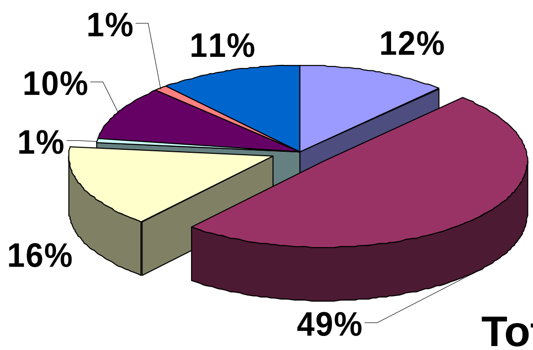
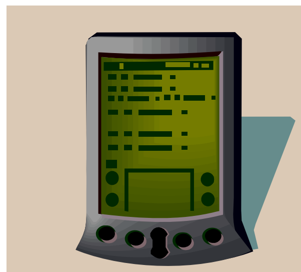
Dynamic Tone Mapping for Backlight Scaling

Ali Iranli
Massoud Pedram

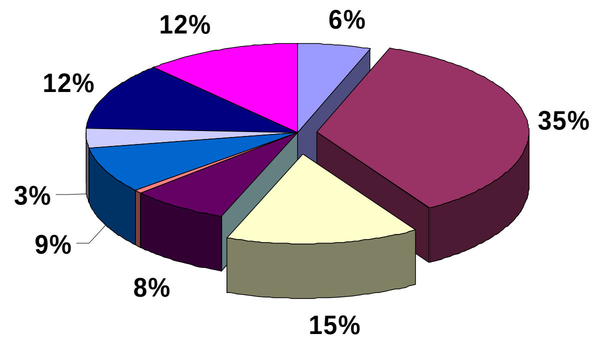
University of Southern California
DAC 2005

Motivation



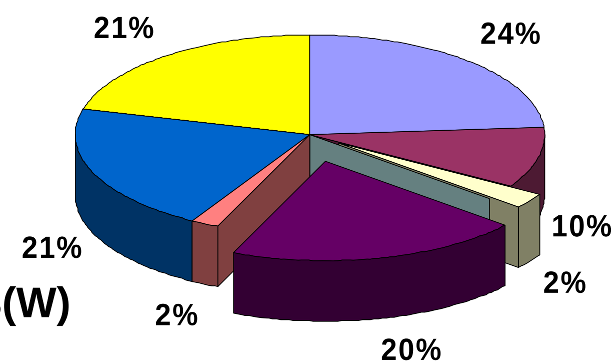


Total Power = 2.96(W)



Total Power = 7.27(W)

Total Power = 1.63(W)



- CPU
- LCD Panel
- SDRAM
- DSP
- HDD
- CDMA
- LCD Backlight
- Bluetooth
- Flash Memory
- 802.11b
- Off-chip buses

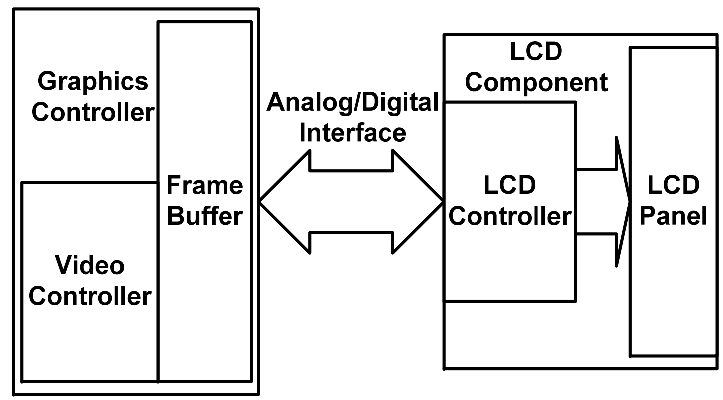
Data from H. Shim et. al., ESTIMEDIA 2004

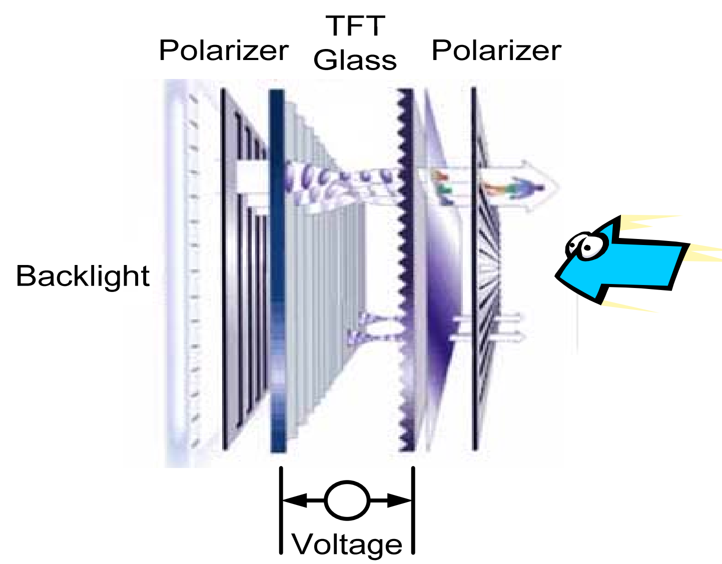
Outline

- Introduction
- Dynamic Backlight Scaling (DBS) Problem
  - Previous Work
- Human Visual System
- Dynamic Tone Mapping
- Experimental results
- Conclusion

Display Architecture

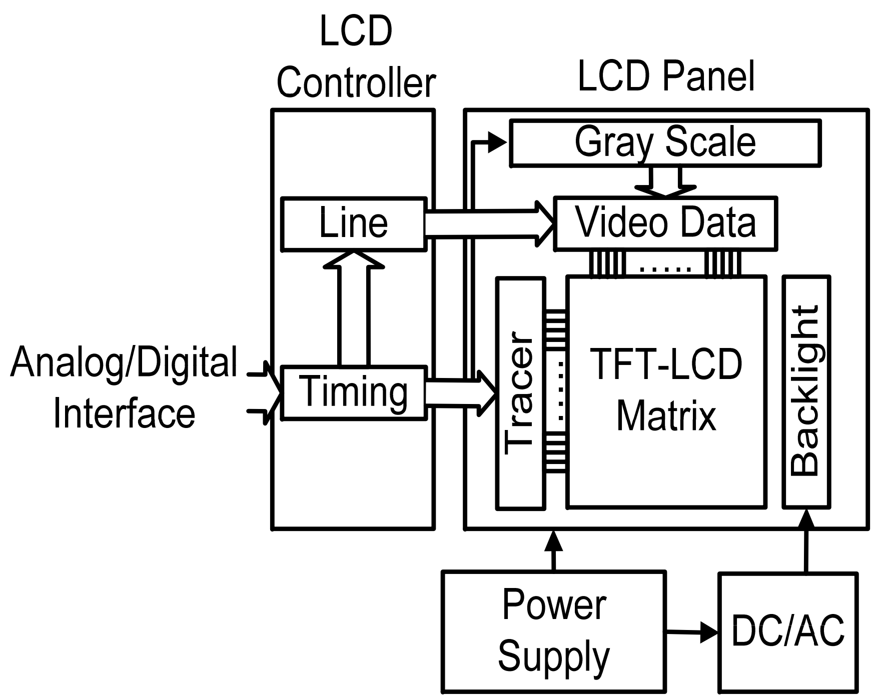
- The image data is first saved into the frame buffer memory by the video controller and then it is transmitted to the LCD
- LCD controller receives the video data and generates a proper grayscale for each pixel
- A displayed pixel looks bright if its transmittance is high, meaning it passes the backlight. On the other hand, a displayed pixel looks dark if its transmittance is low, meaning that it blocks the backlight



