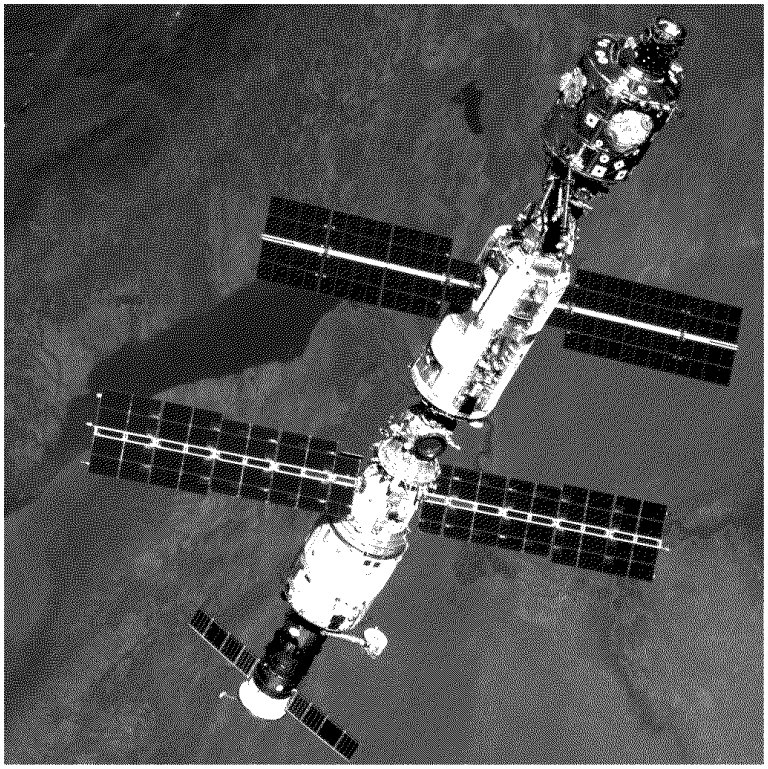


Figure 2 –Dithered 1024x1024x1-bit image of the International Space Station.

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The image in Figure 2 is a reduced resolution image that has been dithered to simulate a binary image of the original. Note that some gray scale information has been preserved but much of the detail has been lost. This is a result of the fact that some resolution information is actually contained in the gray scale information.

A substantial resolution tradeoff can be made with gray-level information. As seen by these images (Figure 4 and Figure 5), a reduction in resolution by as much as 4x4 with an 8-bit image still preserves most of the apparent resolution that exists in a dithered 1-bit image.

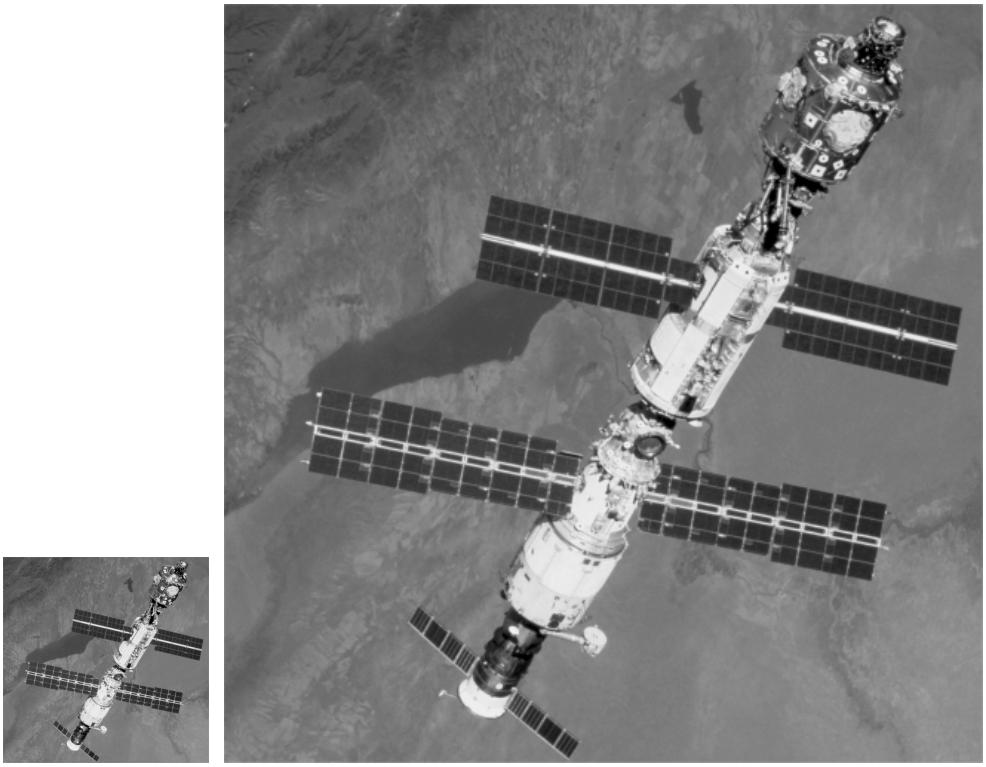


Figure 3 – (Left) Resized 512x512x8-bit image of the International Space Station, (Right Enlarged pixels to match overall image dimensions from Figure 1.

