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Minds in Motion

A Look at the Algorithms and Tuning that Enable the DaVinci™ Technology Image Pipeline

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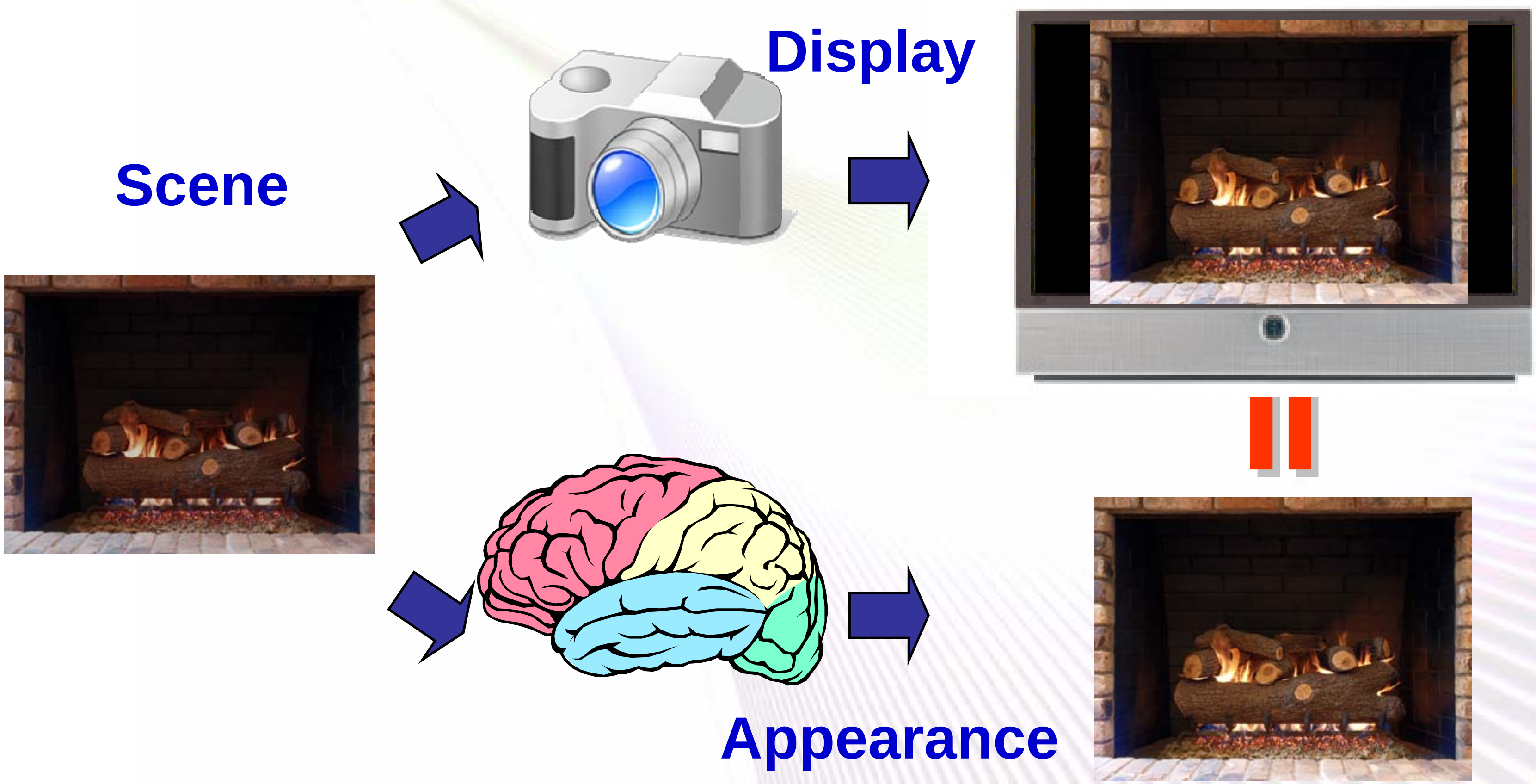
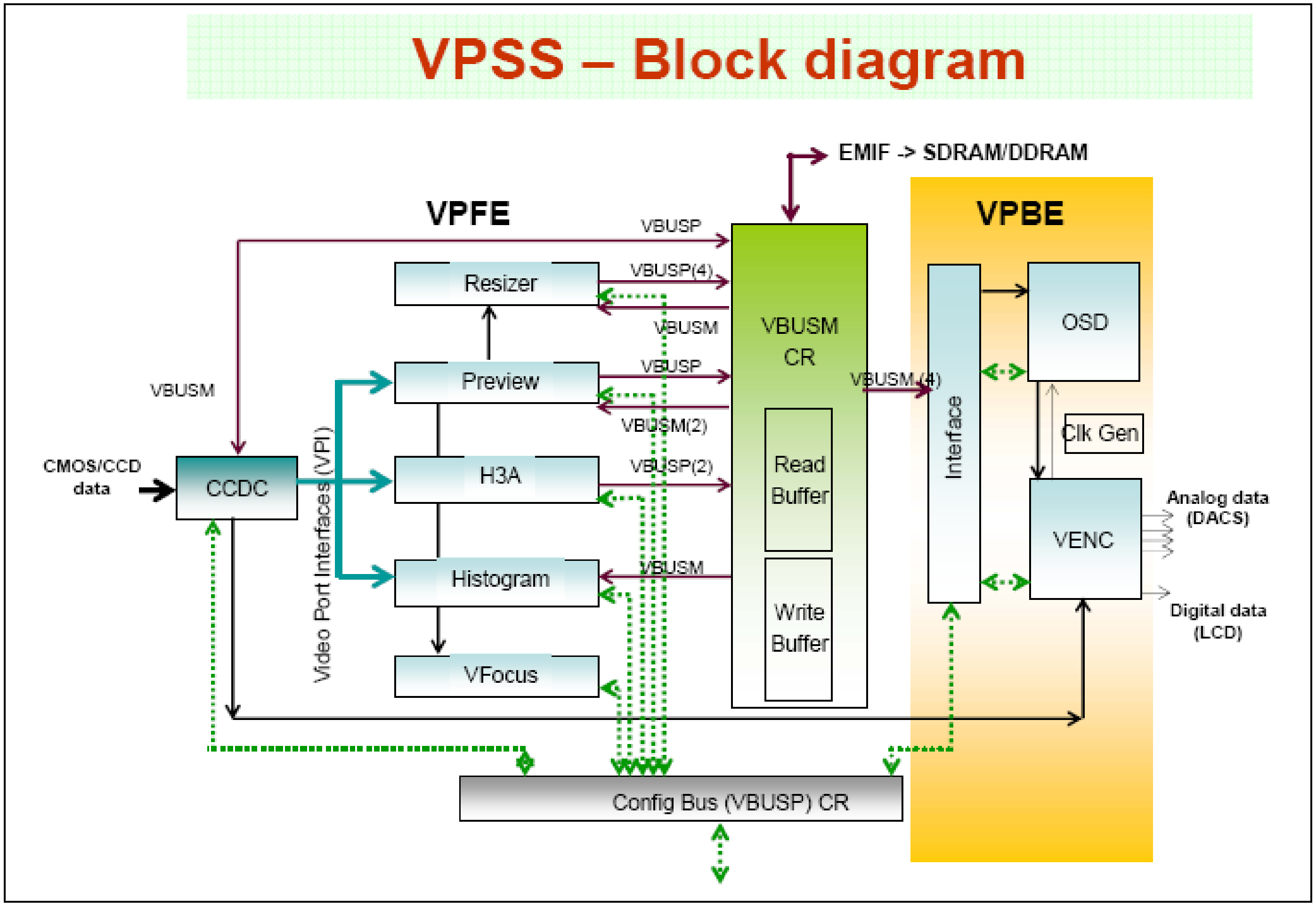
Outline

- DaVinci Image Pipeline
- DaVinci Image Pipeline Algorithms
- DaVinci Image Pipeline Tuning
- Conclusions

