

# Image Quality Measurement and Modeling for Digital Photography

ICIS 2002 Tokyo



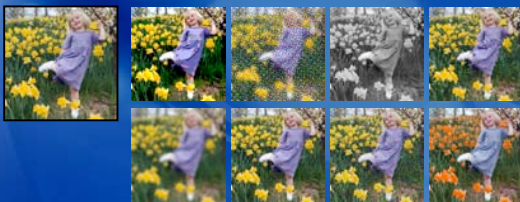
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## Outline

- Measuring Image Quality
- Colorimetric Approach
- Spatial Vision Approach
- Systems Approach
- Need for a Fundamental Approach for Digital Photography

## Color Image Quality

Reductions in image quality correspond to perceptible visual *differences* from some ideal and the *magnitude* of such differences.



## Thresholds

Threshold metrics describe the probability of detection of image artifacts.

JNDs — Just Noticeable Differences

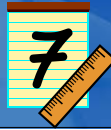


## Scales

Interval scales of image quality describe the magnitudes of changes in image quality that are clearly perceptible.

Image A is *N*-units better than Image B.

A greater challenge ...



## Image Quality Circle

Engeldrum (2000)

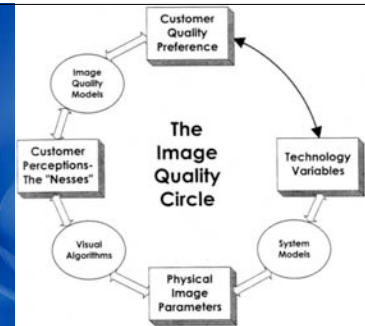


Figure 2.3 - The complete Image Quality Circle showing all the Connecting Links.

## Systems vs. Fundamental Approaches

**Systems:** Relate Technology Variables Directly to Observer Ratings (JNDs or Scales).  
{Psychophysics & Statistics}

**Fundamental:** Relate Image Measurements to Observer Quality Scales (or JNDs) Regardless of Image Source  
{Psychophysics & Vision Modeling}

## Historical Approaches

- Colorimetric Measurements
- Spatial Vision Models
- Systems Metrics

## Colorimetric Approaches



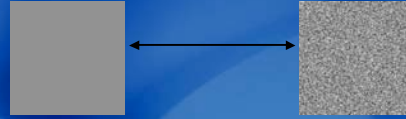
For Simple (Constant) Viewing Conditions:

- CIE LAB  $\Delta E_{94}$  (or CIEDE2000)
- Patch-by-Patch (or Pixel-by-Pixel)
- Min., Mean, Max., Histogram
- Variance, Correlation, etc.

Color Appearance Models Sometimes Applied to More Complex Conditions:

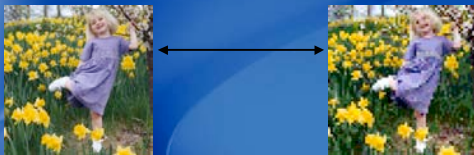
- CIECAM97s (or CIECAM02)

## Spatial Vision Approaches



- Models of Spatial Vision ("Detection Models")
- Detectable Differences in Various Spatial Frequency Channels? (Overall?)
- Based on Human CSF / Threshold Data
- e.g., Daly's "Visible Differences Predictor", Lubin's "Sarnoff Model"