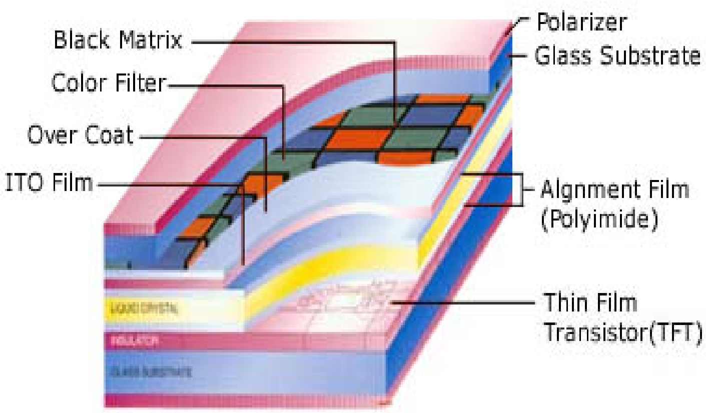


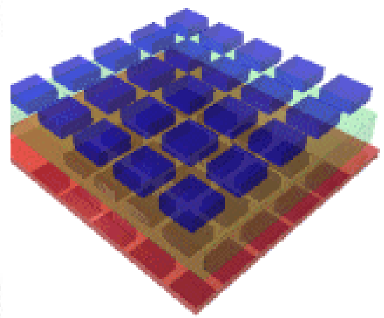
LCD Component

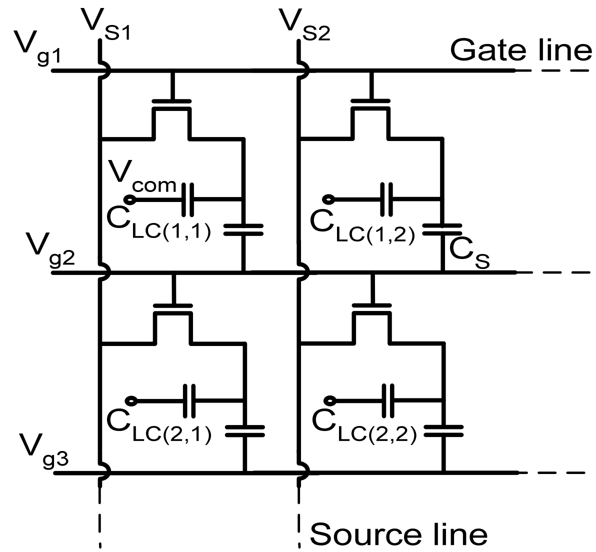
- LCD controller extracts the timing information and the grayscale level of each pixel from the video interface signal
- Tracer scans rows of LCD matrix one-by-one to refresh the grayscale level of each row
- Different grayscale levels are represented by different voltage values at the output of grayscale block



Thin Film Transistor Cell

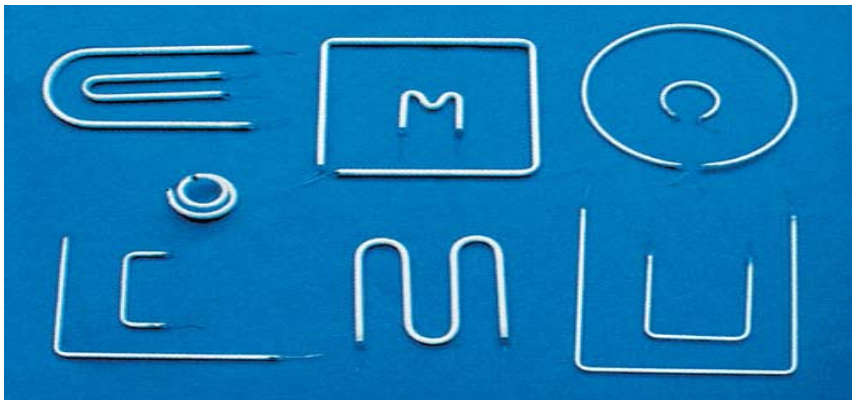


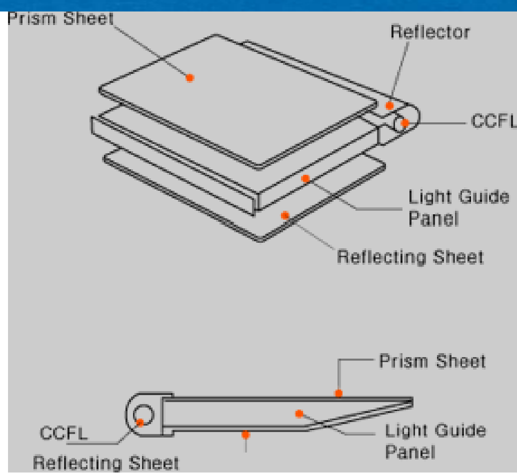




- Each pixel on screen is a capacitor applying electrical field to the corresponding liquid crystal cell
- Different voltage levels on each capacitor produces different transmittance for each liquid crystal cell and hence different grayscale level for the corresponding pixel

Cold Cathode Fluorescent Lamp (CCFL)



