ClearType

Optimal Filtering For Patterned Displays

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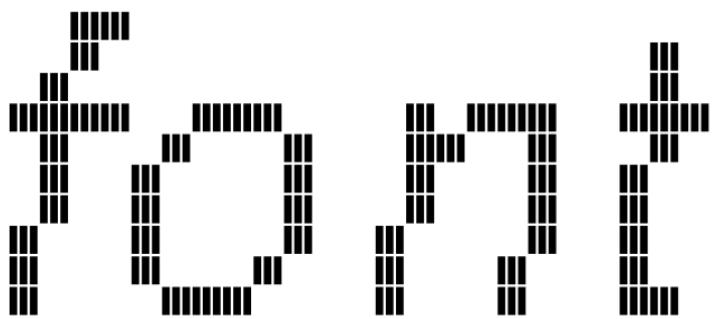
Overview: What is ClearType?

- "ClearType is a software system that enhances resolution and readability of fonts on displays that contain a reapeting pattern of addresable colored subpixel".
- "Filtering in ClearType is based on a perceptual model of human vision that leads to an optimization technique for finding the best output values".

Unfiltered:



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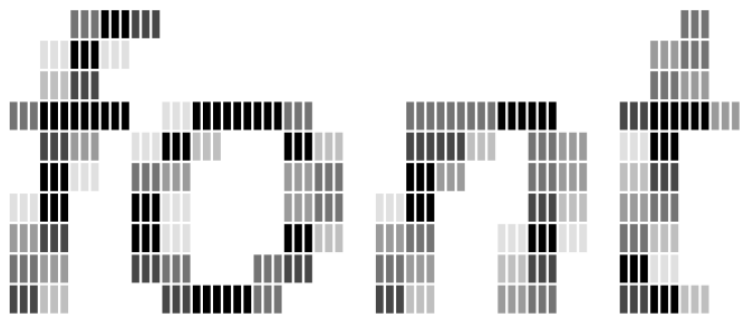
Standard Box Filter Antialiasing:



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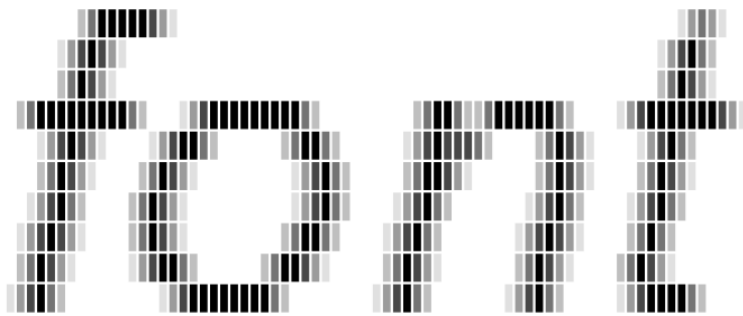
ClearType:

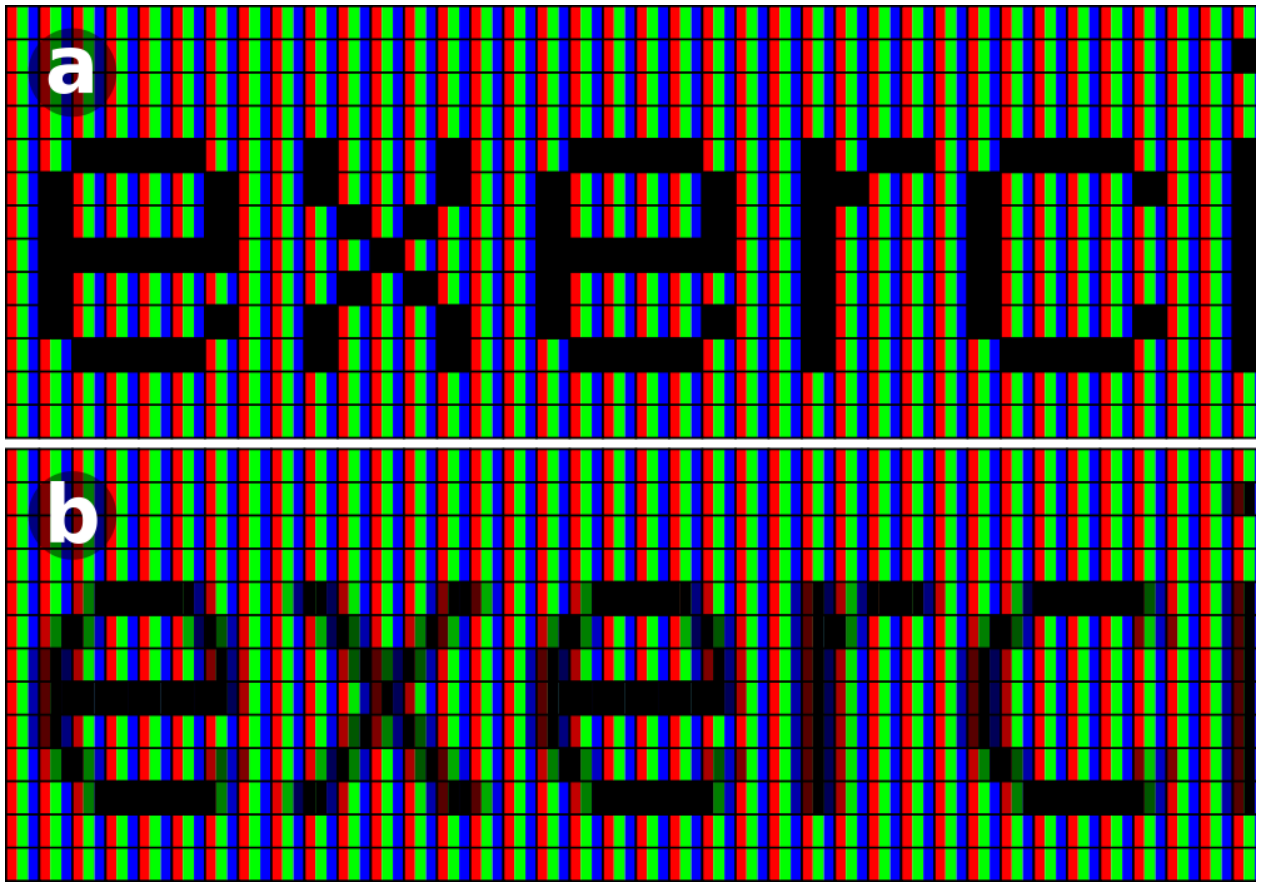


Overview: Luminance Resolution

- "There is an oppotunity to increase the effective resolution of a patterned display by treatening the subpixels separately".
- "However, treating each subpixel purely as a luminance source, while ignoring the color of the subpixel, creates large color fringing errors".

Overview: Luminance Resolution

Full Luminance Resolution $\Longleftrightarrow$ Color Error

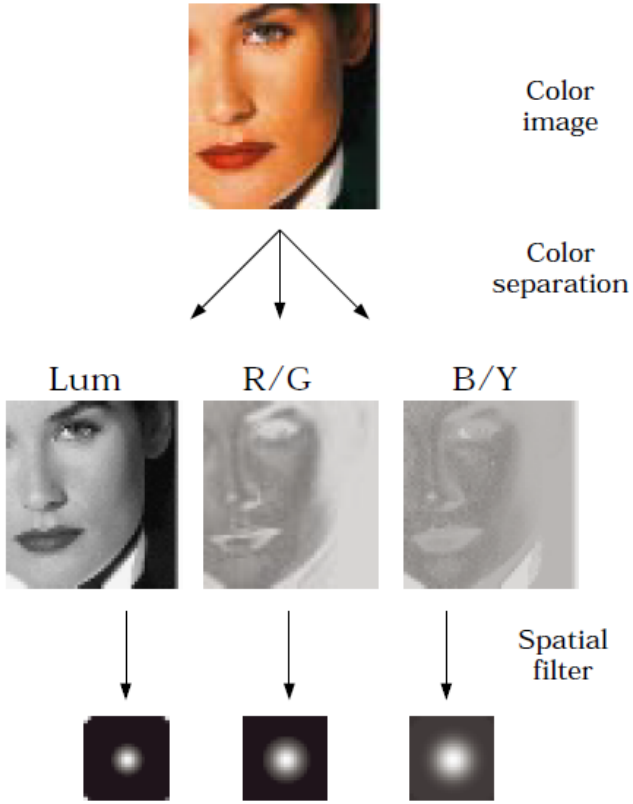


- "Tradeoff can be balanced through a perceptual error metric."

Perceptual Error Metric (PEM): Motivation

- Perceptual Error Metric is based on psychophysical experiments carried by Brian Wandell[3].
- Objetive : Measure the **perceived** color error of an image reproduction.
- Focus on : Patterned regions of the image.
- Implementation :
  - Color Separation.
  - Spatial Filter: **Simulate the spatial blurring by the human visual system**.
- External Parameters:
  - Distance from observer to the image reproduction.
  - Spatial resolution of the image reproduction (ppi).

