

Lab 2

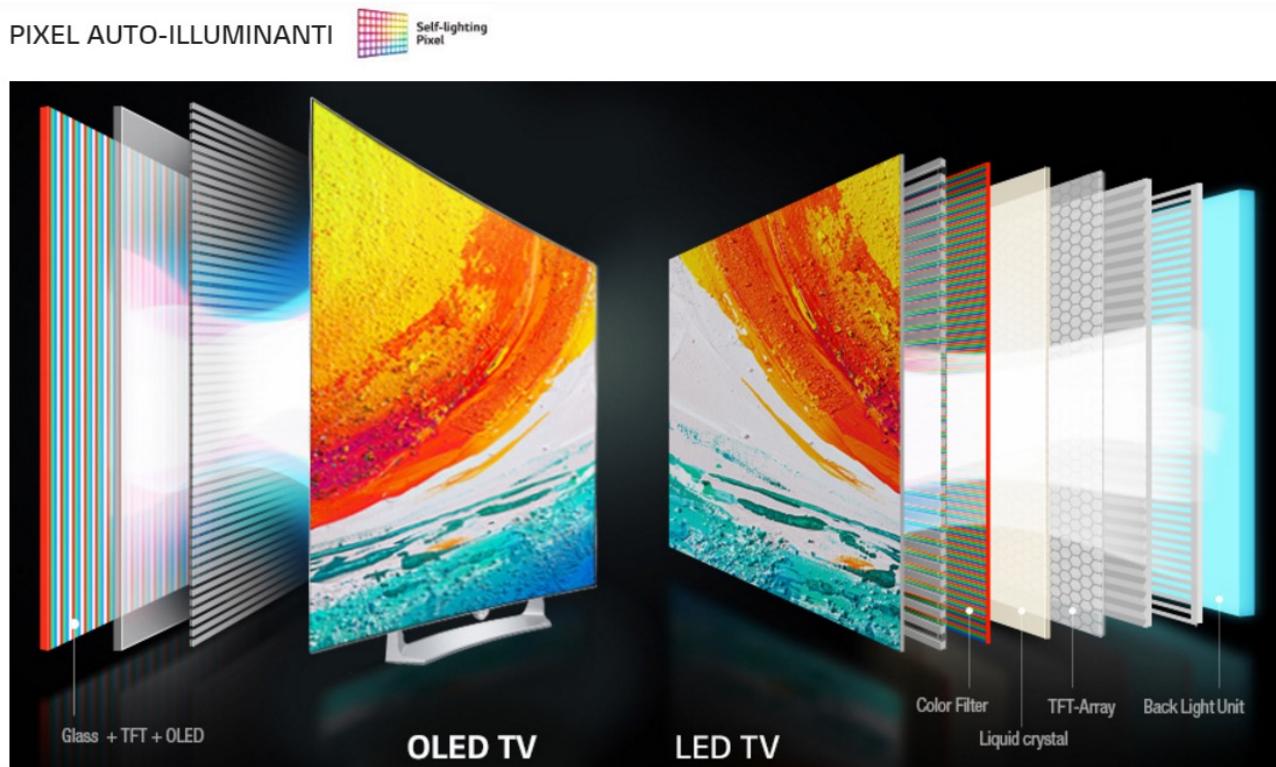
Energy Efficient Displays

Objective and organization

- Demonstrates how manipulation of an image can be used to tradeoff image quality and power saving in emissive displays
 - 1 report – 2 days
 - Matlab
- Organize all implemented methods in functions and scripts to **automatically** test and evaluate all images and all techniques

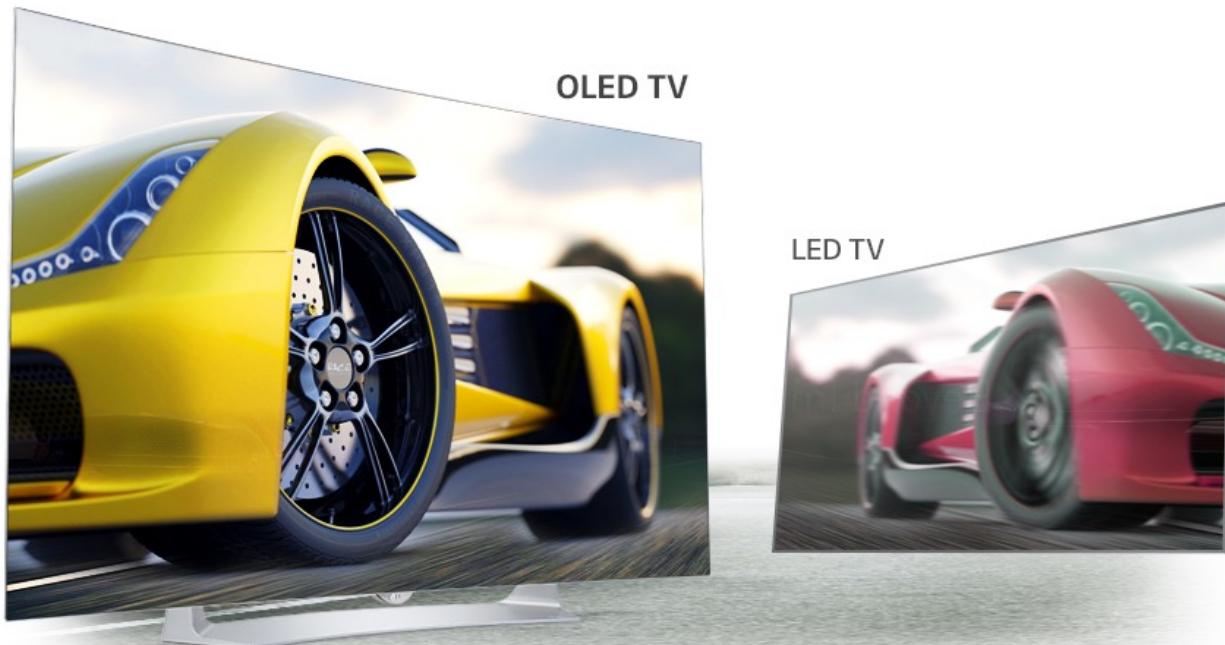
OLED vs LED

- OLED TVs
 - Do not require external lighting
 - Better black levels



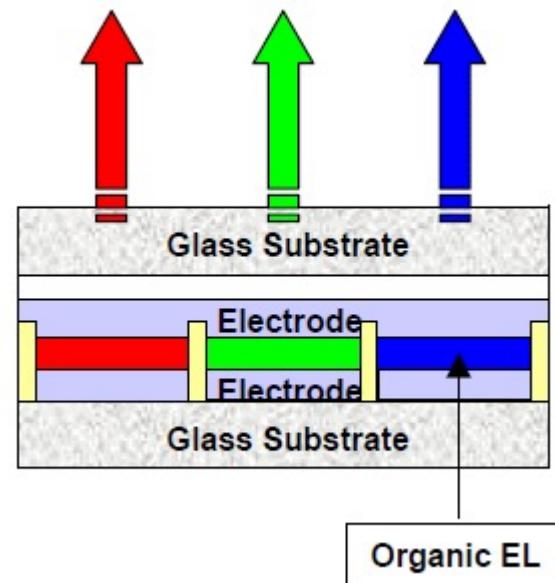
OLED vs LED

- OLED TVs
 - Pixels are independent from each other
 - More sense of depth
 - Higher contrast makes images more realistic