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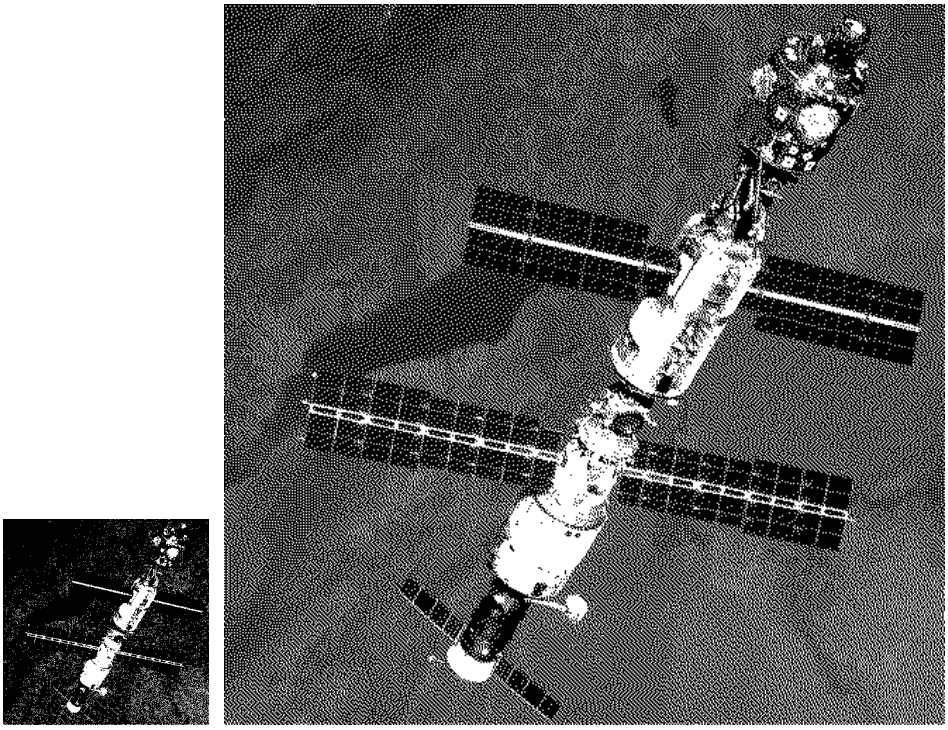


Figure 4 – (Left) Dithered 512x512x1-bit image of the International Space Station, (Right Enlarged pixels to match overall image dimensions from Figure 1.

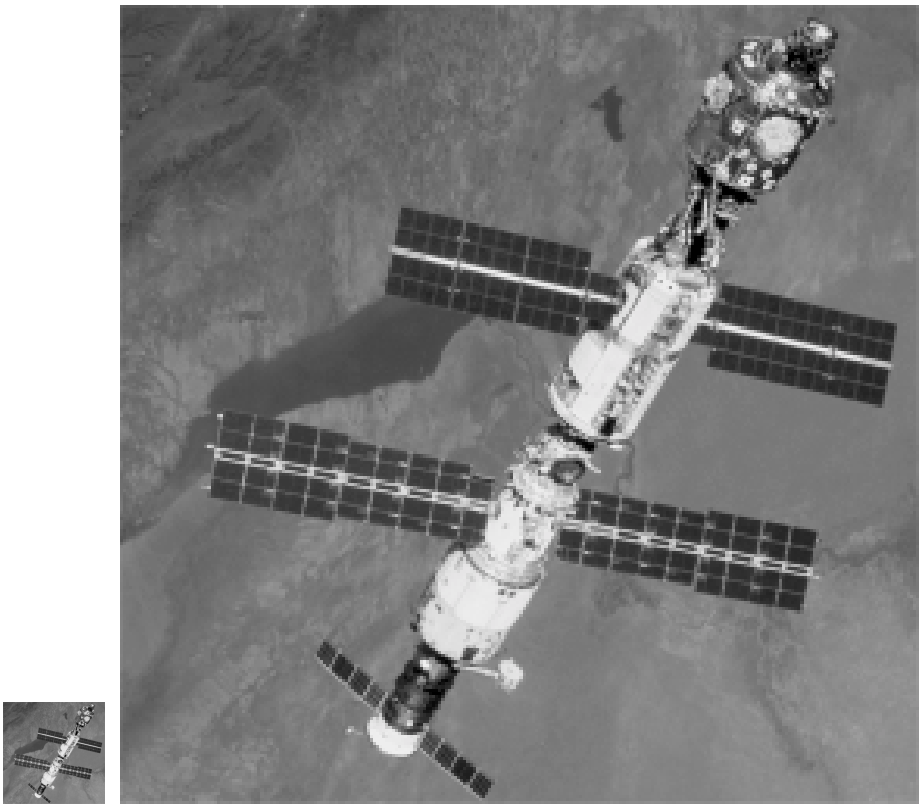


Figure 5 – (Left) Resized 256x256x8-bit image of the International Space Station, (Right Enlarged pixels to match overall image dimensions from Figure 1.

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The resolution/gray scale trade-off can be used to create gray scale images with a binary information system. The sacrifice is that a larger number of pixels will be needed to present the information. Analogously, the resolution/gray scale trade-off can be used to create higher resolution images by enlarging the pixel size. The sacrifice is that more information must be presented by each pixel.

The rule of thumb that can be used is that the resolution scales as 75% of the information presented by a pixel. By this rule, an increase in the number of bits from 1 to 8 is equivalent to a factor of six reduction in resolution. By this calculation, a 512 X 512 X 1 bit image would be equivalent to an 85 X 85 X 8 bit image.

Of course the rule of thumb may not apply to all types of image presentation systems but as can be seen by the above images it is generally true.

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