Digital Imaging



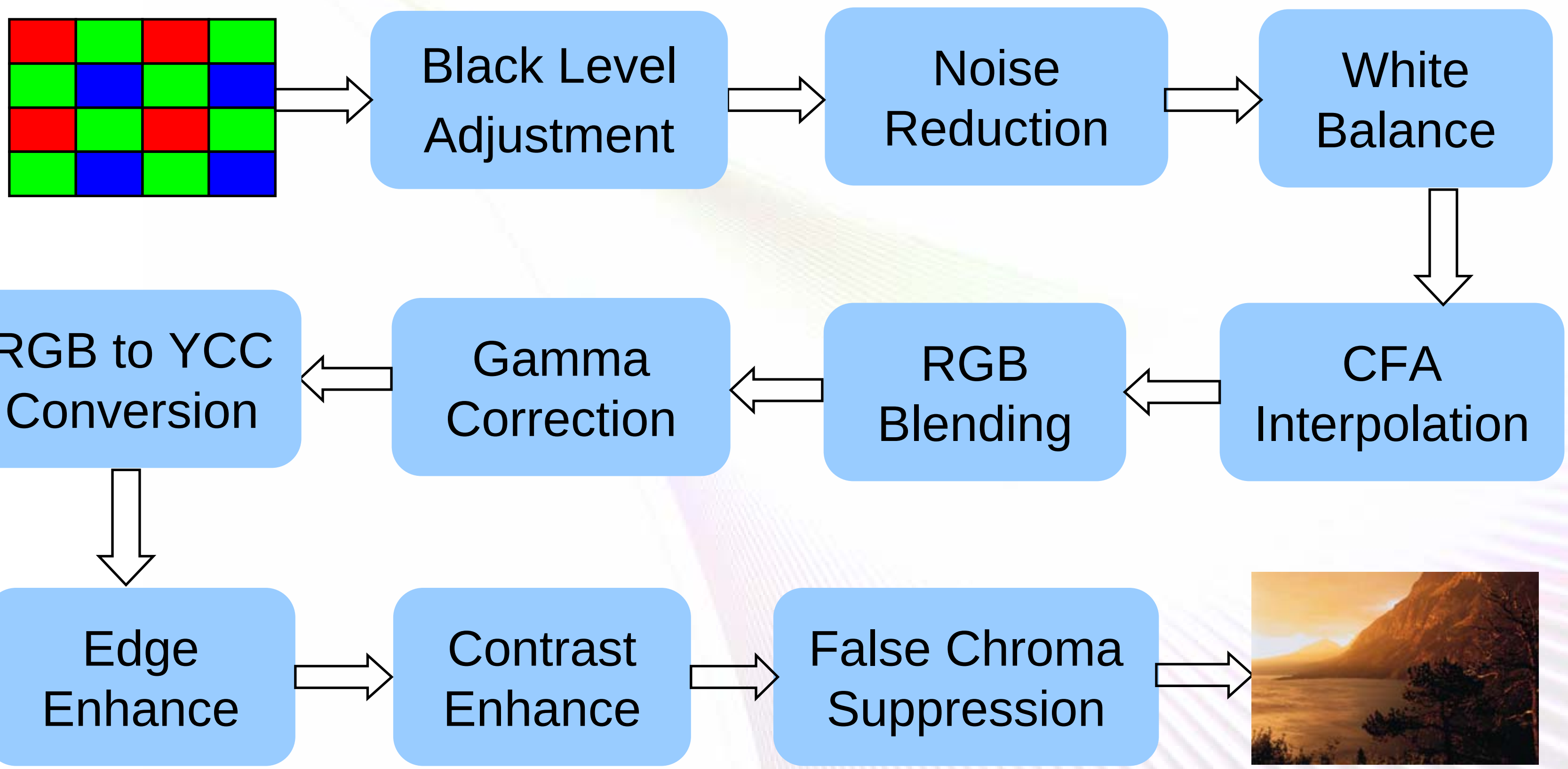
DaVinci VPSS



DaVinci Image Pipeline

- Implemented in VPSS Preview Engine
  - Fast for real-time video processing
- DaVinci Image Pipeline Driver
  - Refer to Session S285113, “The New and Enhanced DaVinci VPSS Drivers”

DaVinci Image Pipeline



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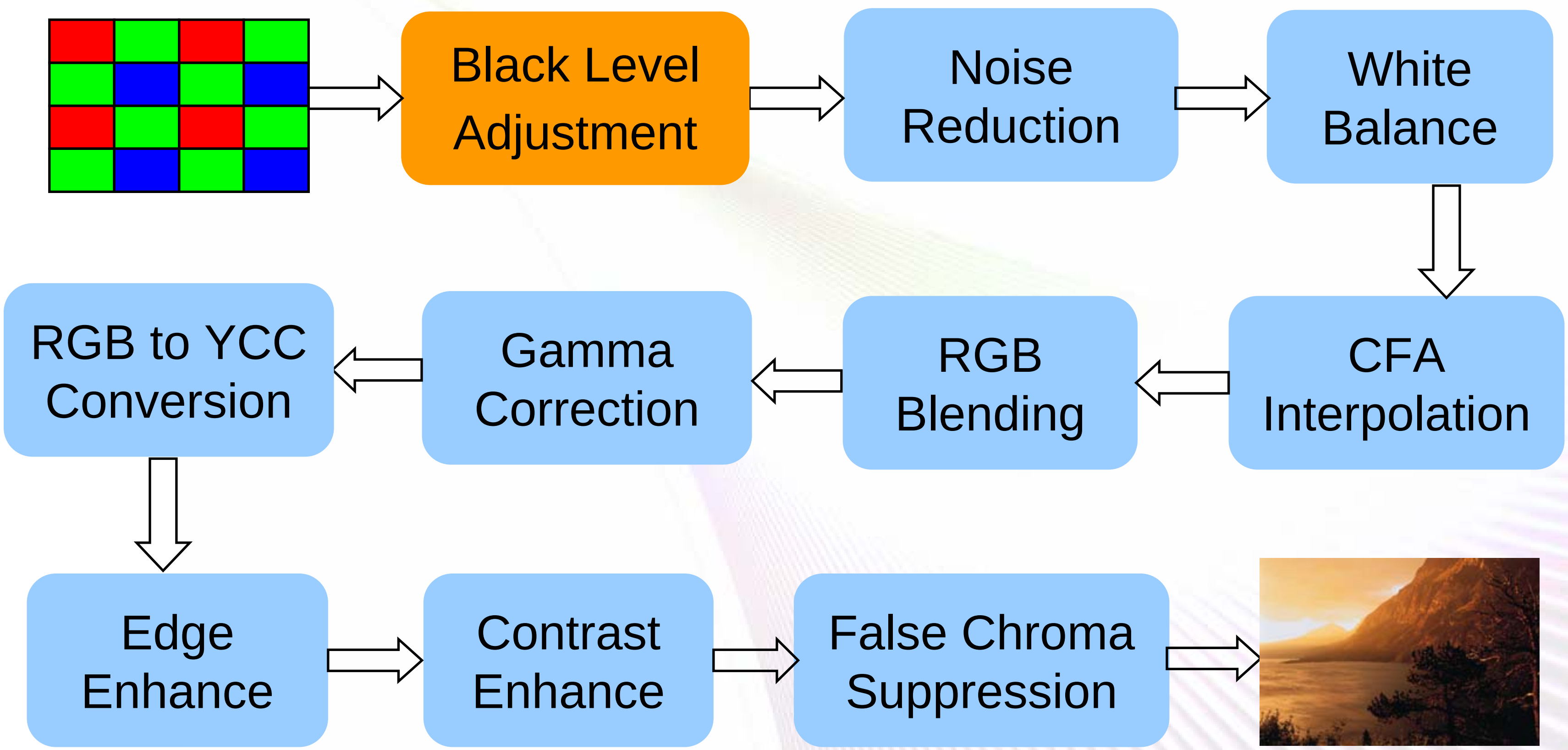
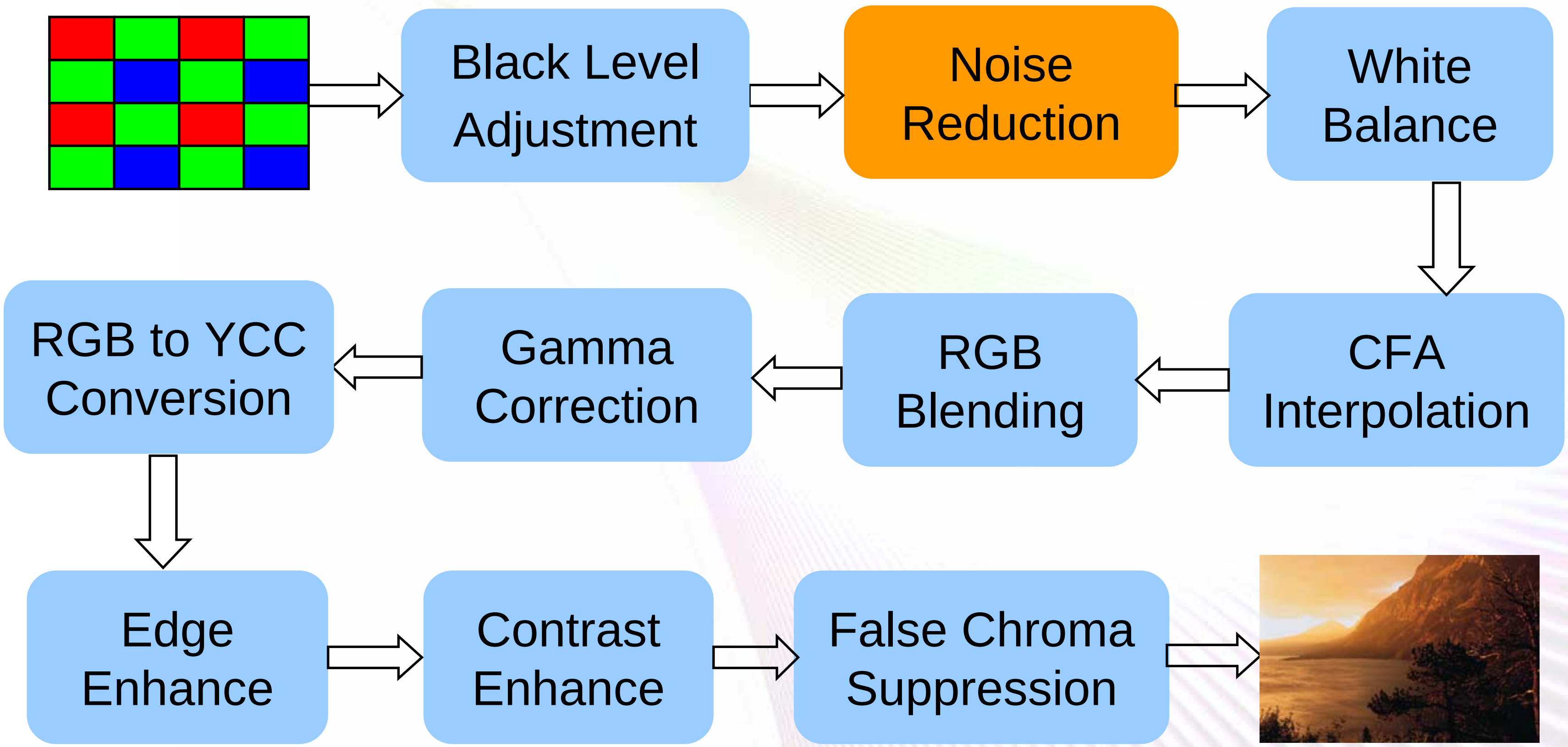
DaVinci Image Pipeline