OLED

- Interesting case study from our perspective...
- Organic light-emitting diode (OLED)
 - Do not require external lighting
 - Pixels are emissive
 - Emissive layer is a film of organic compound which *emits light in response to an electric current*
- Each pixel is made of three devices corresponding to red, green and blue components



OLED

- In LCDs, backlight dominates power consumption and color has only negligible power impact
- With OLED displays, the color of a pixel impacts on power consumption
 - E.g., hungry blue
 - Different luminance efficacies
 - Different images imply different power consumption



Day 1

**Energy efficient image
processing**

OLED

- Power consumption depends on color components of a pixel...
 - So we can save power by changing the spectrum of the image!
 - First class of power saving methods:
 - Change pixel color
 - Given a certain tolerance level on color distortion

Assignment 2 - Part 1



Compute power consumption

Apply image transformation



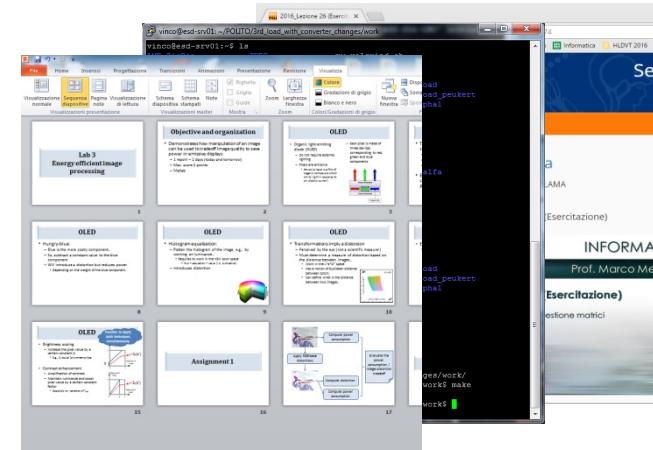
Compute distortion

Compute power consumption

Evaluate the power consumption / image distortion tradeoff

1. Identification of images

- Test images will be:
 - The images from the USC SIPI database
 - <http://sipi.usc.edu/database/database.php?volume=misc>
 - The images from the BSDS500 training set
 - http://www.eecs.berkeley.edu/Research/Projects/CS/vision/grouping/BSR/BSR_bsds500.tgz
 - 5 images representing screenshots of your computer
- Different colors and characteristics...



2. Manipulation of images

- Experiments require to adopt different color spaces...
- **TASK:** Learn how to:
 - Import the image
 - `imread()` function
 - Extract the R, G, B channels
 - Convert between different color spaces
- Refer to:
 - <http://it.mathworks.com/help/images/index.html>



Documentation

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Documentation

Image Processing Toolbox

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- › GPU Computing



Image Processing Toolbox

R2014b

Perform image processing, analysis, and algorithm development

[Getting Started](#) [Examples](#) [Release Notes](#)

› Import, Export, and Conversion

Image data import and export, conversion of image types and classes

› Display and Exploration

Interactive tools for image display and exploration

› Geometric Transformation, Spatial Referencing, and Image Registration

Scale, rotate, perform other N-D transformations, provide spatial information, align images using automatic or control point registration

› Image Enhancement

Contrast adjustment, morphological filtering, deblurring, and other image enhancement tools

› Image Analysis

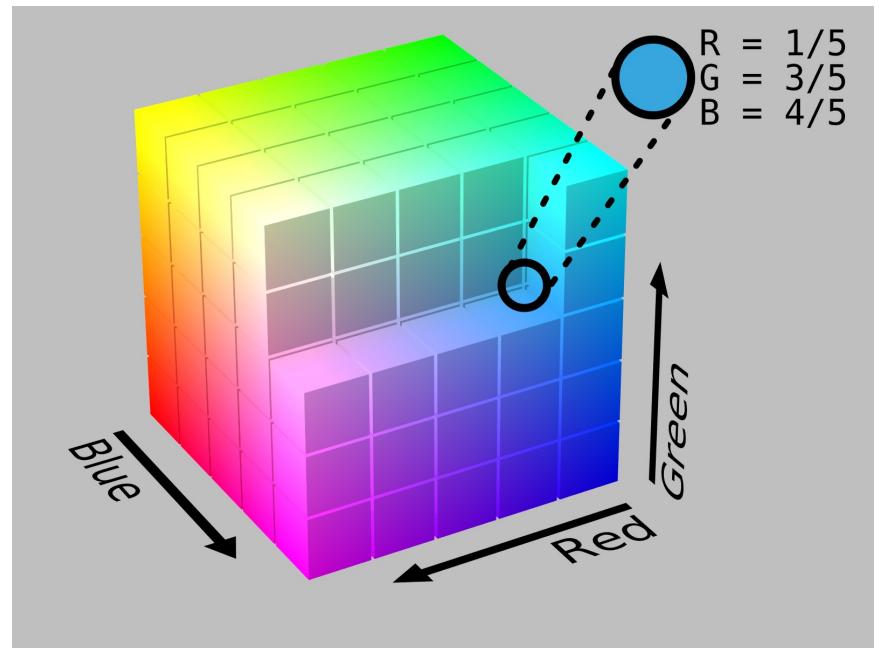
Region analysis, texture analysis, pixel and image statistics

Color

Color space conversions, support for International Color Consortium (ICC) profiles

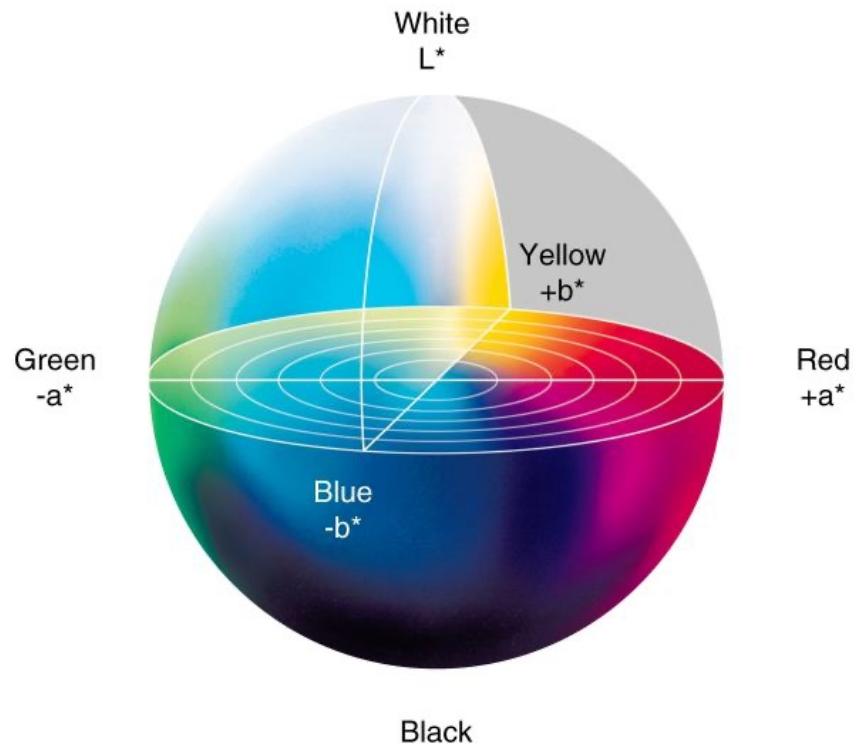
2. Manipulation of images

- RGB
 - Additive color space
 - All possible colors that can be made from three colorants for red, green and blue
 - Stores individual values for red, green and blue
 - Convenient color model for computer graphics as it is similar to the human visual system
 - Used in LCDs