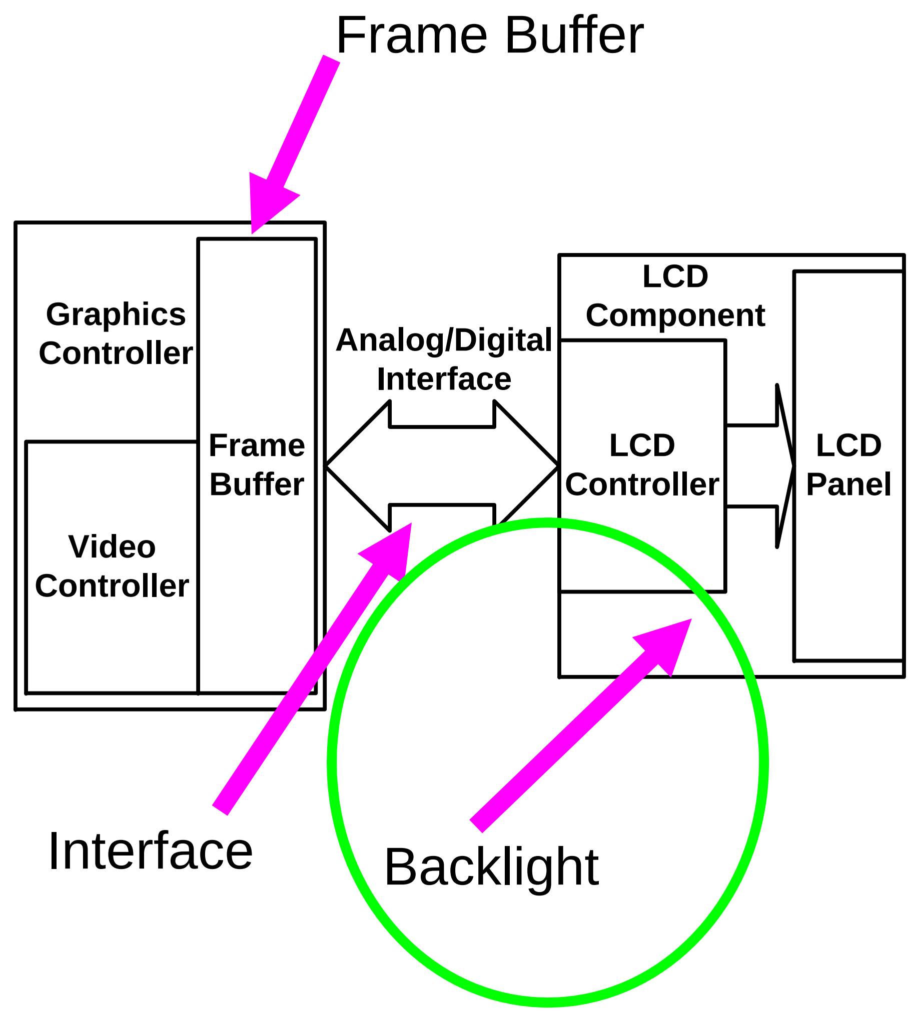


- CCFL is the most efficient electrical-to-optical energy transducer with efficiencies ~ 20%
- Conversion efficiency is function of,
  - Current
  - Temperature
  - Drive waveform
  - Length, width, and gas type
- LCD displays usually have one or two CCFL and a light guide panel to distribute light behind the LCD evenly

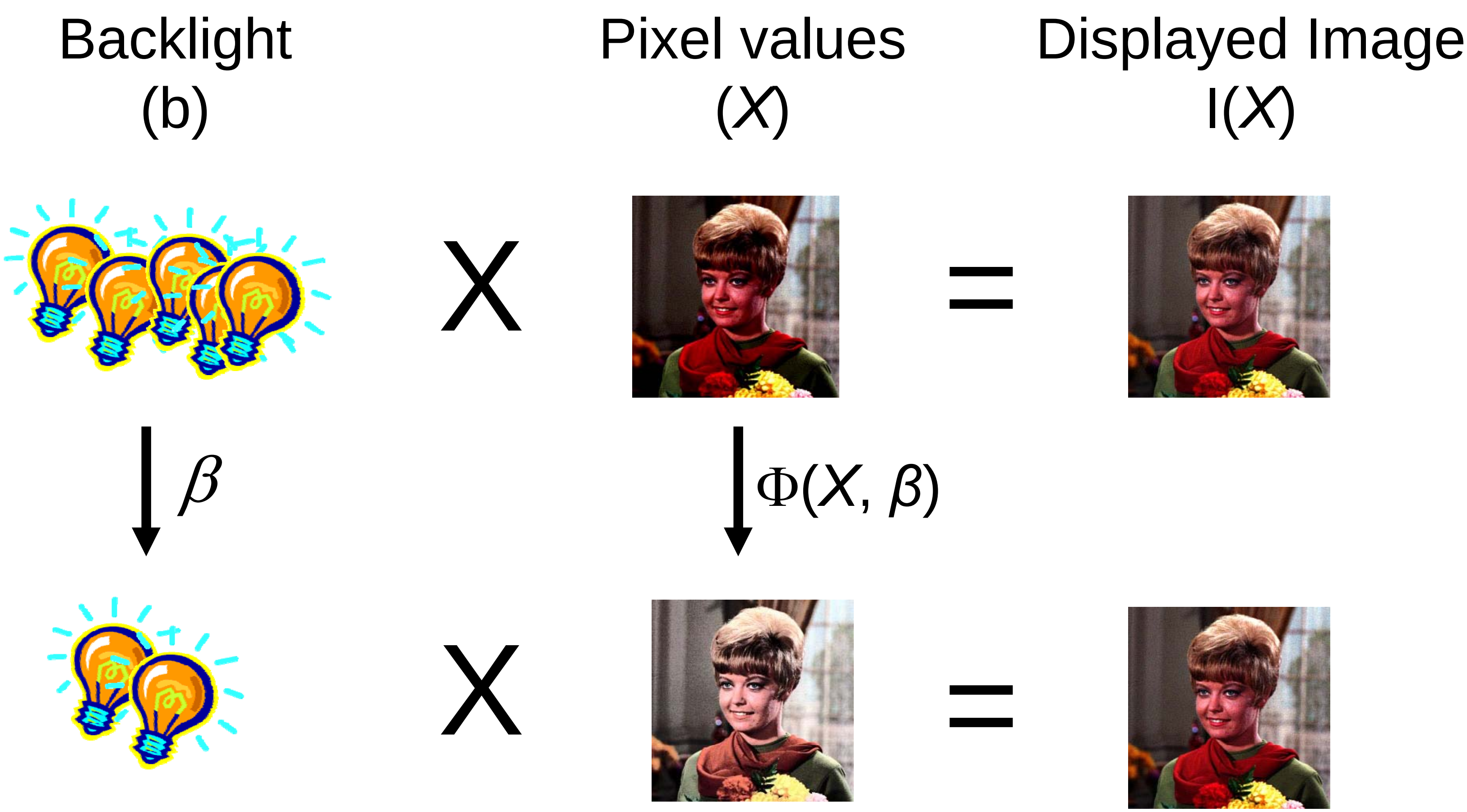
Energy Management Solutions

Focusing on:

- Frame buffer
  - Reduce the number of updates in frame buffer e.g., compressed buffer
- Digital/analog interface between the graphics controller and the LCD controller
  - Minimize the switching activity on the video display e.g., chromatic encoding
- LCD controller and the backlight
  - Dim the display backlight to consume less energy e.g., backlight scaling