Why Black Level Adjustment

- Black level leads to the whitening of image dark region and perceived loss of overall contrast
- Dark current from the sensor and lens flare from the lens are the main reasons

DaVinci Image Pipeline

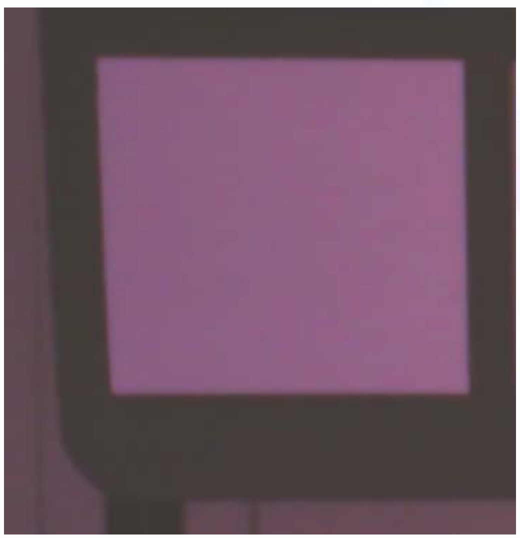


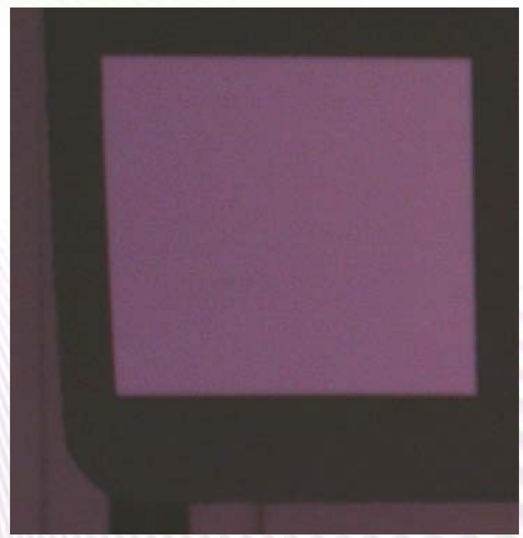
Why Noise Filter

- Noise is everywhere
  - Optical signal
  - Electrical signal
  - Digital signal

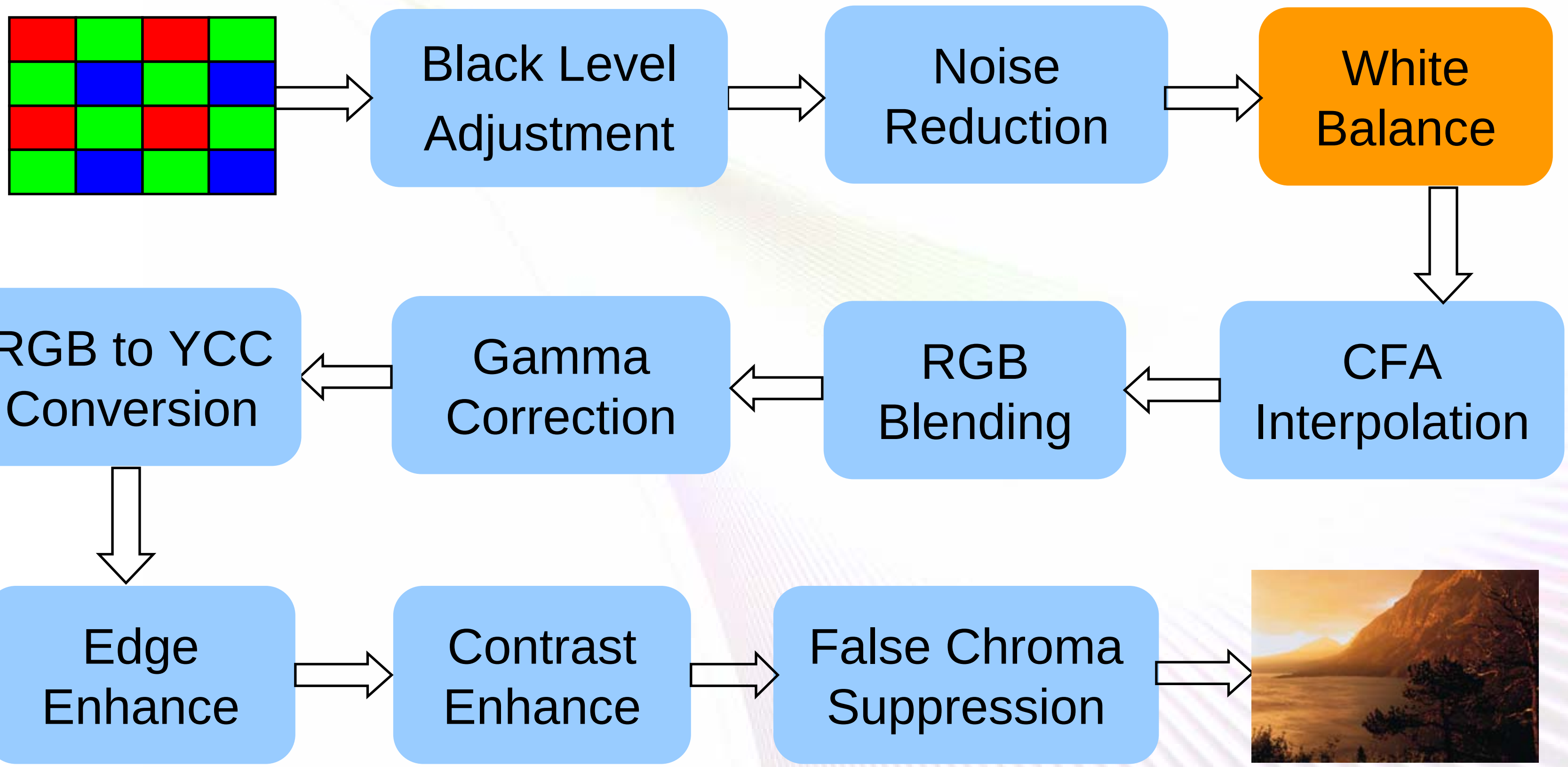
Noise Filter

- Goal: Remove noise
- Method
  - Searching the similar neighbor pixels (Similarity is defined by Threshold)
  - Averaging similar neighbors
  - Weighted sum with original pixels