2. Manipulation of images

- Lab
 - One channel for luminance (L) and two color channels (a and b)
 - Includes all perceivable colors
 - Super-set of RGB
 - The space is a three-dimensional Real number space
 - Allows the definition of Euclidean distance

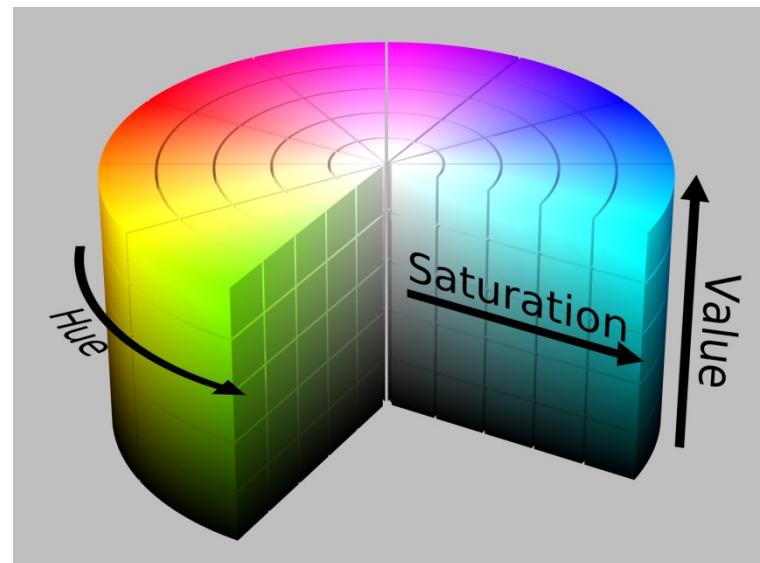


the difference between two images in this space is more similar to the difference we can appreciate using our eyes

2. Manipulation of images

- HSV
 - Hue
 - Perceived color
 - Saturation
 - Colorfulness, amount of white component
 - Value
 - Brightness
 - Cylindrical-coordinate representations of points in an RGB color model
 - Widely used in computer graphics

we will use this space





Compute power consumption

Apply image transformation



Compute distortion

Compute power consumption

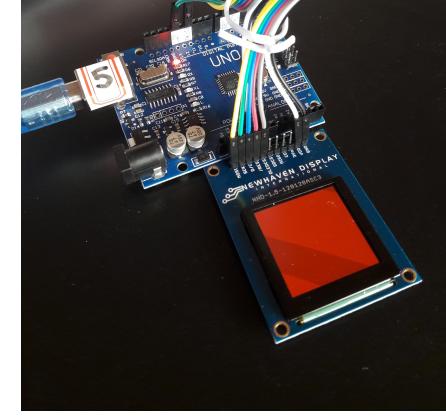
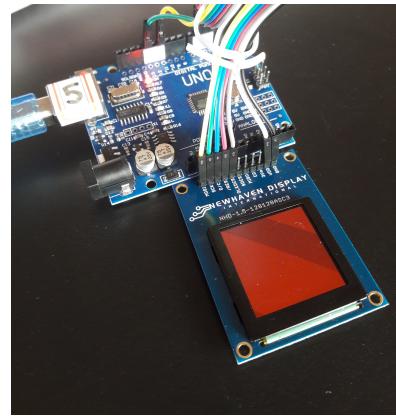
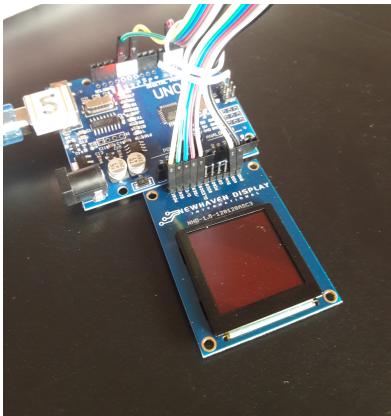
Evaluate the power consumption / image distortion tradeoff

3. Evaluation of power consumption

- Power model
 - $P_{pixel} = f(R) + h(G) + k(B)$
 - Depends on pixel color in terms of RGB components
 - f, h and k determined experimentally by:
 - Setting black screen to estimate C
 - For f, set G and B components to 0 and vary R component
 - Similar for h and k
 - $P_{image} = C + \sum_{i=1}^n \{f(R_i) + h(G_i) + k(B_i)\}$
 - Sums up power contributions of single pixels
 - C static power independent of pixel values

1. Evaluation of power consumption

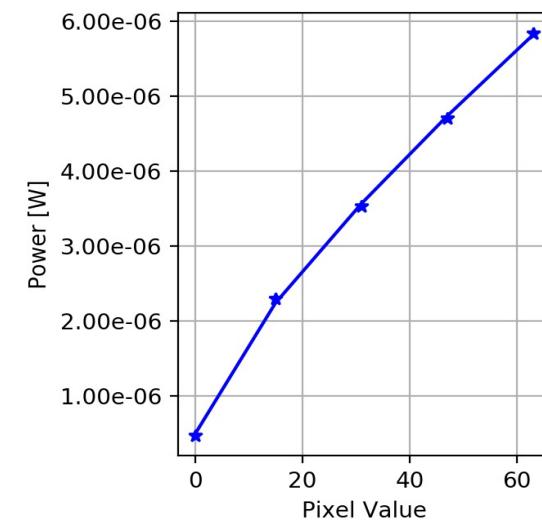
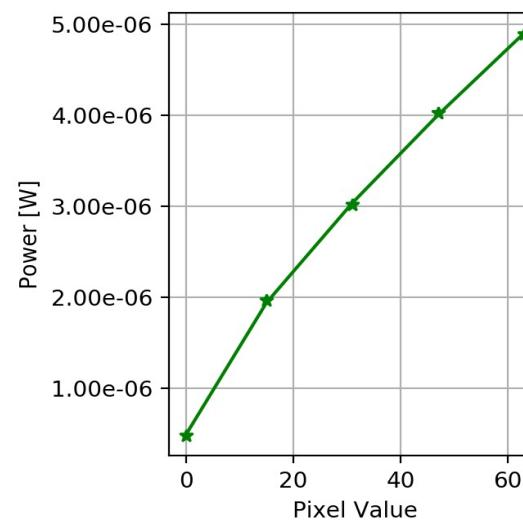
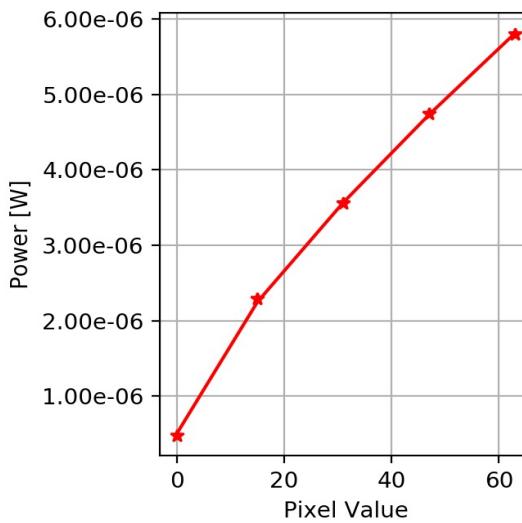
- Experimental Setup:
 - Show monochromatic images with different RGB values on the OLED, e.g.:



- Measure power supply current (and convert to power)

1. Power model for the provided OLED (cont'd)

- Interpolation:
 - Find regression model type that fits best the data and determine the corresponding parameters



- For this Lab, we used a model format from literature (see next slide)

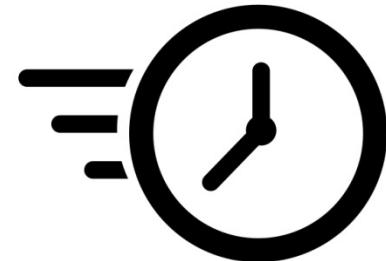
Assignment 2 – Part 1

- **TASK:** Define a MATLAB function that estimates power consumed to display an image

- $$- P_{pixel} = w_R * R^\gamma + w_G * G^\gamma + w_B * B^\gamma$$

- $$- P_{image} = w_0 + \sum_{i=1}^n \{P_i(R, G, B)\}$$

- $- R, G, B$ are pixel values between 0 and 255



γ	w_0	w_R	w_G	w_B
0.7755	$1.48169521 \times 10^{-6}$	$2.13636845 \times 10^{-7}$	$1.77746705 \times 10^{-7}$	$2.14348309 \times 10^{-7}$



Compute power consumption

Apply image transformation



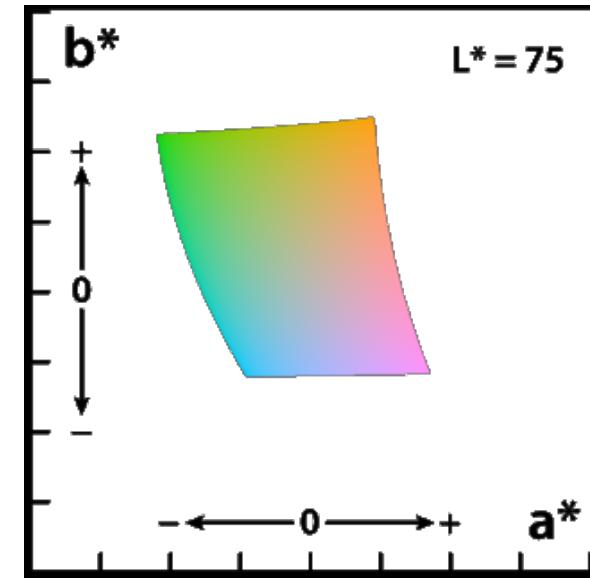
Compute distortion

Compute power consumption

Evaluate the power consumption / image distortion tradeoff

4. Evaluation of image distortion

- Transformations imply a distortion
 - Must determine a measure of distortion based on the *distance* between images...
 - We will work in the $L^*a^*b^*$ space
 - Has a notion of Euclidean distance between colors that well matches the perceived distortion
 - Can define what is the distance between two images..
 - Importantly, distortion is different from perceived **visual quality**, which is subjective, not a scientific measure!

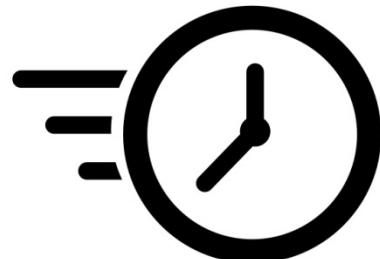


4. Evaluation of image distortion

- Evaluation of image distortion
 - Difference between two images
 - $\varepsilon(image_i, image_j) = \sqrt{\sum_{k=1}^N ((L_{i,k} - L_{j,k})^2 + (a_{i,k} - a_{j,k})^2 + (b_{i,k} - b_{j,k})^2)}$
 - N = number of pixels
 - k = kth pixel
 - Pixel per pixel, compute the difference of L, a and b components between the two images

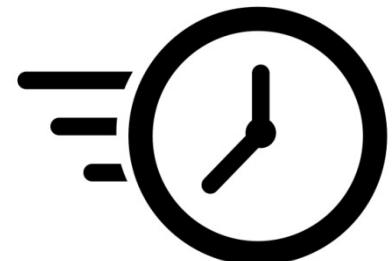
Assignment 2 – Part 1

- **TASK:** Define a MATLAB function that estimated the distortion w.r.t. the original image
 - $\varepsilon(image_i, image_j) = \sqrt{\sum_{k=1}^N ((L_{i,k} - L_{j,k})^2 + (a_{i,k} - a_{j,k})^2 + (b_{i,k} - b_{j,k})^2)}$
 - Work in the L*a*b* space and compute the Euclidian distance pixel per pixel
 - Convert by using MATLAB's `rgb2lab()` and `lab2rgb()` functions



Assignment 2 – Part 1

- Easier to reason in terms of **percentage** distortion
 - E.g., distortion of new image w.r.t. distortion between a ~~black and a white~~ two different images image
 - $dist = \frac{\varepsilon(image_{new}, image_{orig})}{W*H*\sqrt{(100^2+255^2+255^2)}} \cdot 100 \quad (\%)$
because luminance is in 2's complement in lab





Compute power consumption

Apply image transformation



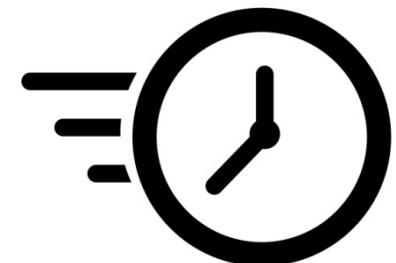
Compute distortion

Compute power consumption

Evaluate the power consumption / image distortion tradeoff

Assignment 2 – Part 1

- **TASK:** Experiment with various **image manipulation strategies** to reduce power consumption:
 - Pixel-wise transformations
 - Work on colors
 - Histogram equalization sometimes it is saving power, sometimes no...do something more after
 - Work on luminance (requires HVS color space)
 - Other types of brightness/contrast modifications



Assignment 2 – Part 1

- Apply each transformation **to all images!**
 - In your report, show (and comment) summary tables. For example:
 - Average, standard deviation, mean, max of power saving
 - Average, standard deviation, mean, max of distortion
 - Moreover, show (and comment) **some representative examples** of transformations outputs
 - E.g., the images for which you get most/least saving/distortion.
 - Do **not** include 50 pictures for each transformation in the report!!