Backlight Scaling

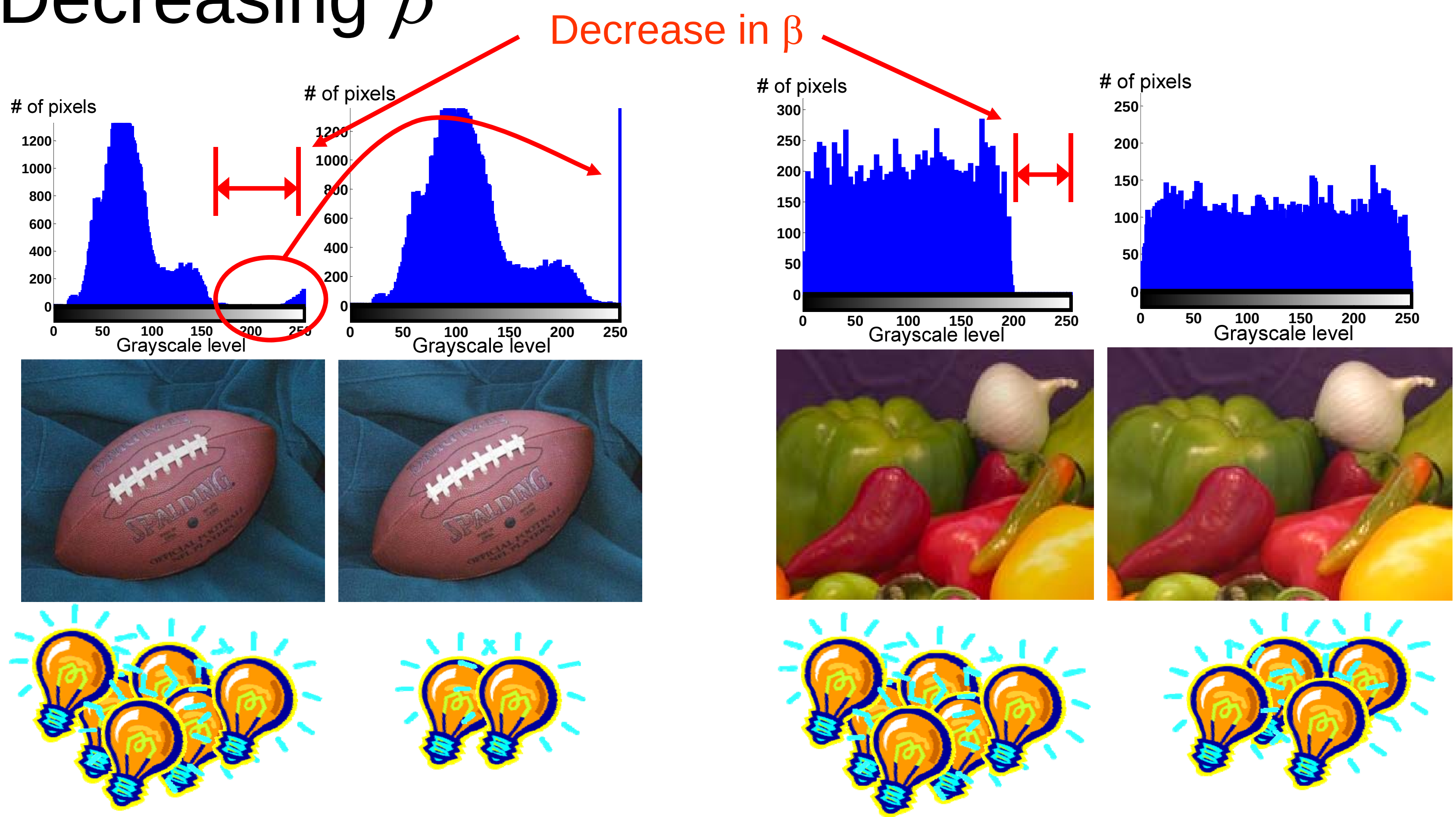


Dynamic Backlight Scaling (DBS) Problem

- Let χ and $\chi' = \Phi(\chi, \beta)$ denote the original and the transformed image data, respectively
- Moreover, let $D(\chi, \chi')$ and $P(\chi', \beta)$ denote the distortion of the images χ and χ' and the power consumption of the LCD-subsystem while displaying image χ' with backlight scaling factor, β

- **Dynamic Backlight Scaling (DBS) Problem:** Given the original image χ and the maximum tolerable image distortion D_{max}, find the backlight scaling factor β and the corresponding pixel transformation function $\chi'=\Phi(\chi,\beta)$ such that $P(\chi', \beta)$ is minimized and $D(\chi, \chi') \leq D_{max}$

Decreasing β



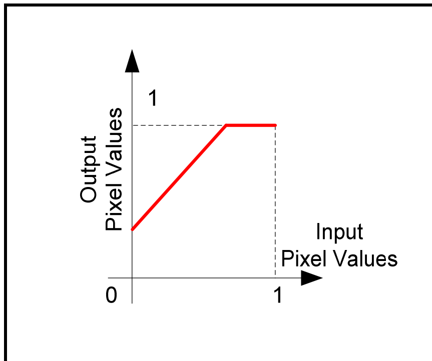
- Smaller dynamic range of the image results in larger decrease in β and therefore larger energy saving for a given maximum distortion level

Previous Work

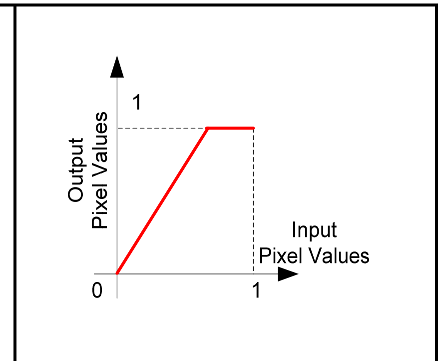
- Chang, Choi and Shim 2003, proposed grayscale spreading and grayscale shift approaches for backlight scaling
(figures a, b)

- Cheng and Pedram 2004, proposed single band grayscale spreading
(figure c)

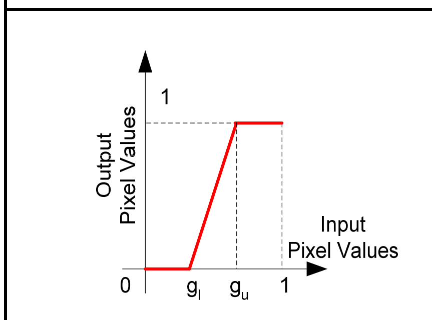
- Iranli and Pedram 2005, Histogram Equalization based multi-band grayscale spreading
(figure d)