Perceptual Error Metric (PEM): Motivation



- "Human visual system separates image data into a brightness channel (black/white), and two opponent color channels: red/green and blue/yellow".
- Spatial blurring by the HVS is stronger in the red/green and blue/yellow channels than in the luminance channel.

Perceptual Error Metric (PEM): ClearType Formulation

- **Input**$\rightarrow \gamma_{kd}$:Full color image sampled at the same positions of the subpixels.
- **Output**$\rightarrow \alpha_k$:Singly-colored subpixel luminance.
- **Parameters**$\rightarrow M_{ck}, C_{cd}$: Matrices of transformation to opponent color space c.
- PEM defines a linear term for **each** opponent color space c:

$$E_{ck} = M_{ck}\alpha_k - \sum_{d=0}^{2} C_{cd}\gamma_{kd}$$

Perceptual Error Metric (PEM): ClearType Formulation

- The error is transformed into a Fourier basis

$$\hat{E}_{cn} = \sum_{k=0}^{N-1} E_{ck}\phi_{kn}$$

- Since HVS acts as a low-pass spatial filter, each frequency is weighted according to a low pass model. Different models apply to each opponent channel according to the blurring intensity.

$$\begin{aligned} W_0(f_n) &= \min\{1, (8/f_n)^8\}, \\ W_1(f_n) &= \min\{1, (5/f_n)^4, W_0(f_n)\}, \\ W_2(f_n) &= \min\{1, (3/f_n)^4, W_0(f_n)\} \end{aligned}$$

- The error function to be minimized is given by

$$\sum_{c=0}^{2}\sum_{n=0}^{N-1} W_{cn}\hat{E}_{cn}\hat{E}^*_{cn}$$

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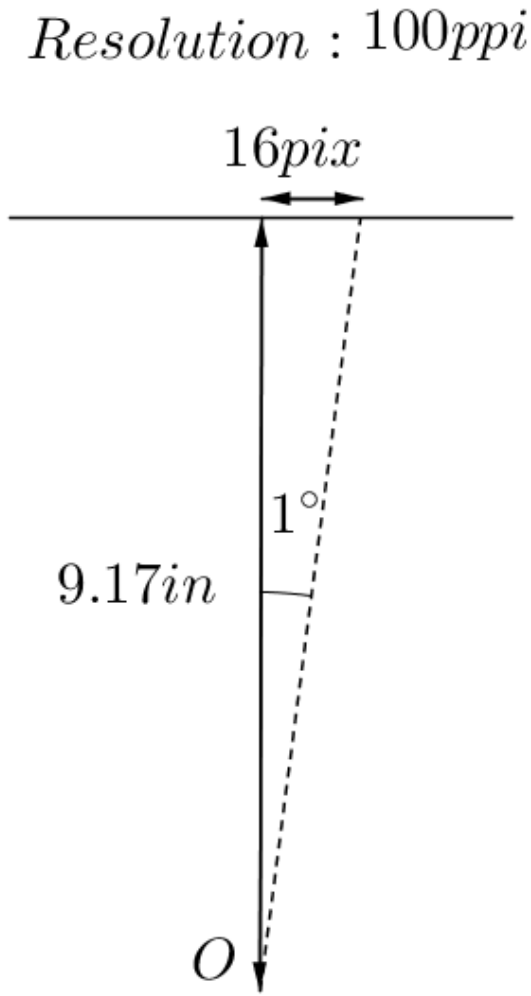
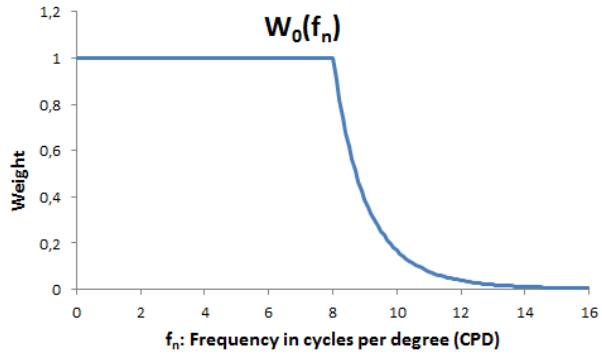
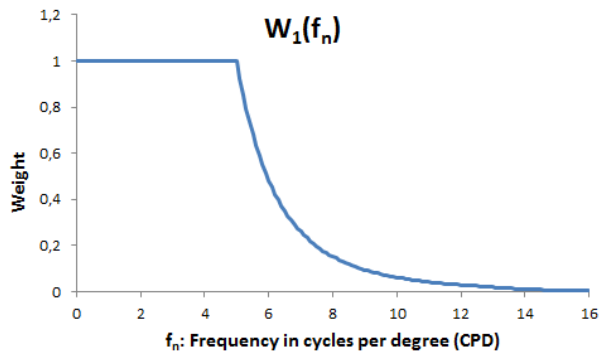
Low Pass Model: Assumptions