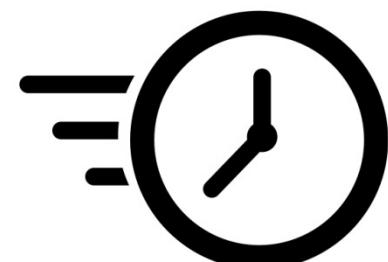


Image Transformations

- **Hungry-blue:**
 - Blue is the more costly component..
 - So, subtract a constant value to the blue component
 - Will introduce a distortion but reduces power
 - Depending on the weight of the blue component
- **Histogram equalization:**
 - Flatten the histogram of the image, e.g., by working on luminance...
 - Requires to work in the HSV color space
 - Hue – saturation – value (i.e., luminance)
 - Introduces distortion. What about power?
- **Other types of brightness/contrast transformations:**
 - E.g. Convert to HSV and scale the value component ($V \rightarrow k^*V$ with $k < 1$) or do some more complex transformation
 - **Use your creativity!!!**



Compute power consumption

Apply image transformation



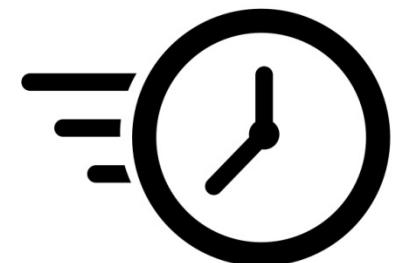
Compute distortion

Compute power consumption

Evaluate the power consumption / image distortion tradeoff

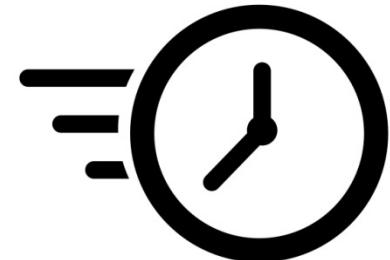
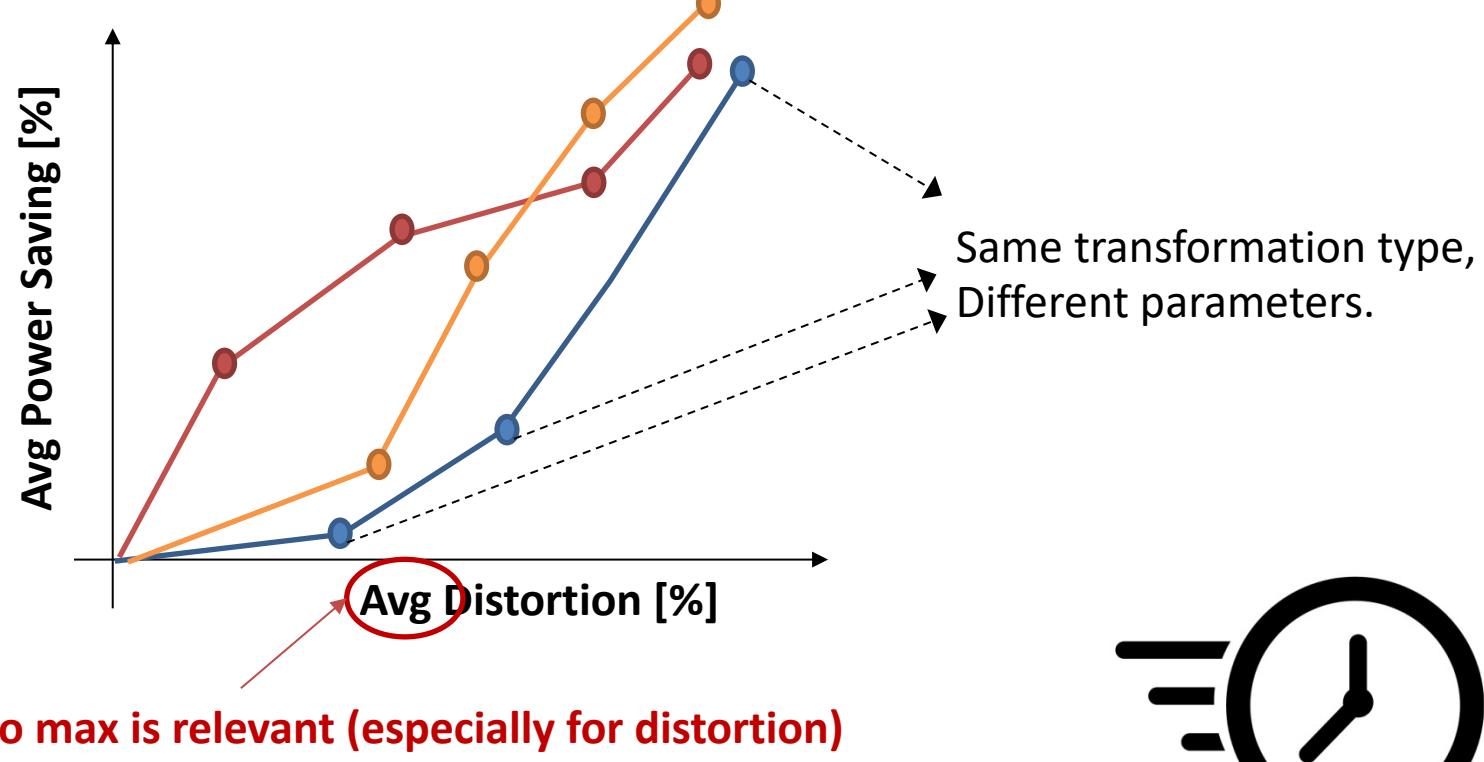
Assignment 2 - Part 1

- Analyse power/distortion tradeoff
 - Do different images behave differently?
 - What changes in terms of power consumption with different manipulation strategies?
 - How can I save more power with lower distorsions?
 - Etc.



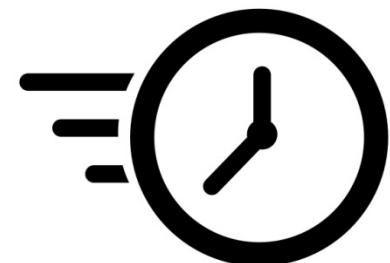
Assignment 2 - Part 1

- Example: Pareto curve



Assignment 2 - Part 1

- Compare the transformations you applied and find the solution that:
 - **Minimizes the average power consumption** (i.e., maximizes avg power saving)
 - Under an **average distortion** constraint (e.g., avg distortion smaller than 1%, 5%, 10%)



Assignment 2 - Part 1

- Example:
 - Blue reduction
 - Power saving
29.11%
 - Distortion
30.99%
 - Histogram equalization
 - Power saving
11.99%
 - Distortion
8.46%



Original image



After blue reduction



After histogram equalization

Day 2

Dynamic Voltage Scaling

Dynamic Voltage Scaling of OLEDs

- Power consumption of OLEDs depends only on pixels...
 - No back light
 - Pixels are emissive, i.e., emits light in response to an electric current
- ... and pixels power consumption depends on:
 - Displayed colors
 - Hungry blue / low power green
 - **Input current**