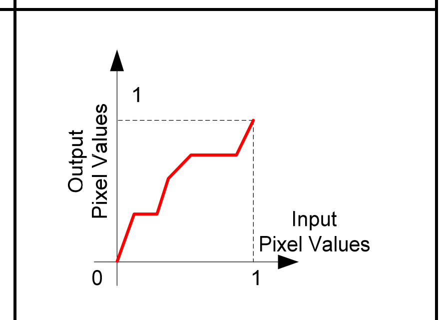
a. grayscale shift



b. grayscale spreading



c. single-band grayscale spreading



d. multi-band grayscale spreading

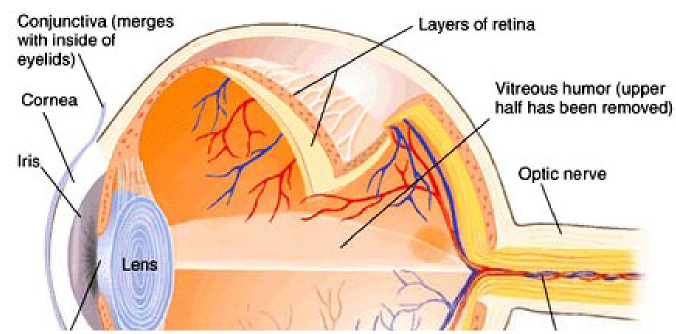
Pros and Cons

- Pros,
  - Preserve brightness/contrast of the displayed image
  - Minimize image distortion by saturating minimal number of pixels
  - Achieve 20% power saving in display subsystem

- Cons,
  - Pixel-by-pixel manipulation of the image ➔ applicable to still images
  - Requires image histogram information
  - Does not accurately model the eye's brightness perception, i.e. incomplete image distortion measure
  - Does not fully utilize the power saving potential

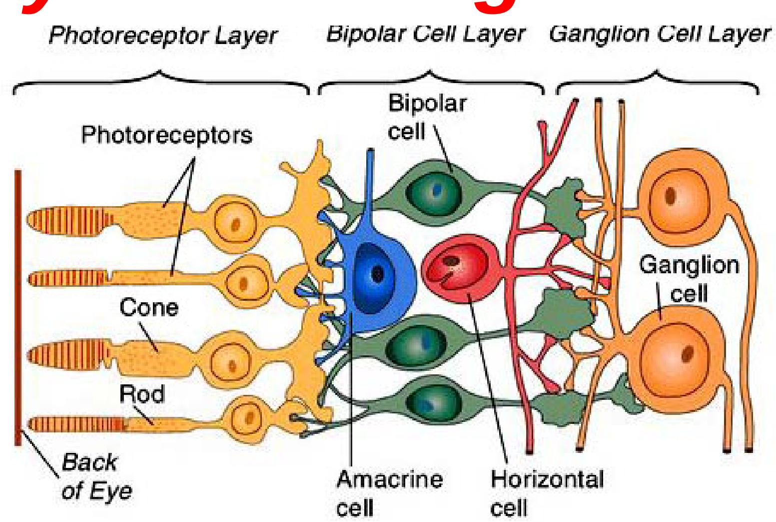
Human Visual System

- Visual Photoreceptors
  - Rods, No color
  - Cones, color
- Visual Ranges



How our visual system handles such a large dynamic range?

  - Photoptic, 10 to 10^8 cd/m^2, cones active
- Dynamic Range
  - Visual Sensors, $1:10^{14}$
  - Neuron Connections, $1:10^{3/2}$



Luminance Adaptation

- Eye first adapts to some *adaptation luminance* value, and then perceives images in some dynamic range near this value
- Just Noticeable Difference (JND),

$$\Delta L(L_a) = 0.0594 \cdot (1.219 + L_a^{0.4})^{2.5}$$

L_a : *Adaptation Luminance*

ΔL : *Just Noticable Difference*

- Brightness perception is the magnitude of the subjective sensation which is produced by visible light

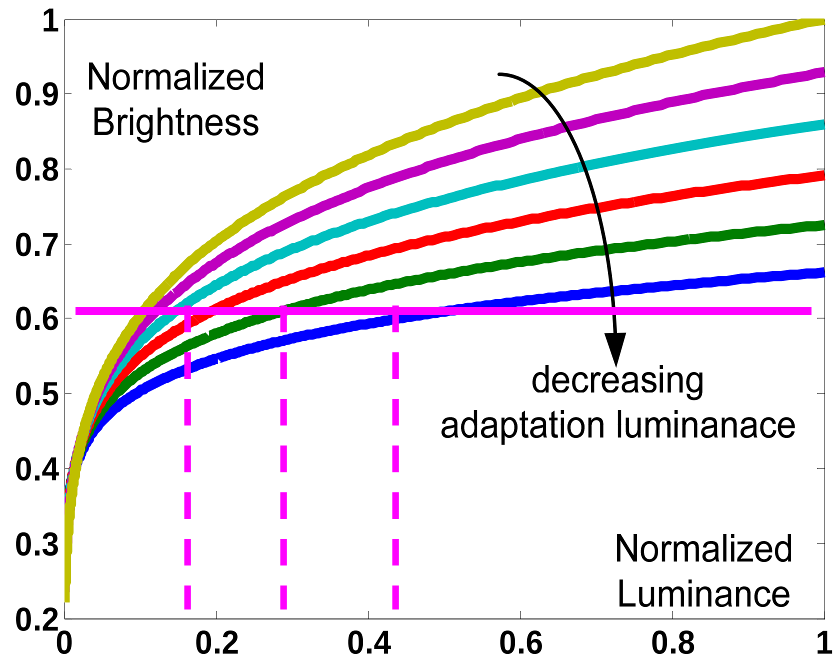
Brightness Perception

- In 1963, Stevens et al. devised the '*brils*' units to measure the subjective value of brightness, *B*
- One *bril* equals the sensation of brightness that is induced in a fully dark-adapted eye by a brief exposure to a 5-degree solid-angle white target of 1 micro-lambert luminance