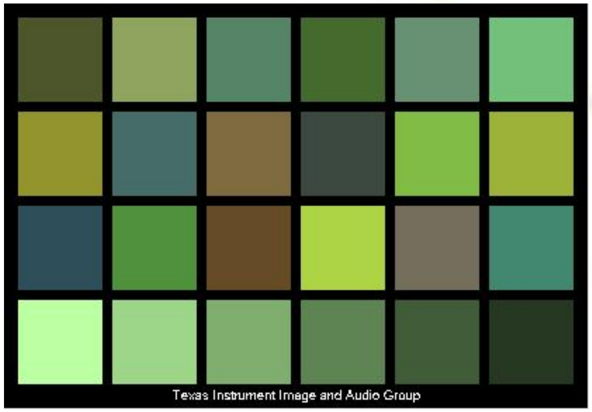

NF on


NF off

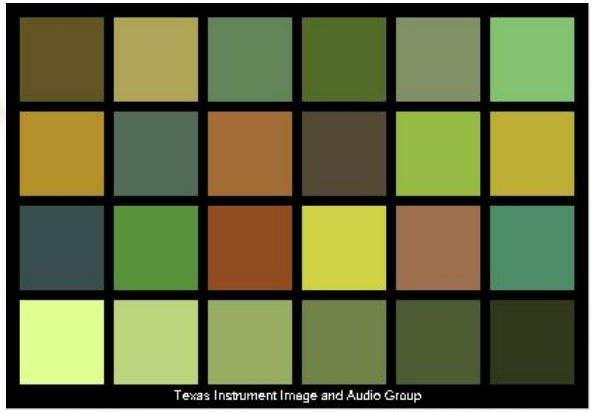
DaVinci Image Pipeline



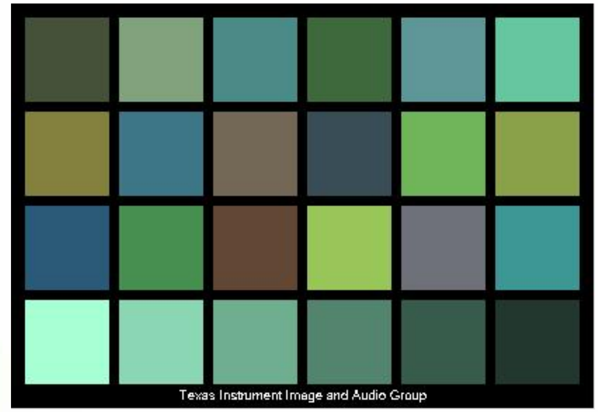
Why White Balance



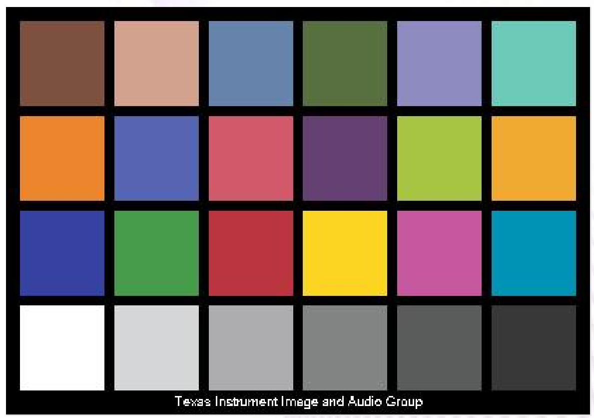
Incandescent Light



Fluorescent Light



Daylight



Human Perception

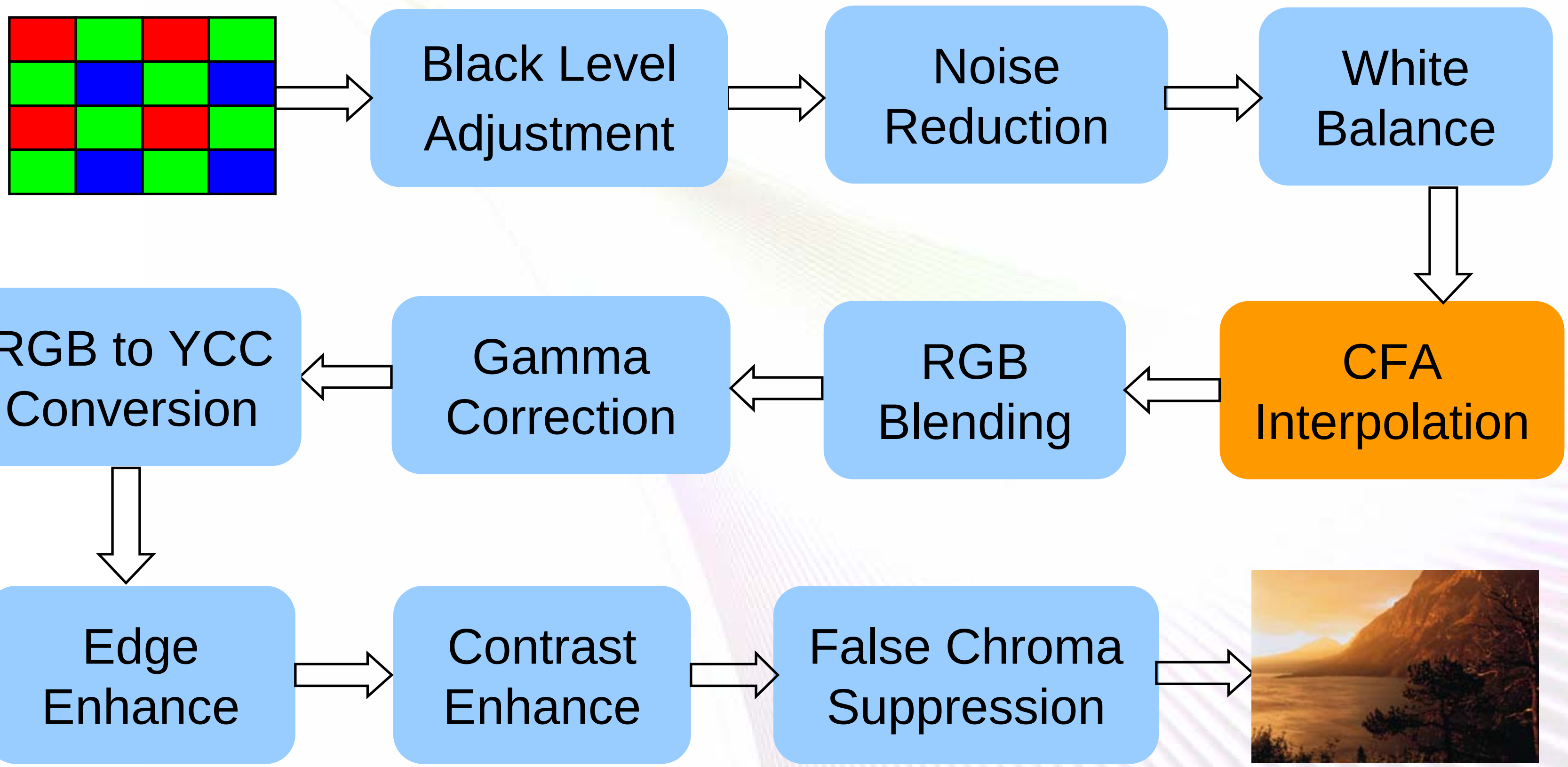
White Balance

- Goal: Make white to be white
  - Automatically compensate color differences

- Model

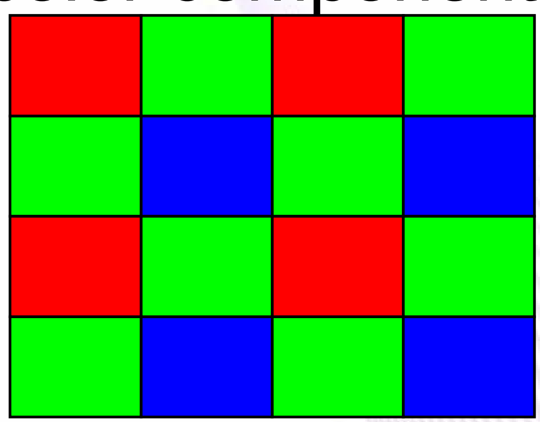
$$\begin{bmatrix} R' \\ G' \\ B' \end{bmatrix} = \begin{bmatrix} R \times W_R \\ G \times W_G \\ B \times W_B \end{bmatrix}$$

DaVinci Image Pipeline



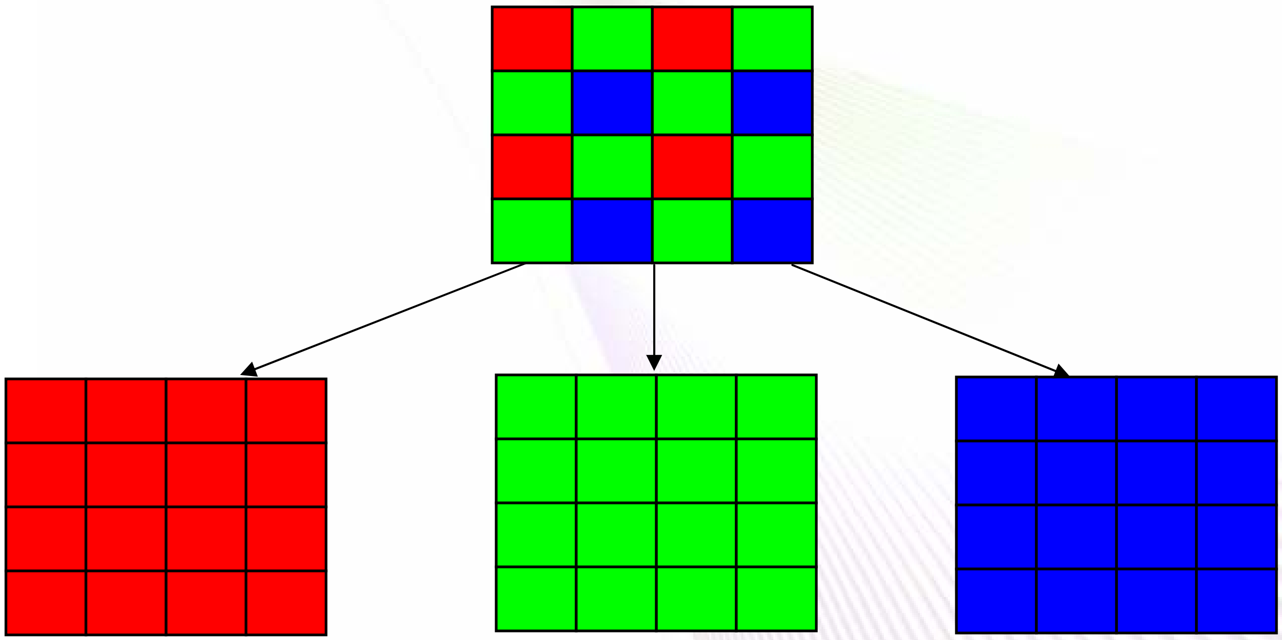
Why CFA Interpolation

- Cameras have only one sensor
- Three components are needed to represent color
- Color Filter Array (CFA) is applied to a CCD or CMOS sensor
- Obtain one color component at each pixel