DVS for OLEDs

- Supply voltage is set to maximum to support full luminance of pixel
 - But maximum luminance may not be necessary
- Dynamic Voltage Scaling
 - Scale the supply voltage
 - Reduces maximum current that can flow
 - Saves power
 - Note that reducing current implies changing the RGB color of some pixels!
 - Sacrifice image quality for power saving

DVS for OLEDs

- Effects of DVS
 - Reducing current implies changing the RGB color of pixels!
 - Emitted color strictly depends on input current
 - Reduced voltage → reduced current through some pixels

ORIGINAL
IMAGE



SIMULATED
VOLTAGE SCALING



DVS for OLEDs

- Effects of DVS
 - Sacrifice image quality for power saving
 - Reduced color luminance
 - Color distortion in displayed images
 - Saved power

ORIGINAL
IMAGE



SIMULATED
VOLTAGE SCALING
APPROX. 20%
POWER SAVING



DVS for OLEDs

- Can compensate the image distortion by applying an image compensation
 - E.g., working on image luminance



Original image



Effect of voltage scaling



Effect of image compensation + voltage scaling

Assignment 2 – Part 2



1

Compute power consumption

Evaluate the power consumption / image distortion tradeoff

3

Modify luminance
(brightness/contrast/
both)

2

Apply DVS
(displayed_image)

Compute distortion

Compute power consumption



Apply DVS
(displayed_image)

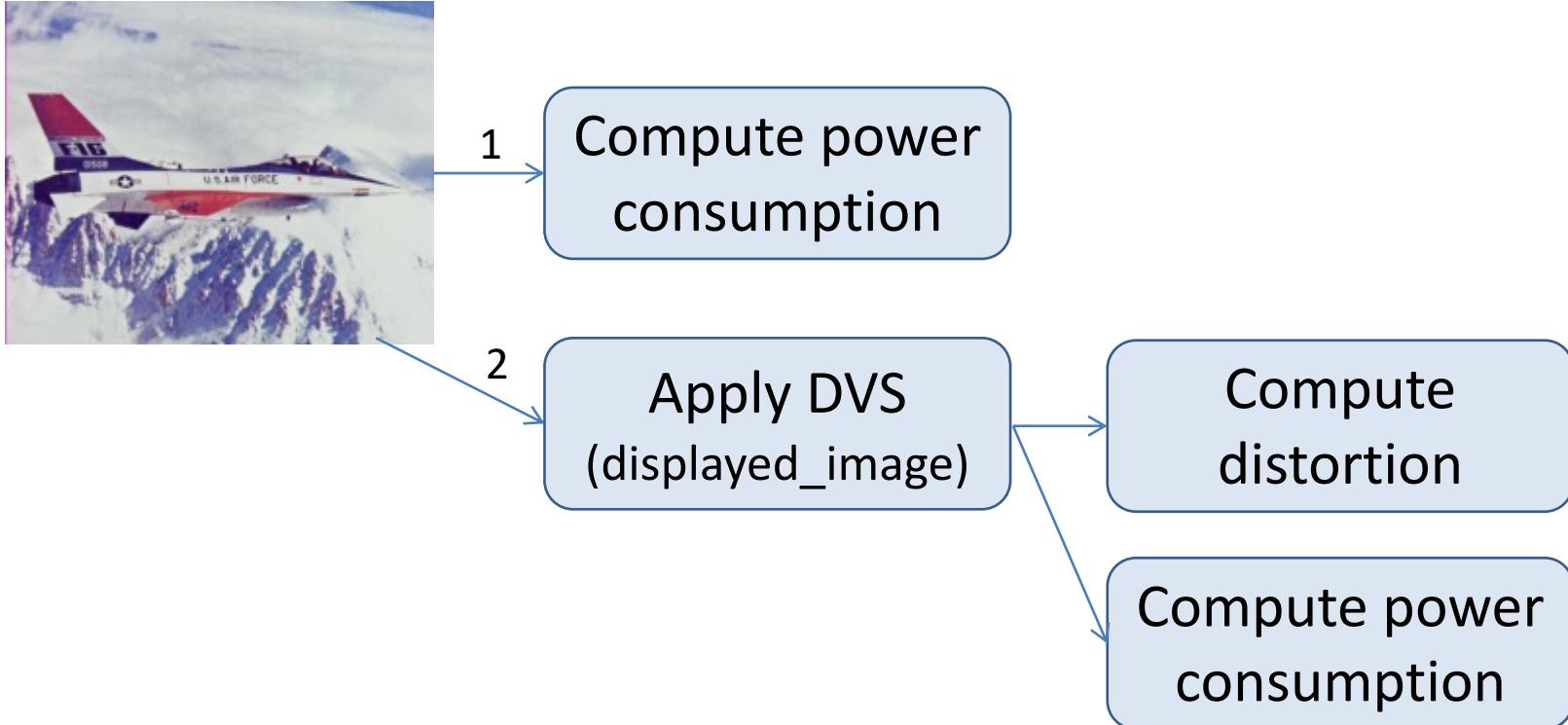
Compute distortion

Compute power consumption



1

Compute power
consumption





1

Compute power consumption

2

Apply DVS
(displayed_image)

Modify luminance
(brightness/contrast/
both)

Compute distortion

Compute power consumption



3

Apply DVS
(displayed_image)

Compute distortion

Compute power consumption



1

Compute power consumption

Evaluate the power consumption / image distortion tradeoff

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Modify luminance
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Apply DVS
(displayed_image)

Compute distortion

Compute power consumption



Apply DVS
(displayed_image)

Compute distortion

Compute power consumption

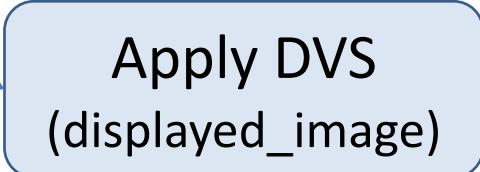


1



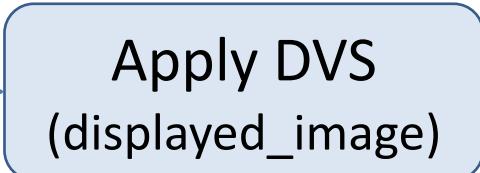
Evaluate the power consumption / image distortion tradeoff

2

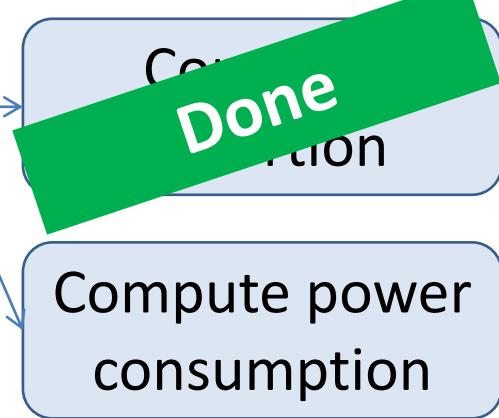


Modify luminance
(brightness/contrast/
both)

3



Compute power consumption



Assignment 2 - Part 2: How To



1

Compute power consumption

Evaluate the power consumption / image distortion tradeoff

3

Modify luminance
(brightness/contrast/
both)

2

Apply DVS
(displayed_image)

Compute distortion

Compute power consumption



Apply DVS
(displayed_image)