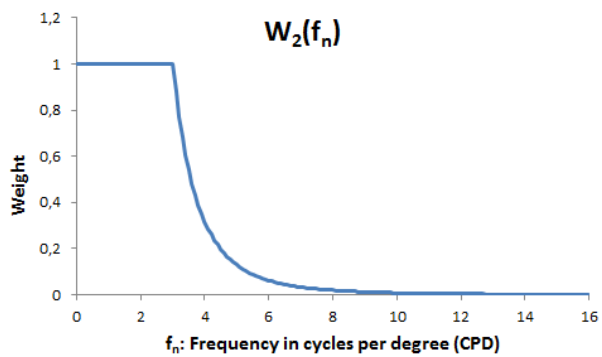


Nyquist = 0.5 cycles per pixel = 8 cycles per degree = $f_{N/6}$

Low Pass Model: Weights

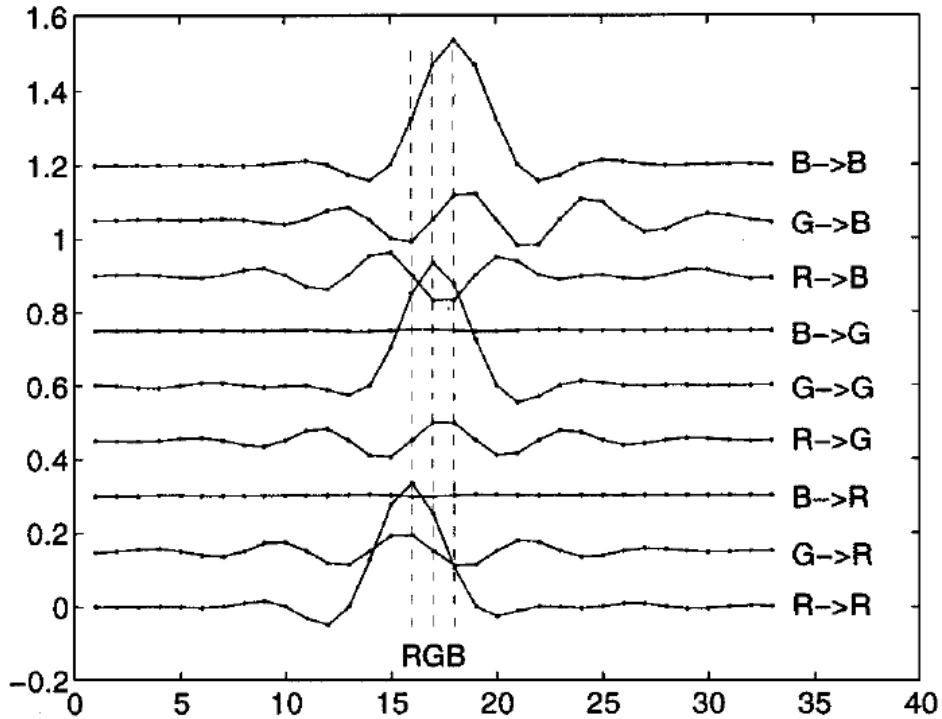






Optimal Filter

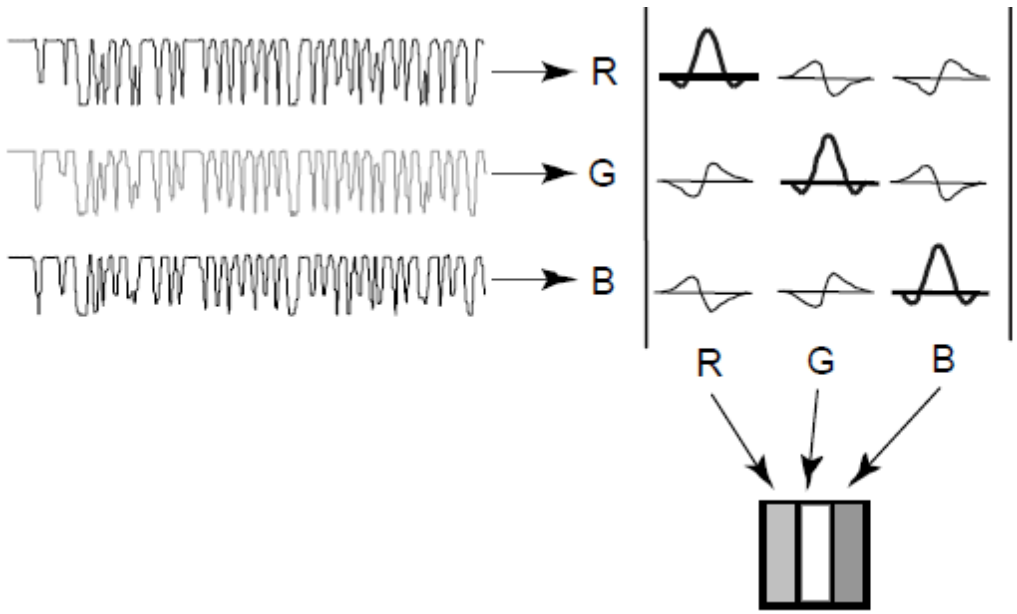
- The solution to the linear system can be expressed as a set of nine filters, one for every combination of input and subpixel color.



- Filters that connects the same color ,i.e., $R \rightarrow R$, $G \rightarrow G$, $B \rightarrow B$, are nearly identical low pass filters centred underneath the corresponding location of the subpixel.

Optimal Filter

- To obtain the luminance value at a R subpixel, the three filters $R \to R, G \to R, B \to R$ are applied to the R, G, B, channels of the input image. The output of these three filters are summed together, and we take the value at the R subpixel position.



Real Time Implementation: Box RGB Decimation

- Step 1: Cross color filters are discarded. Only same color filters are taken into account.
- Step 2: Instead of prefiltering with the optimal filter, the filter adopted is a one-pixel-wide box.
- Step 3: Samples of the filtered signal are taken at subpixel locations.