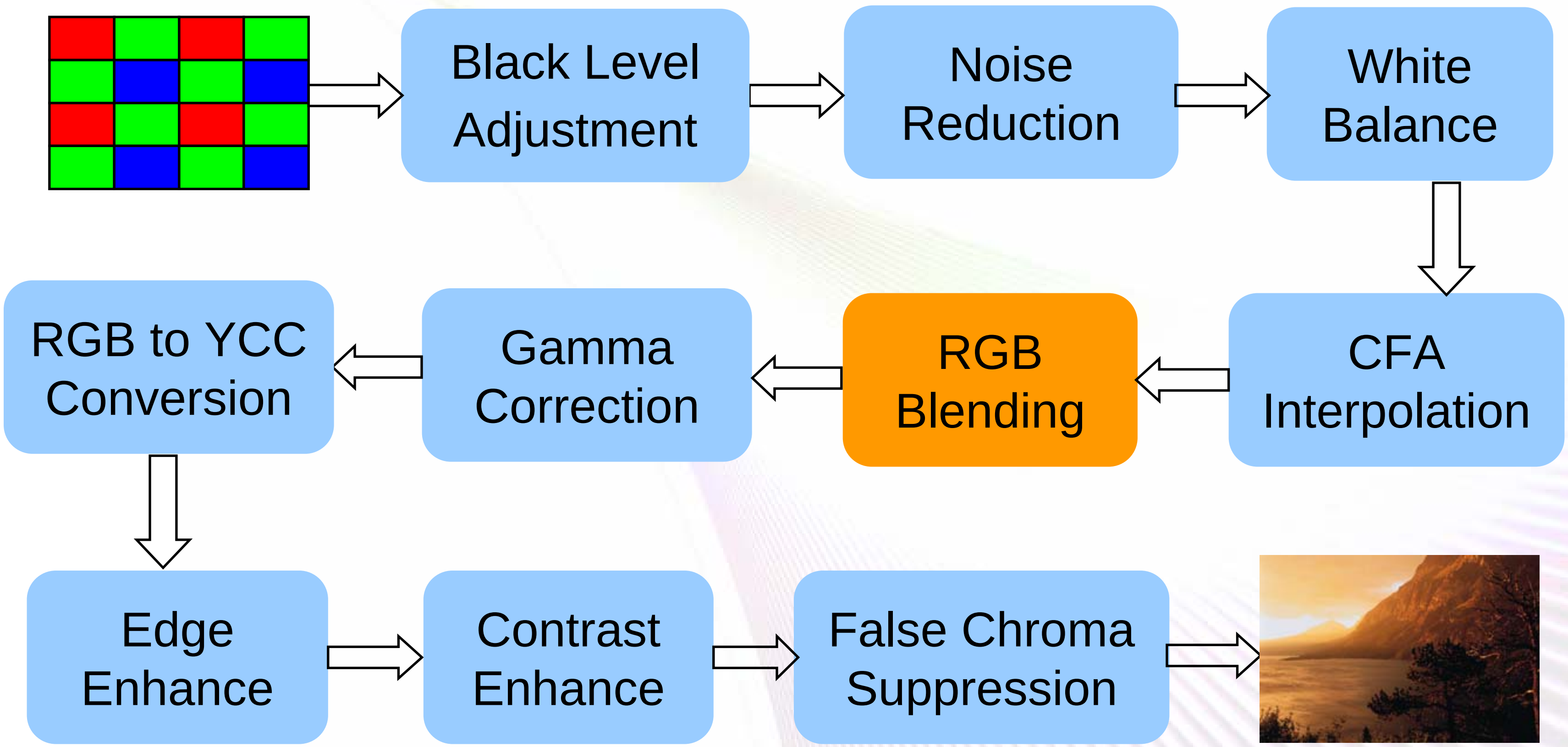


CFA Interpolation

- Goal: Interpolate 2 missing colors for each location

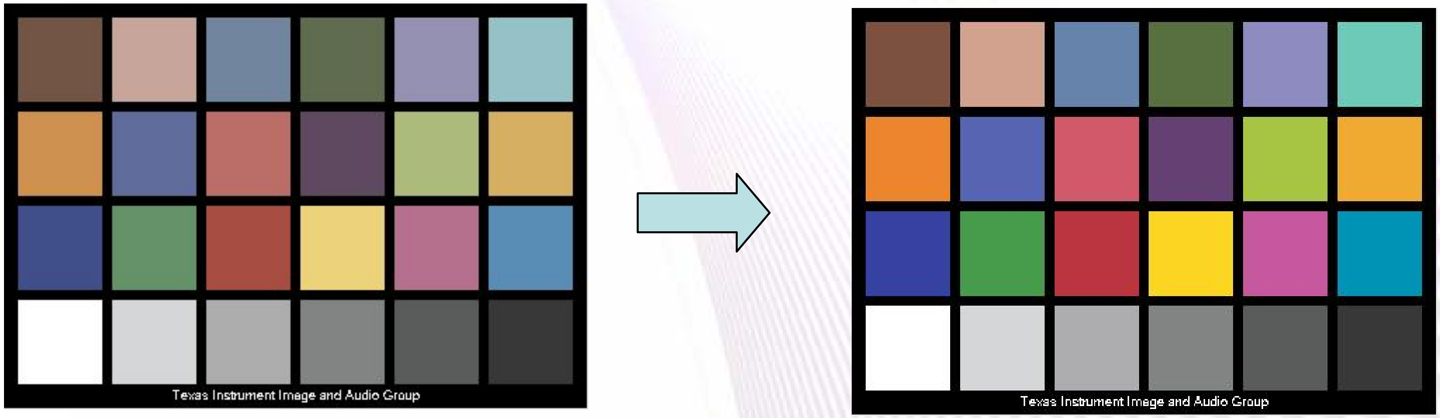


DaVinci Image Pipeline



Why RGB Blending

- Different sensors have different RGB values for a same color
- We need to convert the sensor RGB color space to a standard RGB color space



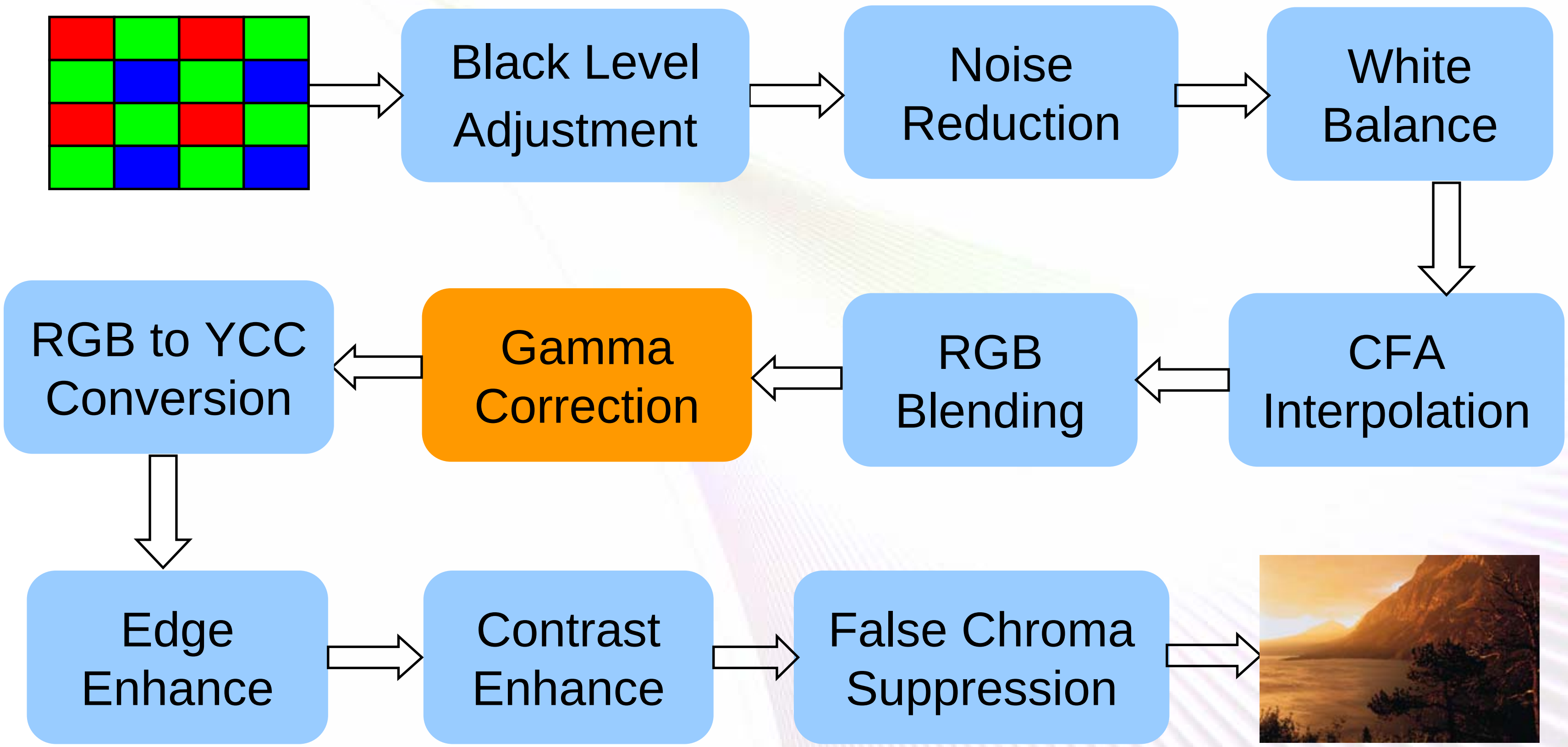
RGB Blending

- Goal: Make the right color
  - Use Rec709 RGB color space

- Model

$$\begin{bmatrix} R' \\ G' \\ B' \end{bmatrix} = \begin{bmatrix} M_{11} & M_{12} & M_{13} \\ M_{21} & M_{22} & M_{23} \\ M_{31} & M_{32} & M_{33} \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