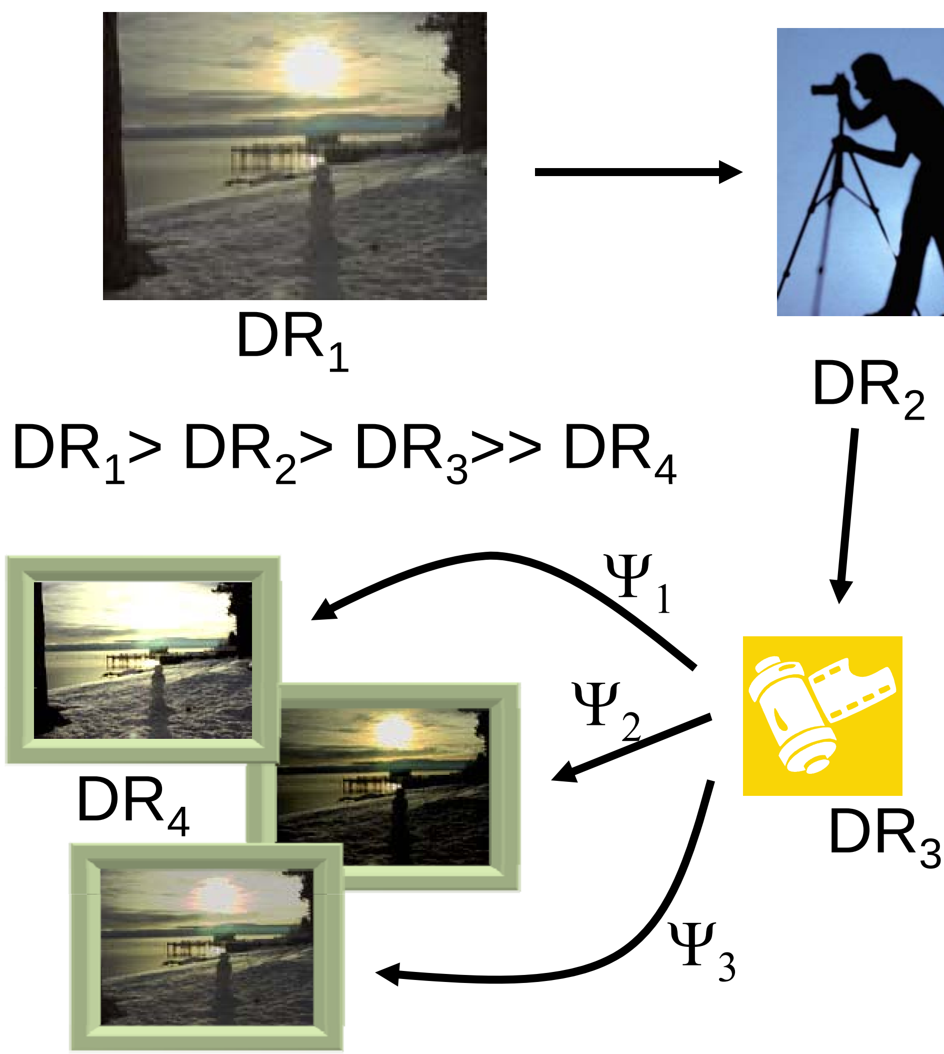
$$B = \lambda \cdot \left(\frac{L}{L_a} \right)^{\sigma}$$

$$\sigma = 0.4 \cdot \log_{10}(L_a) + 2.92$$

$$\lambda = 10^{2.0208} \times L_a^{0.336}$$



What is Tone Mapping



- The dynamic range of light that people experience in the real world is vast
- The range of light one can reproduce on prints spans at best about two orders of absolute dynamic range
- A classic photographic task is the mapping of the potentially high dynamic range of real world luminance to the low dynamic range of the photographic print
- how should one map measured/sensed scene luminance to print luminance, i.e. adopt Ψ_i, and produce a satisfactory picture?

Dynamic Tone Mapping for Backlight Scaling

- Key Idea:
  - The original and backlight scaled image are look similar if perceptible details are preserved; that is if,

$$\Delta L(L_a^{DTM}) = \Phi(\Delta L(L_a^{orig}))$$

L_a^{orig} : Adaptation level for orig. image

L_a^{DTM} : Adaptation level for DTM image

  - The pixel transformation function should consider the variations in human contrast sensitivity for different luminance values

$$\Phi(\chi^{orig}) = \kappa(L_a^{orig}, L_a^{DTM}) \cdot \left(\frac{\chi^{orig}}{L_a^{orig}} \right)^{\gamma(L_a^{orig}, L_a^{DTM})}$$

DTM (Cont.)

$$\Phi(\chi^{orig}) = \kappa(L_a^{orig}, L_a^{DTM}) \cdot \left(\frac{\chi^{orig}}{L_a^{orig}}\right)^{\gamma(L_a^{orig}, L_a^{DTM})}$$

$$\kappa(L_a^{orig}, L_a^{DTM}) = \left(\frac{1.219 + \left(L_a^{DTM}\right)^{0.4}}{1.219 + \left(L_a^{orig}\right)^{0.4}}\right)^{5/2}$$

Match the JND in

Original and

Backlight Scaled images

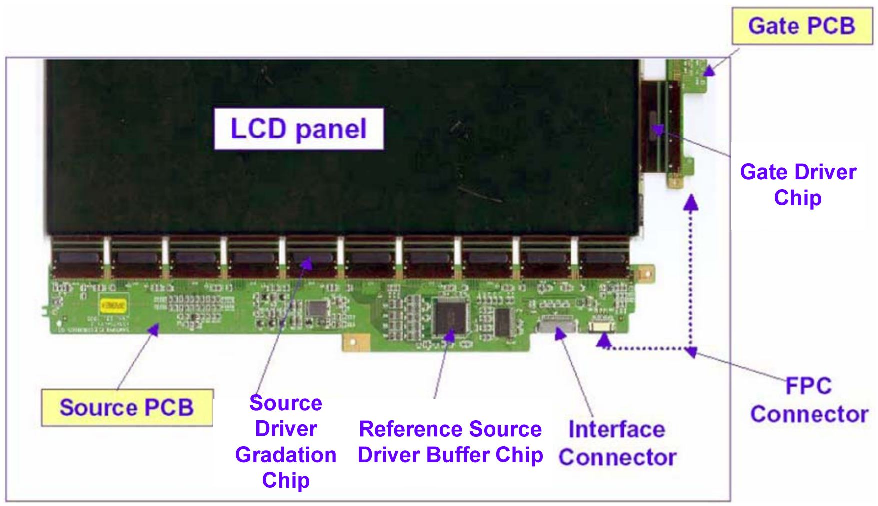
$$\gamma(L_a^{orig}, L_a^{DTM}) = \left(\frac{\sigma^{orig}}{\sigma^{DTM}}\right)$$