## Systems Approaches

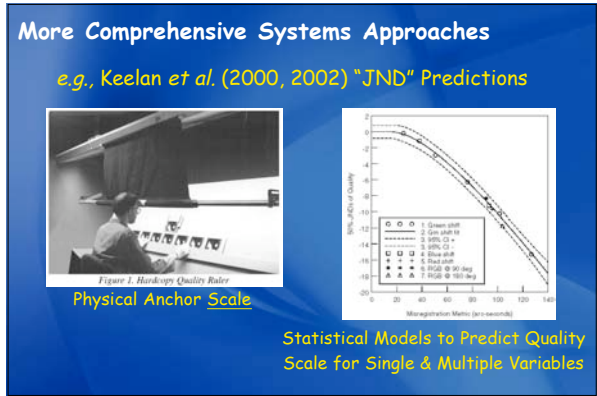
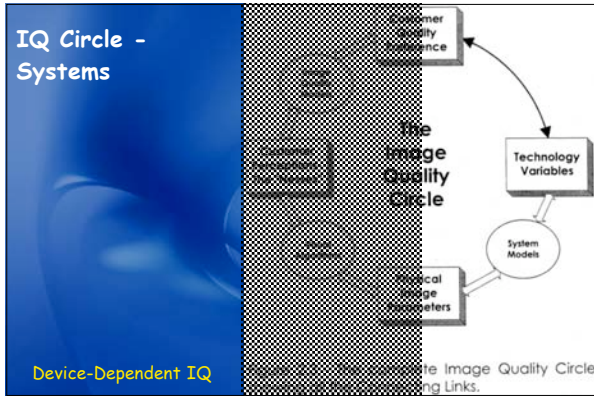


Simple Image Specifications

- Bits per Pixel
- Pixels per Image (or inch, or degree, etc.)
- Noise, Granularity
- Luminance, Contrast, Gamut Volume

## Two Image Quality Paradigms

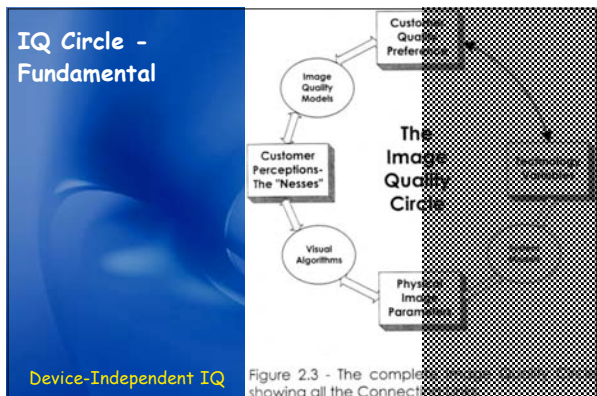
- **Device-Dependent Image Quality**
  - The Systems-Based Approach
- **Device-Independent Image Quality**
  - The Fundamental Approach
  - The Vision-Modeling Approach
  - Image-Appearance Modeling



### Device-Dependent Image Quality

Systems approaches to image quality measurement are analogous to device-dependent color specifications (e.g. RGB, CMYK).

Thus, they represent *device-dependent image quality*.



## The Need for a Fundamental Approach

- Color Approaches Tend to Ignore Spatial Attributes



$\Delta E^* = 50$  for each pixel  
 $\Delta I_m = 0$  for appropriate viewing distance

- Spatial Approaches Tend to Ignore Color Appearance

(Luminance Only, No Adaptation, etc.)

- Image Specifications Tend to Ignore Human Perception

## Image Quality as an Interval Scale

Interval scales have no meaningful zero.

(What is zero image quality?)

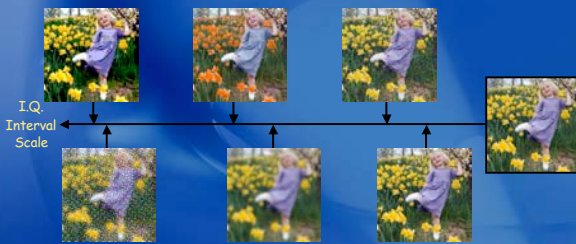


Reduction in image quality can be a ratio scale.

(Zero reduction in IQ is a sub-threshold difference.)

## A Unified Approach

An image quality metric can be derived as a measure of perceived difference from an ideal image.



## Device-Independent Image Quality

Fundamental approaches to image quality measurement are analogous to device-independent color specifications (e.g., XYZ, CIELAB  $L^*a^*b^*$ , CIECAM JCh).

Thus, they represent *device-independent image quality*.

ASSERTION: Device-independent image quality is necessary for open digital imaging systems.