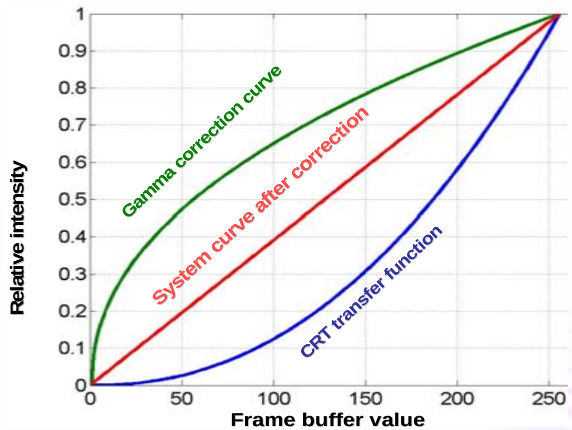
DaVinci Image Pipeline



Gamma Correction

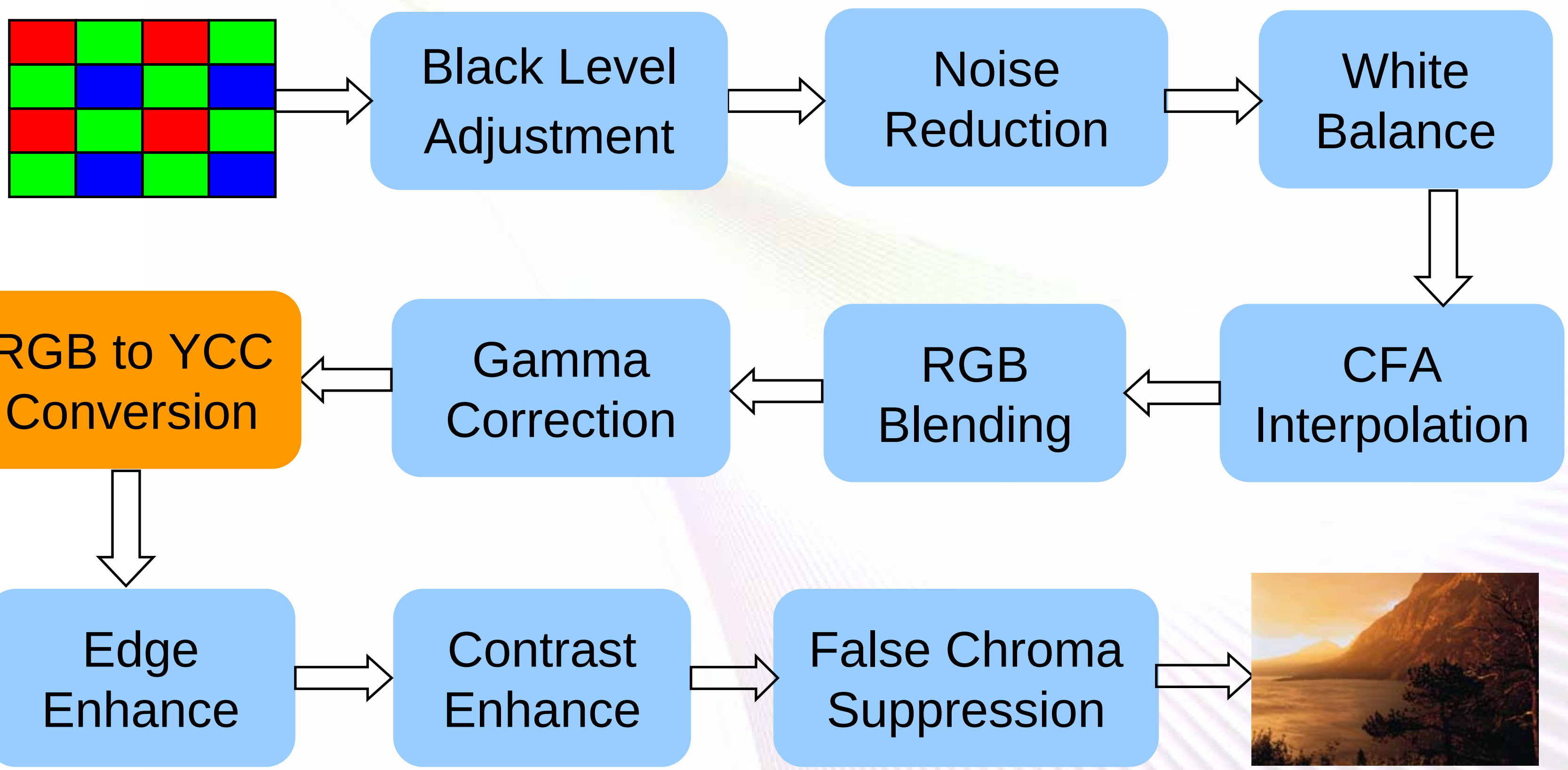
- Goal: Compensate the nonlinearity of the output device
- Model:

$$R' = R^{1/\gamma} \quad G' = G^{1/\gamma} \quad B' = B^{1/\gamma}$$



- Gamma Table
  - Use standard Gamma, for example, Rec709 and SMPTE 240M

DaVinci Image Pipeline



Why RGB-to-YCC Conversion

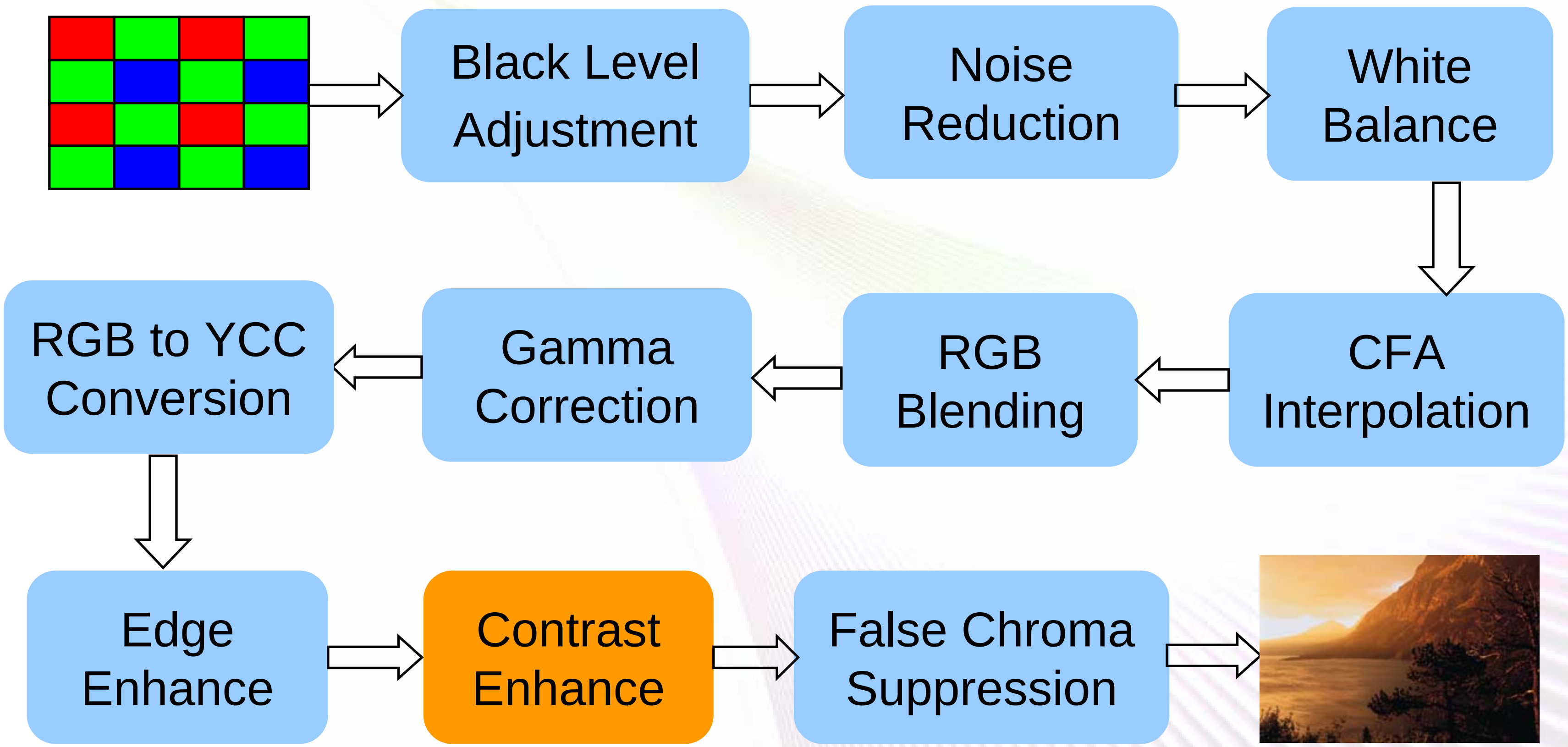
- Human eyes are more sensitive to luminance than color information
- We need to separate luminance component (Y) from color components (Cb, Cr) for different processing using different precisions
- Also needed for video encoder