Compute distortion

Compute power consumption

1. Cell current calculation and evaluation of power consumption

- Given the RGB color of each pixel, determine current flowing through the cell

$$I_{cell} = \frac{p_1 V_{dd} D_{RGB}}{255} + \frac{p_2 D_{RGB}}{255} + p_3 \quad [mA]$$

D_{RGB} is the RGB color value of current pixel

- Determine power consumption
 - Different (less accurate) model w.r.t. the one used in Part 1**, but expressing dependency from DVS

$$P_{panel} = V_{dd} \sum_{i=1}^W \sum_{j=1}^H I_{cell(i,j)} \quad [mW]$$

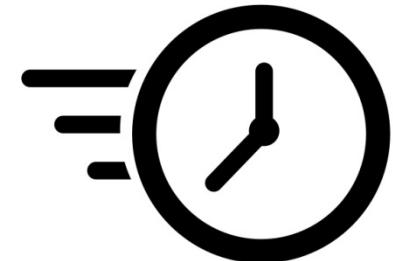
Assignment 2 – Part 2

- **TASK:** Implement the new current and power models

$$- I_{cell} = \left(\frac{p_1 V_{dd} D_{RGB}}{255} \right) + \left(\frac{p_2 D_{RGB}}{255} \right) + p_3 \quad [mA]$$

- $p_1 = +4.251\text{e-}05$
- $p_2 = -3.029\text{e-}4$
- $p_3 = +3.024\text{e-}5$
- Default $V_{dd} = 15V$

Better to have two separate functions (see later)



$$- P_{panel} = V_{dd} \sum_{i=1}^W \sum_{j=1}^H I_{cell(i,j)} \quad [mW]$$

also: sum of all R,G,B components



1

Compute power consumption

Evaluate the power consumption / image distortion tradeoff

3

2

Modify luminance
(brightness/contrast/
both)



Apply DVS
(displayed_image)

Compute distortion

Compute power consumption

Apply DVS
(displayed_image)

Compute distortion

Compute power consumption

2. Application of voltage scaling

- Voltage supply determines the maximum current that can flow in the OLED
 - Current value → pixel color
- Effect simulated by the function $mode$ ALWAYS 1
 - Given an image as the matrix of currents corresponding to pixels
 - Applies voltage scaling with the specified V_{dd}
 - **This function is provided. You don't have to implement it.**
 - Try example.m in the test code

2. Application of voltage scaling

- Effect simulated by the *displayed_image()* function
 - Computes the maximum current that can flow with the new V_{dd}
 - Determines the corresponding maximum RGB value RGB_{max}
 - Any RGB value higher than RGB_{max} is saturated to RGB_{max}

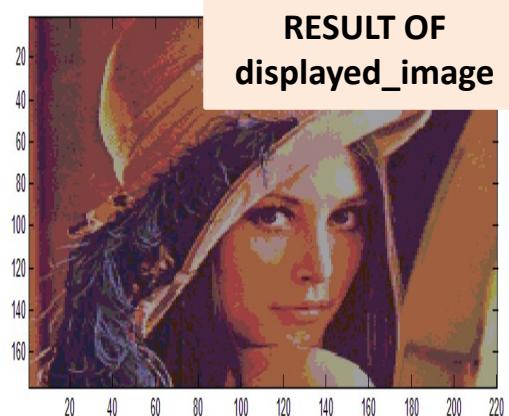
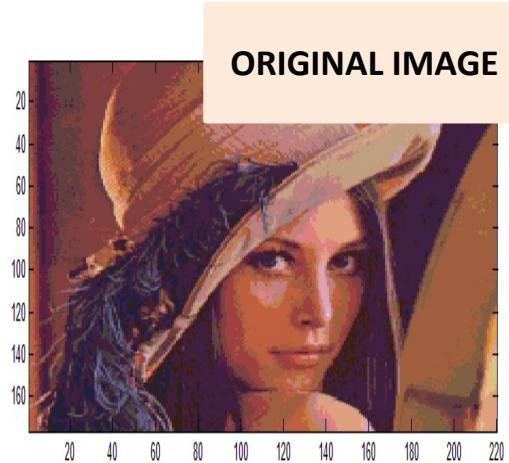
2. Application of voltage scaling

- Given
 - $I_{cell} = \left(\frac{p_1 V_{dd} D_{RGB}}{255} \right) + \left(\frac{p_2 D_{RGB}}{255} \right) + p_3$
- The maximum current given V_{dd} is:
 - $I_{max} = \left(\frac{p_1 V_{dd} [255 255 255]}{255} \right) + \left(\frac{p_2 [255 255 255]}{255} \right) + p_3$
- ...and the maximum RGB that can be displayed without distortion is:
 - $RGB_{max} = \frac{(I_{max} - p_3) 255}{p_1 V_{dd} + p_2}$
 - Whenever $I_{cell} > I_{max}$ the pixel is assigned RGB value RGB_{max}
 - Saturate to the maximum RGB value that can be generated given V_{dd}

2. Application of voltage scaling

- Note: the image RGB values do not actually change!
 - What changes is the *effect* on the display
 - *displayed_image()* function simulates this effect

we can act only BEFORE calling this function!!!



2. Image after voltage scaling

```
function out = displayed_image(I_cell, Vdd, mode)

SATURATED = 1;
DISTORTED = 2;

p1 = 4.251e-05;
p2 = -3.029e-04;
p3 = 3.024e-05;
Vdd_org = 15;                                Maximum current that can
                                                flow with reduced voltage

I_cell_max = (p1 * Vdd * 1) + (p2 * 1) + p3;    image_RGB_max = (I_cell_max - p3)/(p1*Vdd_org+p2) * 255;    out = round((I_cell - p3)/(p1*Vdd_org+p2) * 255);    Maximum RGB value that can be
                                                represented (lower than 255)

if (mode == SATURATED)
    out(find(I_cell > I_cell_max)) = image_RGB_max;    Matrix of RGB values of the original
                                                image (given the currents)

else if (mode == DISTORTED)
    out(find(I_cell > I_cell_max)) = round(255 - out(find(I_cell > I_cell_max)));
end
end
end
```

Saturates to max RGB value
(Focus on this mode!)