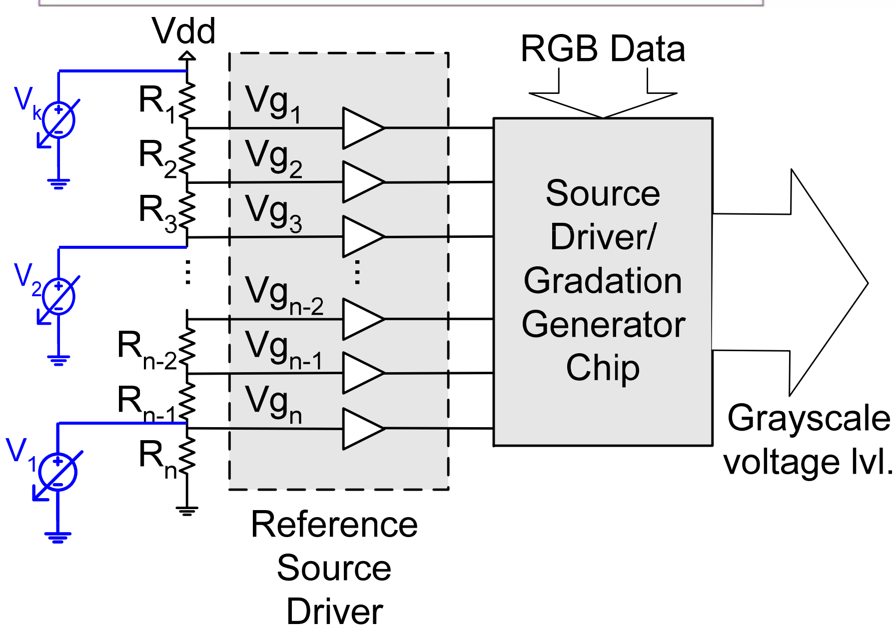
Change the scaling factor

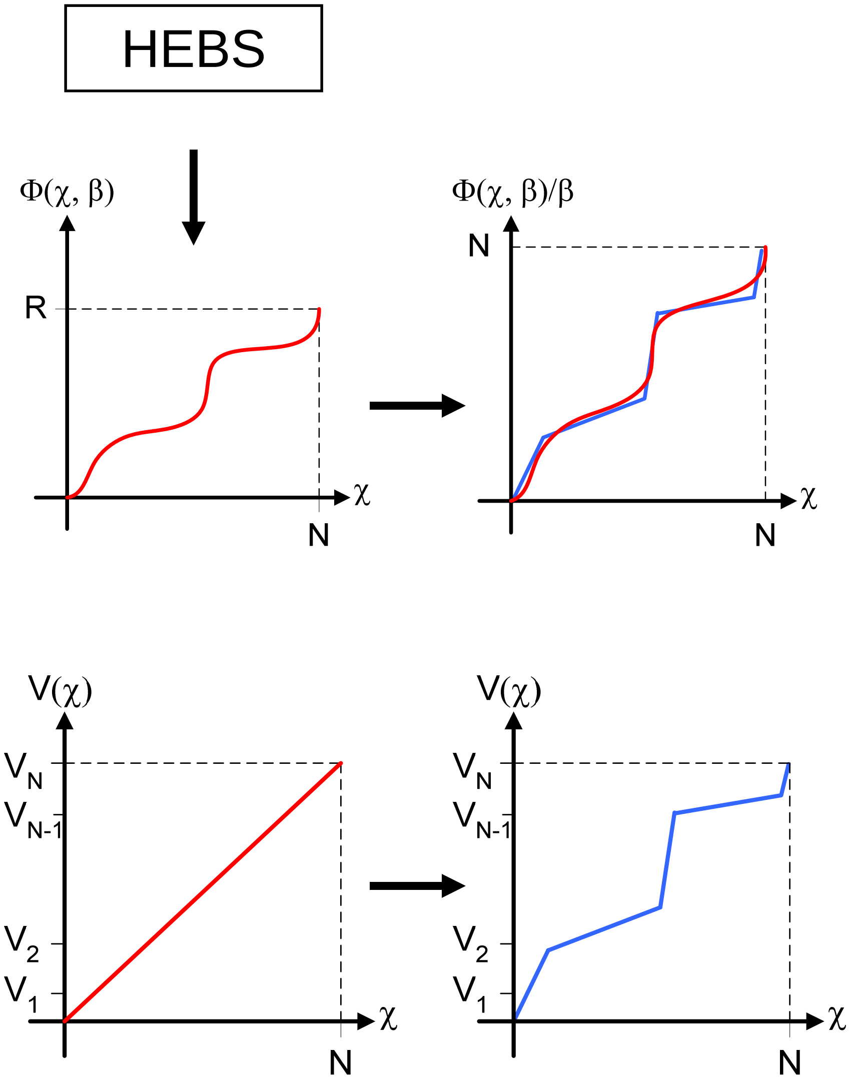
Based on the HVS's

Contrast sensitivity factor

DTM Implementation





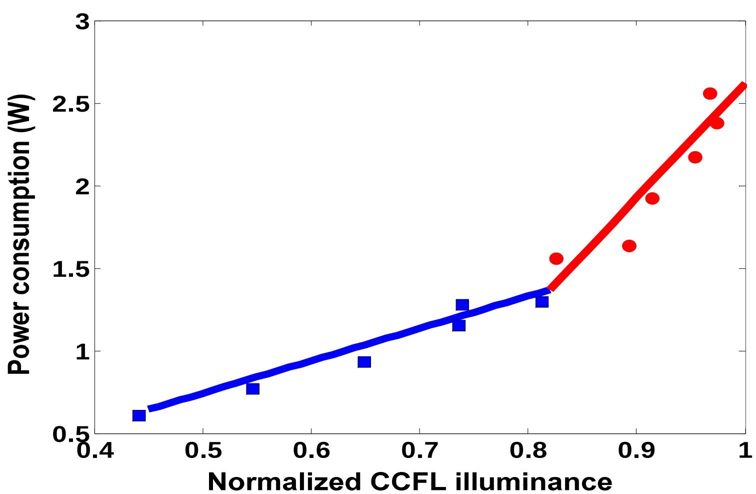


Energy Consumption Models

- CCFL power consumption for LG Philips TFT-LCD LP064V1,

$$P_{backlight}(\beta) = \begin{cases} A_{lin}.\beta + C_{lin} & 0 \le \beta \le C_s \\ A_{sat}.\beta + C_{sat} & C_s < \beta \le 1 \end{cases}$$

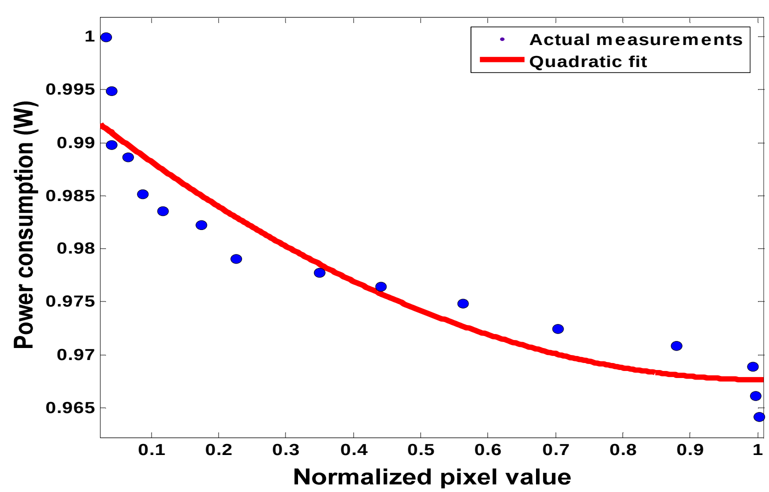
C_s=0.8234, A_{lin}=1.9600, C_{lin}=-0.2372, A_{sat}=6.9440, and C_{sat}= –4.3240