RGB-to-YCC Conversion

- Goal: Convert RGB to YCbCr based on standard formula

$$\begin{pmatrix} Y \\ C_b \\ C_r \end{pmatrix} = \begin{bmatrix} 0.2989 & 0.5866 & 0.1145 \\ -0.1687 & -0.3312 & 0.5000 \\ 0.5000 & -0.4183 & -0.0816 \end{bmatrix} \times \begin{pmatrix} R \\ G \\ B \end{pmatrix}$$

DaVinci Image Pipeline



Contrast Enhancement

- Contrast: Increasing or decreasing the range
- Brightness: Increasing or decreasing the level

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DaVinci Image Pipeline Tuning

- Tune parameters to achieve high-quality images and videos
- Sensors
  - Different sensors have different quality
  - Different sensors have different characteristics
- Image pipelines
  - Balance different image processing functions
- Customers
  - Different image and video quality preferences

Image Pipeline Tuning Challenges

- Must tune for each image sensor module
- Must tune based on customer image and video quality preferences
- No standard tuning methodology or quality metric
- Tuning each new camera takes time to achieve best image and video quality

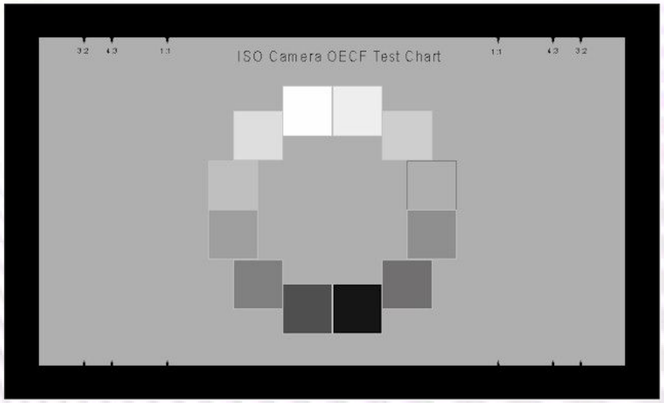
Tuning Equipment

- Sensor module
- Light box
  - Provide different color temperatures
  - Tune white balancing
- Flash meter
  - Measure light intensity (Lux)
- Uniform light sources
  - Provide uniform lighting
  - Tune noise filtering

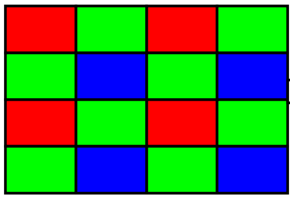
Test Charts

- ColorChecker
  - Tune white balancing
  - Tune RGB blending

- ISO OECF Chart (ISO-14524)
  - Tune noise filtering



DaVinci Image Pipeline



Black Level Adjustment → Noise Reduction → White Balance → CFA Interpolation → RGB Blending → Gamma Correction → RGB to YCC Conversion → Edge Enhance → Contrast Enhance → False Chroma Suppression →

Black Level Adjustment

- Goal: Make black to be black
- Model:

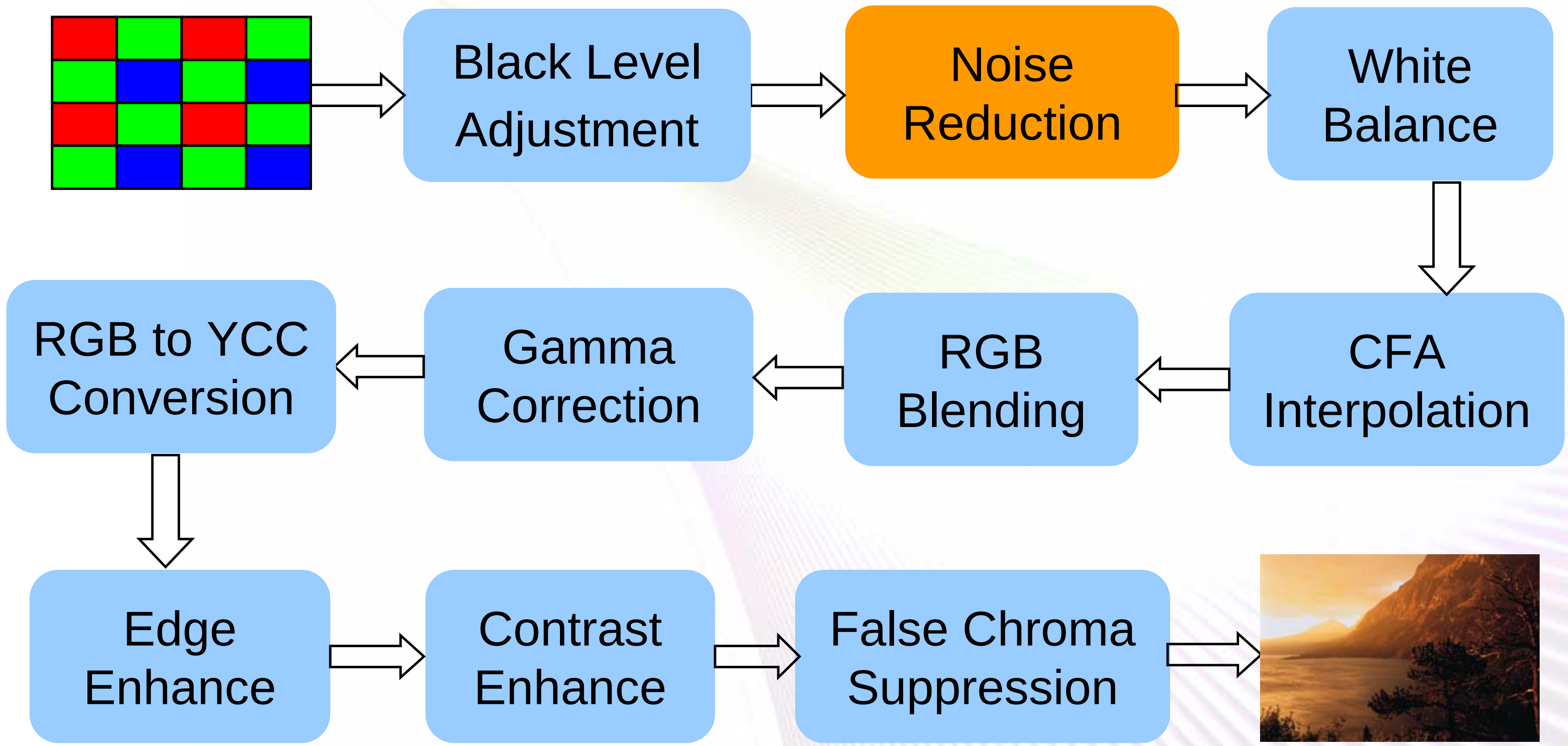
$$R'_{i,j} = R_{i,j} - O^{R}{}_{i,j}$$

$$G'_{i,j} = G_{i,j} - O^{G}{}_{i,j}$$

$$B'_{i,j} = B_{i,j} - O^{B}{}_{i,j}$$

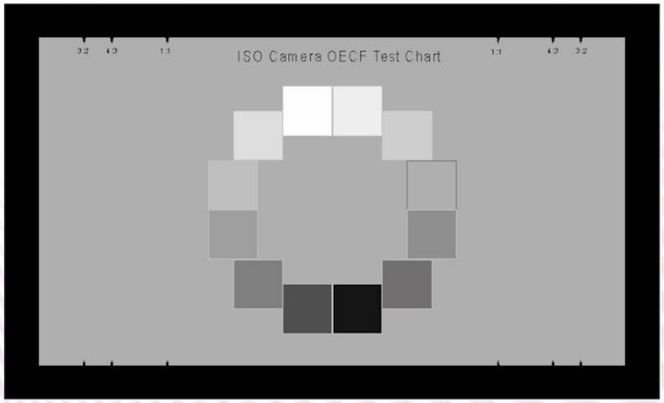
- Methods
  - Characterize the dark current and lens flare
  - Store these values, image-independent or image-dependent
  - Subtract these values from the raw sensor image