1

Compute power consumption

Evaluate the power consumption / image distortion tradeoff

3

Modify luminance
(brightness/contrast/
both)

2

Apply DVS
(displayed_image)

Compute distortion

Compute power consumption



Apply DVS
(displayed_image)

Compute distortion

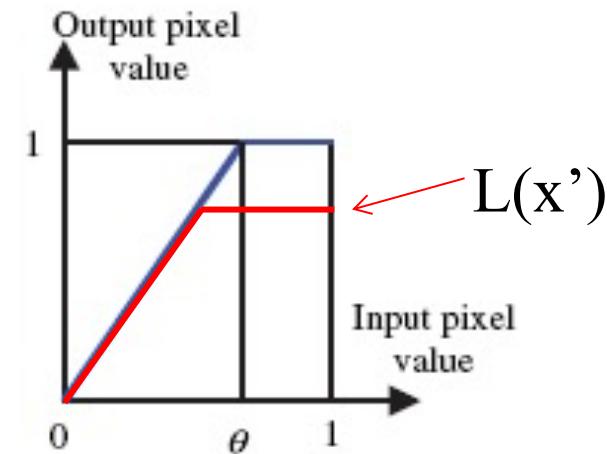
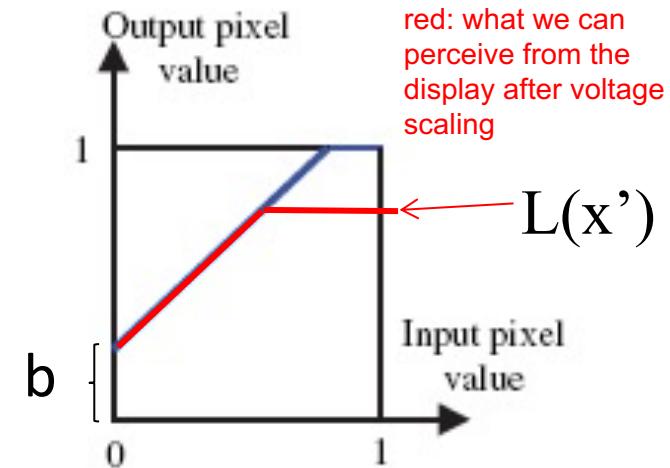
Compute power consumption

3. Apply image compensation

- Want to improve quality of resulting image
 - Apply some techniques **before** DVS!
 - Enhance brightness/contrast of image
- The goal is to increase the perceived image quality!

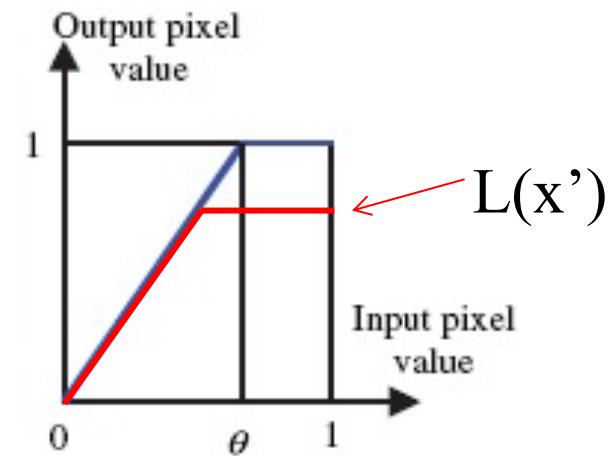
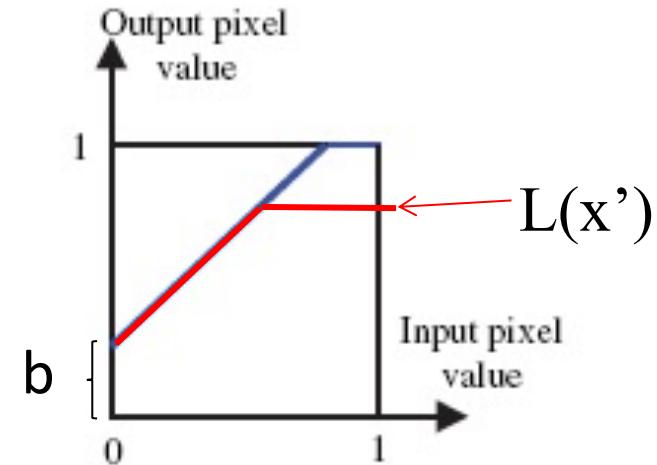
3. Apply image compensation

- Brightness scaling
 - Increase the pixel values by a certain constant b
 - E.g., b equal to luminance loss
 - $V' = v + b$
- Contrast enhancement
 - Amplification of contrast
 - $V' = V * b$
 - Multiply pixel values by a certain constant factor
 - Depends on variation of V_{dd}



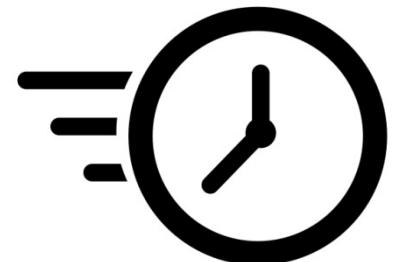
3. Apply image compensation

- Implemented in the HSV space
- You can determine the factor b as dependent from the original V_{dd} and new (scaled) V_{dd}
 - Brightness compensation
 - $V' = V + b$
 - $b(V_{dd} \text{ original}, V_{dd} \text{ new})$
 - Contrast enhancement
 - $V' = V * b$
 - $b(V_{dd} \text{ original}, V_{dd} \text{ new})$
 - Application of both



Assignment 2 – Part 2

- **TASK:** Experiment with various **image compensation strategies:**
 - Brightness scaling
 - Contrast enhancement
 - Combined BS + CE
 - Others... (**again, use your creativity!**).





1

Compute power consumption

Evaluate the power consumption / image distortion tradeoff

3

Modify luminance
(brightness/contrast/
both)

2

Apply DVS
(displayed_image)

Compute distortion

Compute power consumption



Apply DVS
(displayed_image)

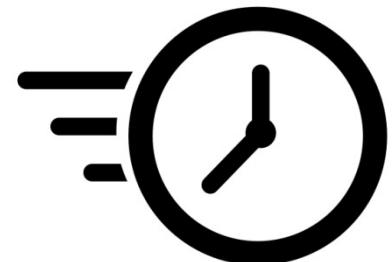
Compute distortion

Compute power consumption

this is more distorted wrt the one just with voltage scaling, but the quality is higher for the user

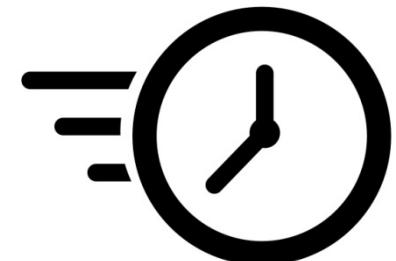
Assignment 2 - Part 2

- Compare the different DVS + image compensation strategies
 - With respect to part 1, you have a new «free variable» → **The DVS voltage**



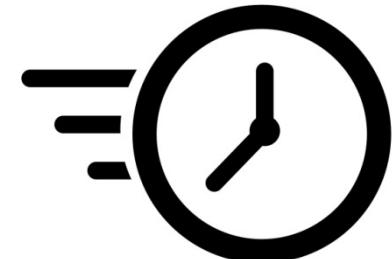
Assignment 2 - Part 2

- The goal becomes «*find optimal supply voltage and compensated image*» to:
 - Minimize power consumption
 - Maximize **perceived visual quality**
- **Important:** image compensations will typically *increase* the distortion.
 - Remember: **visual quality** is different from **distortion!**
 - But the former is only qualitative...



Assignment 2 - Part 2

- So, what you can do, is:
 - Impose a maximum distortion constraint (e.g., 1%, 5%, 10%), as in Part 1
 - Use the LAB distance for distortion, as in Part 1
 - Among the (V_{DD} , compensation) pairs that meet this constraint, select the one that *in your opinion* yields the *best-quality* images
 - **Of course, this is subjective!!!**



Assignment 2 - Part 2

- Apply the overall flow to all images!
 - Automatically, with a script