- TFT-LCD power consumption vs. transmittance *x*,

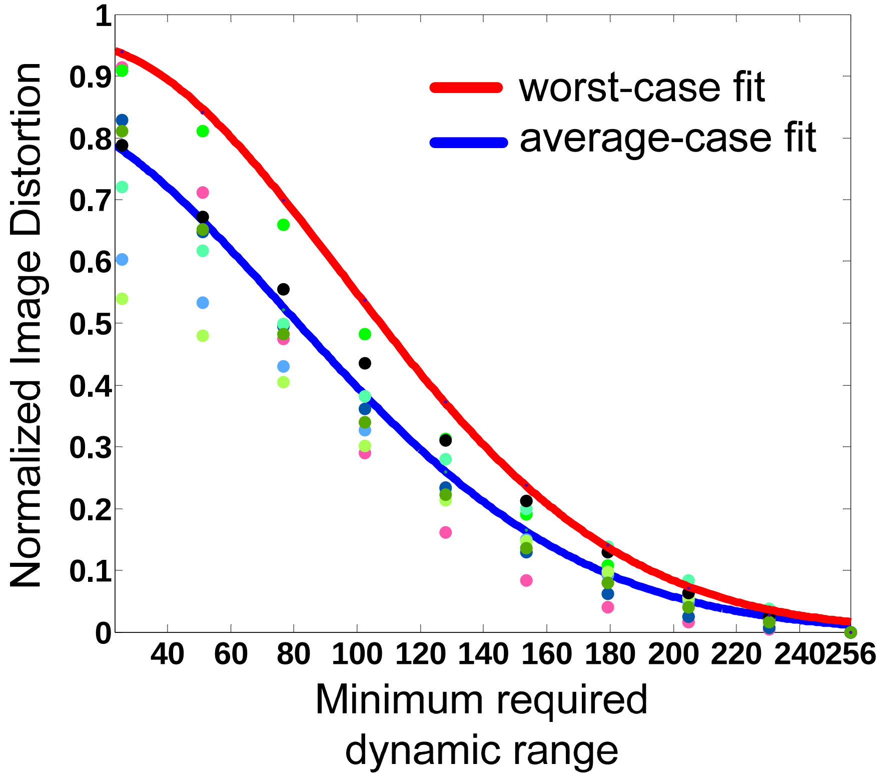
$$P_{TFT\ Panel}(x) = a.x^2 + b.x + c$$

a=0.02449, *b*= –0.04984, *c*=0.993

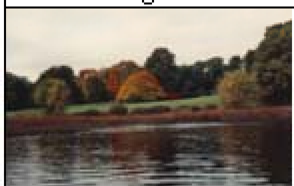
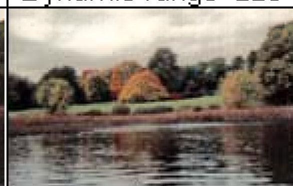
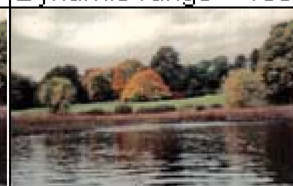
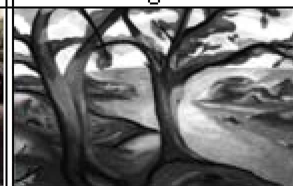
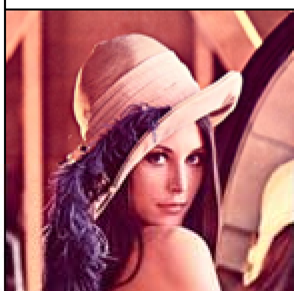
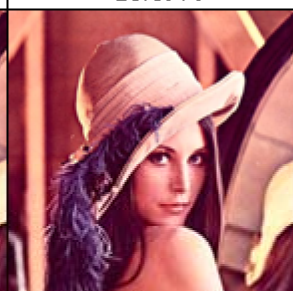
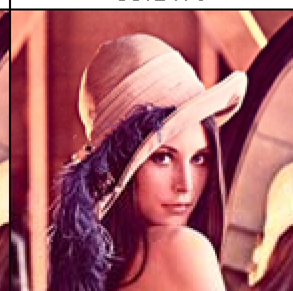
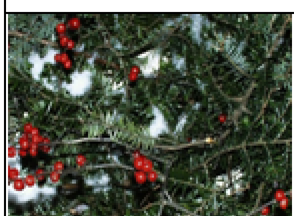
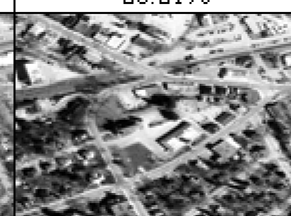
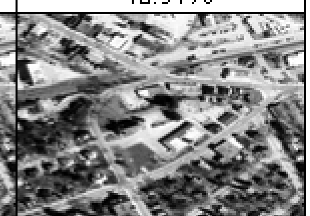


Experimental Setup

- *"Universal image quality index"* developed in NYU is used as our image distortion measure
- Benchmarks are from USC SIPI database



Experimental Results

Original	Dynamic range=220	Dynamic range = 100	Original	Dynamic range=220	Dynamic range = 100
					
Normalized power =1	Distortion=3.1% Power saving =26.19%	Distortion=8.2% Power saving =55.24%	Normalized power =1	Distortion=1.2% Power saving =29.38%	Distortion=6.3% Power saving =50.35%
					
Normalized power =1	Distortion=1.1% Power saving =27.16%	Distortion=7.4% Power saving =54.28%	Normalized power =1	Distortion=0.9% Power saving =26.21%	Distortion=5.1% Power saving =42.57%
					
Normalized power =1	Distortion=2.1% Power saving =30.30%	Distortion=5.5% Power saving =46.32%	Normalized power =1	Distortion=2.1% Power saving =25.15%	Distortion=10.2% Power saving =61.18%

Experimental Results (Cont.)

	Power saving (%)		
Name	**Distortion = 5%**	**Distortion = 10%**	**Distortion = 20%**
Lena	37.43	49.28	59.52
Autumn	35.16	49.20	61.53
football	36.62	45.85	55.57
Peppers	36.60	44.34	56.55
Greens	35.33	45.26	53.58
Pears	37.51	47.16	54.49
Onion	34.26	48.21	60.53
Trees	36.69	44.31	54.62
West	38.52	51.18	57.50
Pout	32.57	43.22	49.54
Sail	32.33	39.18	46.51
Average	35.88	46.16	54.38

Conclusions and Future Work

- Backlight scaling is an effective approach to energy saving in display subsystems
- Simulation results show up to 70% energy saving, approx. 25% system wide energy saving
- Future Work
  - Relax the assumptions of DBS problem
  - Apply and study the tradeoffs of Adaptive Tone Mapping Techniques
  - Application of DTM to video streams
  - Survey and study of other display devices and technologies