DaVinci Image Pipeline

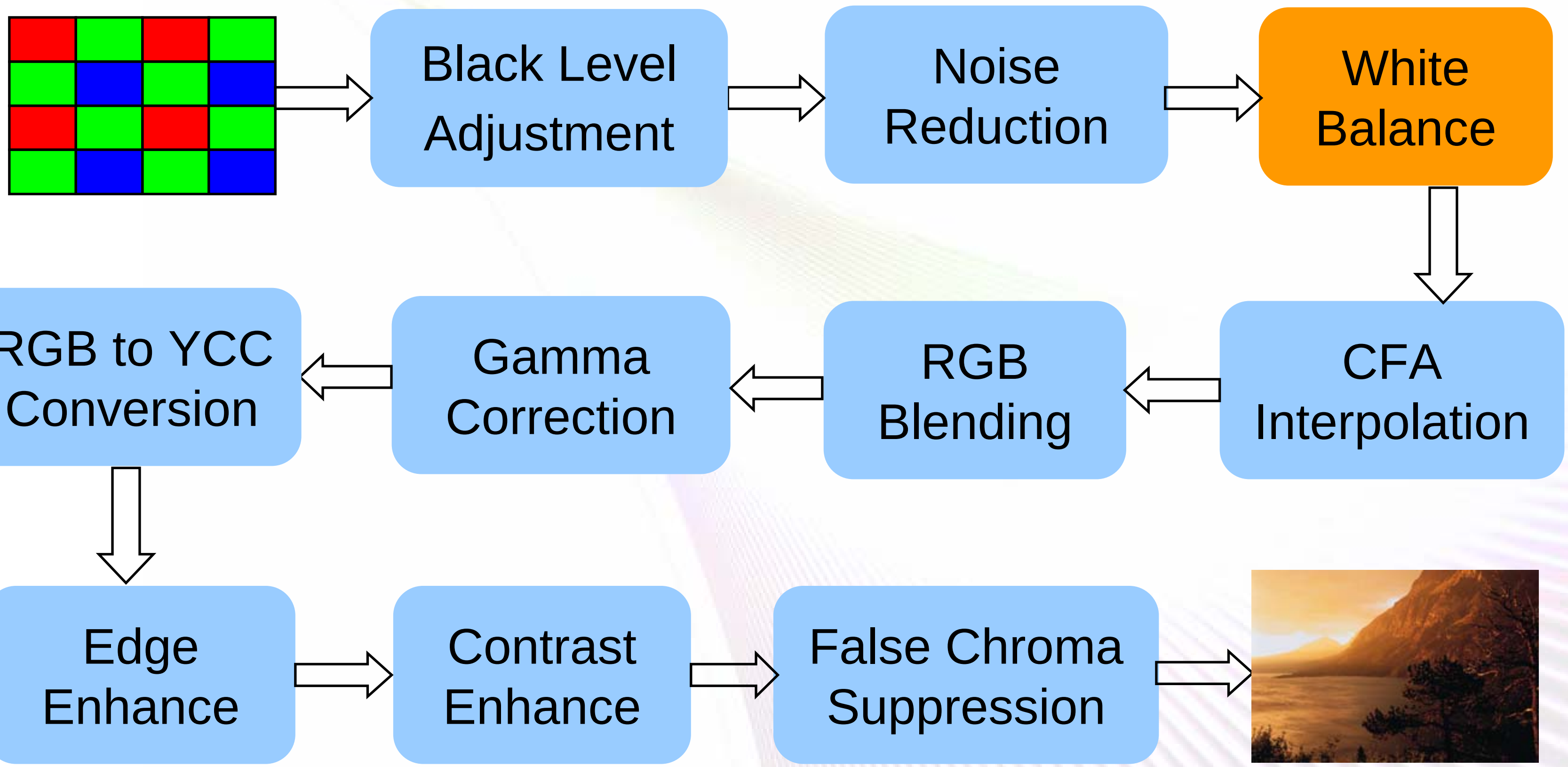


Noise Characterization

- Goal: Characterizes white noise in the Bayer data
- Method
  1. Capture an OECF chart image using a uniform lighting source
  2. Obtain Bayer raw data for 12 uniform gray patches
  3. Compute the mean and std of the intensities for each patch
  4. The std value is the noise std for the luminance level at the mean value
- Noise Models
  - Linear model: N~S
  - Square-root model: N~sqrt(S)
  - Depends on the sensor



DaVinci Image Pipeline



White Balance Tuning

- Goal: Make white to be white
- Source: Raw Bayer data without auto-white-balancing or white balancing tuning
- Model

$$\begin{bmatrix} R' \\ G' \\ B' \end{bmatrix} = \begin{bmatrix} R \times W_R \\ G \times W_G \\ B \times W_B \end{bmatrix}$$

White Balance Tuning Steps

1. Use the ColorChecker chart to collect data
2. Obtain average RGB values of 6 gray patches
3. Mean square error minimization

$$\min f_R(W_R) = \sum_{n=1}^{6} (W_R \times R_n - G_n)^2$$

$$\min f_B(W_B) = \sum_{n=1}^{6} (W_B \times B_n - G_n)^2$$

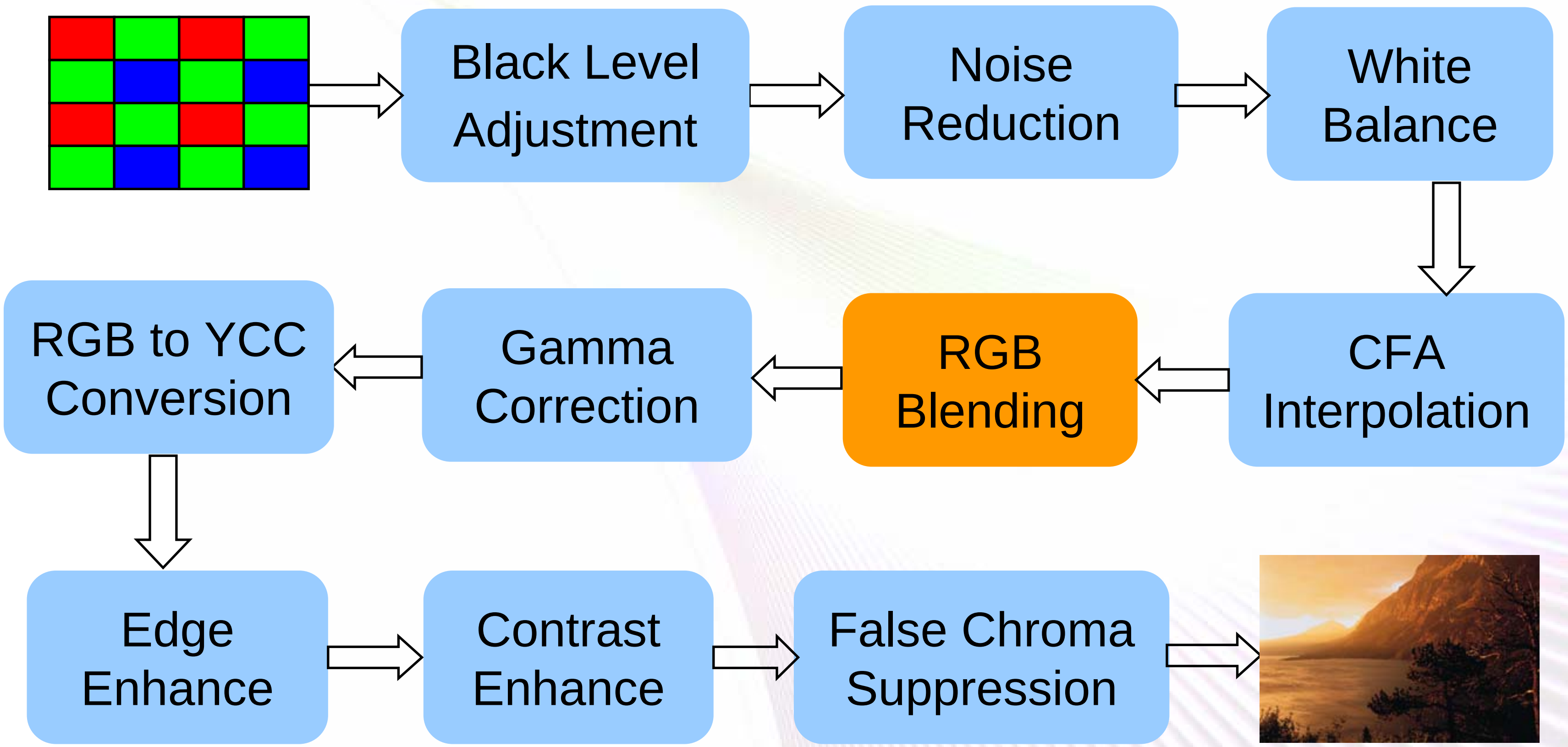
4. Set green gain to be 1

White Balance Tuning Example

Before White Balance

After White Balance

DaVinci Image Pipeline



RGB Blending Tuning

- Goal: Make the right color
- Source: Bayer data after white balancing tuning
- Model

$$\begin{bmatrix} R' \\ G' \\ B' \end{bmatrix} = \begin{bmatrix} M_{11} & M_{12} & M_{13} \\ M_{21} & M_{22} & M_{23} \\ M_{31} & M_{32} & M_{33} \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

- Sum of each row equals 1
- Reference: Finlayson, G.D. and Drew M.S., "Constrained least-squares regression in color spaces," Journal of Electronic Imaging 6(4), 1997

RGB Blending Tuning Steps

1. Use a ColorChecker chart to collect data
2. Obtain average RGB values of 18 color patches of raw data after white balancing and reference images
3. Do inverse Gamma correction on reference RGB values
4. Constrained minimization

$$\min f(\mathbf{M}) = \sum_{n=1}^{18} \sum_{i=1}^{3} \left(\sum_{j=1}^{3} M_{i,j} \times RGB_{j,n} - RGB_{i,n}^{ref} \right)^2$$

$$subject\ to\ \sum_{j=1}^{3} M_{i,j} = 1$$

RGB Blending Tuning Example

Before RGB Blending

After RGB Blending

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Conclusions

- DaVinci Image Pipeline
  - Provides both baseline and enhancement image processing functions
  - Fast for real-time video processing
- DaVinci Image Pipeline Tuning
  - Sensor characteristics
  - Customer preference
- DaVinci Image Pipeline Driver
  - Refer to Session S285113, “The New and Enhanced DaVinci VPSS Drivers”

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Q & A

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