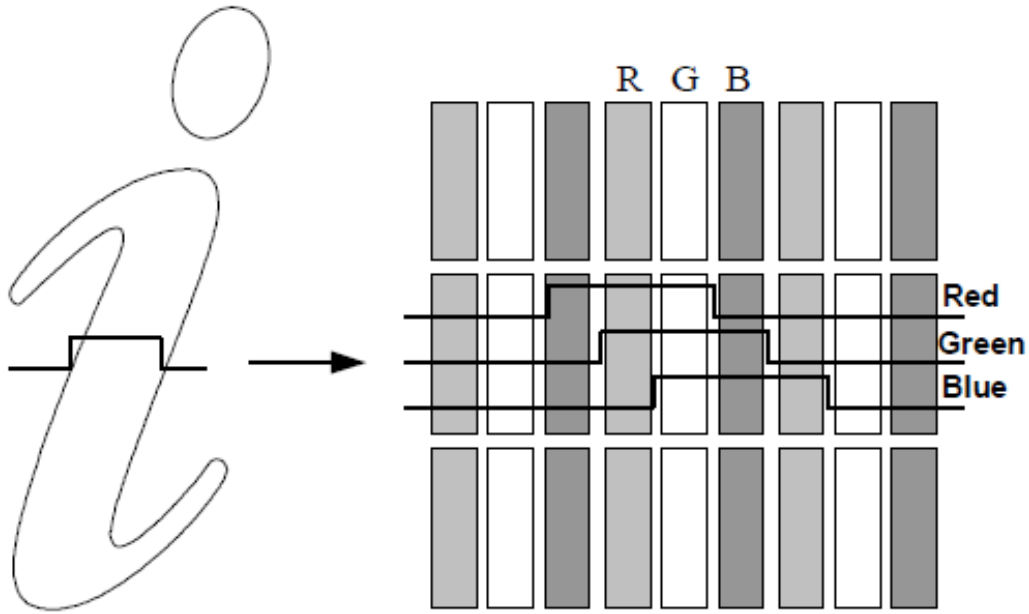
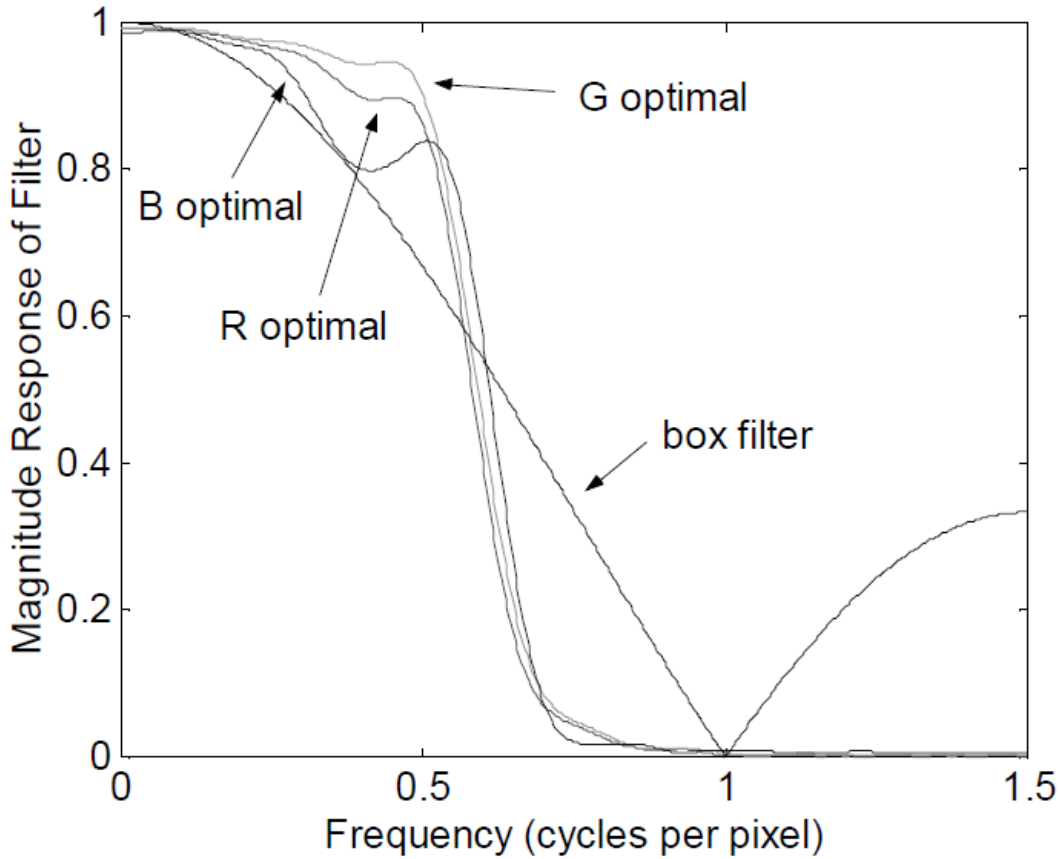


Figure 2. With RGB decimation using box filters, each filter is centered on the output sub-pixel and spans a complete pixel. Shown is a bi-level monochrome signal to be convolved with the three filters.

Spectral Comparision: Optimal Filter - Box RGB Decimation



Implementation Details

- When **optimal filtering** is applied there may be output values below zero or above one. Values below zero are truncated. Values above one lead to a full pixel normalization to maintain color correctness. When **Box RGB Decimation** is applied all values already lie in $[0, 1]$.

- "In order to minimize aliasing caused by displace sampling, we use original images that are sampled at least six times horizontally per pixel".

Conventional Sampling vs. Displaced Sampling

- "Normal antialising methods compute the red and blue subpixel values as if they were coincident with the green subpixel, and then display the red and blue components shifted 1/3 of a pixel to the left or right. The shifting of these primaries lead to blurring".

- "By displacing the antialiasing filters, the optimal filters eliminate this blurring at the expense of slight color fringing".

ClearType. Some Historical and Technical Facts

- "ClearType was introduced as an operating system feature in Windows XP, where it was kept turned off by default. In Windows Vista and Windows 7 ClearType is turned on by default".

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- "Text that is rendered with ClearType can appear significantly different when viewed by individuals with varying levels of color sensitivity". In a study of U.T. Austin, 19 of 51 students declared experiencing some disadvantage at ClearType conditions.

Bibliography

1. *Optimal Filtering for Patterned Displays*. John C. Platt.
2. *20.4: Displaced Filtering for Patterned Displays*. Claude Betrisey et. al.
3. *Foundations of Vision*. Brian Wandell.
4. *A spatial extension of CIELAB for digital color image reproduction*. Xuemei Zhang and Brian Wandell.

Examples!!!