## Psychophysics & Vision Modeling

### Device-Independent Image Quality Requires:

- Psychophysics to Quantify Perceptual Scales
- Vision Modeling to Relate Image Stimuli to Measured Perceptual Scales
- Iteration for Verification

## Human Vision Modeling

- Mathematical Models of Human Visual Performance in Response to Stimuli
- Often Empirical in Nature
- Concerned with Color Vision, Spatial Vision, Temporal Vision, Interactions



## Candidate Models

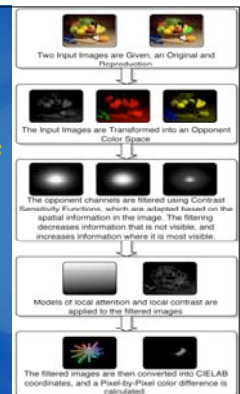
- S-CIELAB (Zhang & Wandell, 1995)
- S-CIELAB + CIEDE2000 (Johnson & Fairchild, 2002)
- CVDM (Jin, Feng, Newell, 1998)
- Modular Approach (Johnson & Fairchild, 2001)
- iCAM + Modular (Fairchild & Johnson, 2002)

## A Modular Framework

Johnson & Fairchild, *CIC 9* (2001)

### Modular Framework for IQ Scales

- Promising Framework for Image Differences
- Flexible Implementation





## $\Delta E$ vs $\Delta Im$

- $\Delta E$  (DE) has come to have a specific meaning in color difference measurement.
- True image difference metrics include higher-order processing and should have a different notation.
- $\Delta Im$  (DIm) proposed for image differences.
- A good  $\Delta Im$  (DIm) metric will reduce to a  $\Delta E$  (DE) metric for reference viewing conditions and configurations.

## Model Structure



Spatial Filtering, Local Attention, Local & Global Contrast, CIE Color Difference

## The Next Step

Unification of Techniques for:  
Color Appearance Specification  
Color Difference Measurement  
Spatial Vision Modeling (Filtering & Adaptation)

RESULT: Image Appearance (& Difference) Model

## iCAM

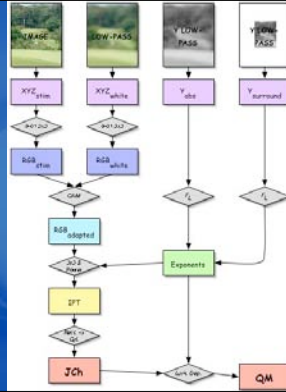
*iCAM* — *image Color Appearance Model*

A simple framework for color appearance, spatial vision effects, image difference (quality), image processing, and temporal effects (eventually)

An "Image Appearance Model"

## Spatial iCAM

Submitted to :  
CIC-10 (2002)  
CIE Congress (2003)



## Sneak Preview

Im

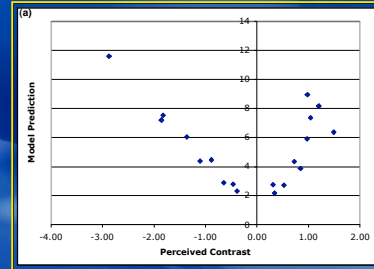


Image Difference Prediction (Contrast Data)

## A Word on Preferences

- Preferences can be Treated Similarly
- Difference from Ideal
- "Naturalness"



## Research Objectives

- Realization of Device-Independent Image Quality
- Collection of Psychophysical Image Quality and Image Preference Scales
- Formulation of Unified Model for Color Appearance, Image Reproduction, & Image Quality/Differences (an Image Appearance Model)



## Outlook (The Light Booth)

Image quality measurement will always require visual evaluation in addition to mathematical modeling just as a light booth is still required for basic colorimetry.

There are always other variables.



## Conclusion

- Device-Dependent Image Quality
  - Very Effective for Known or Closed Systems
- Device-Independent Image Quality
  - Necessary for Open Systems
  - Necessary for Revolutionary Systems
  - Necessary for Digital Photography?
- Image Appearance Models will Facilitate DI IQ

Thank You

