Image Quality Measurements: Necessity, Numbers and '....nesses'.

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University of Westminster

Digital Futures 2009: Image Physics & Psychophysics
November 3rd, The Institute of Physics, London

Overview

- Need for measurement
- Quality defined
- Historical perspective and transference
- Imaging with numbers but without too many numbers!
- The ‘Nesses’
- Physical & Psychophysical measures

  psychophysics/psychometrics

  relationships with observations (HVS),
- Conclusions

Why Measure?

To provide a quantitative basis for the use and comparison of products and devices

To provide a means of improving quality

To provide a means for modelling systems and deciding what aspects need improving

To understand the systems

What is Quality?

Degree of excellence, relative nature or, kind or, character. (OED)

All those features of product (or service) which are required by the customer. (ISO 9000)

The integrated set of perceptions of the overall degree of excellence of an image.

(Engeldrum, 2000)

Others to be defined later

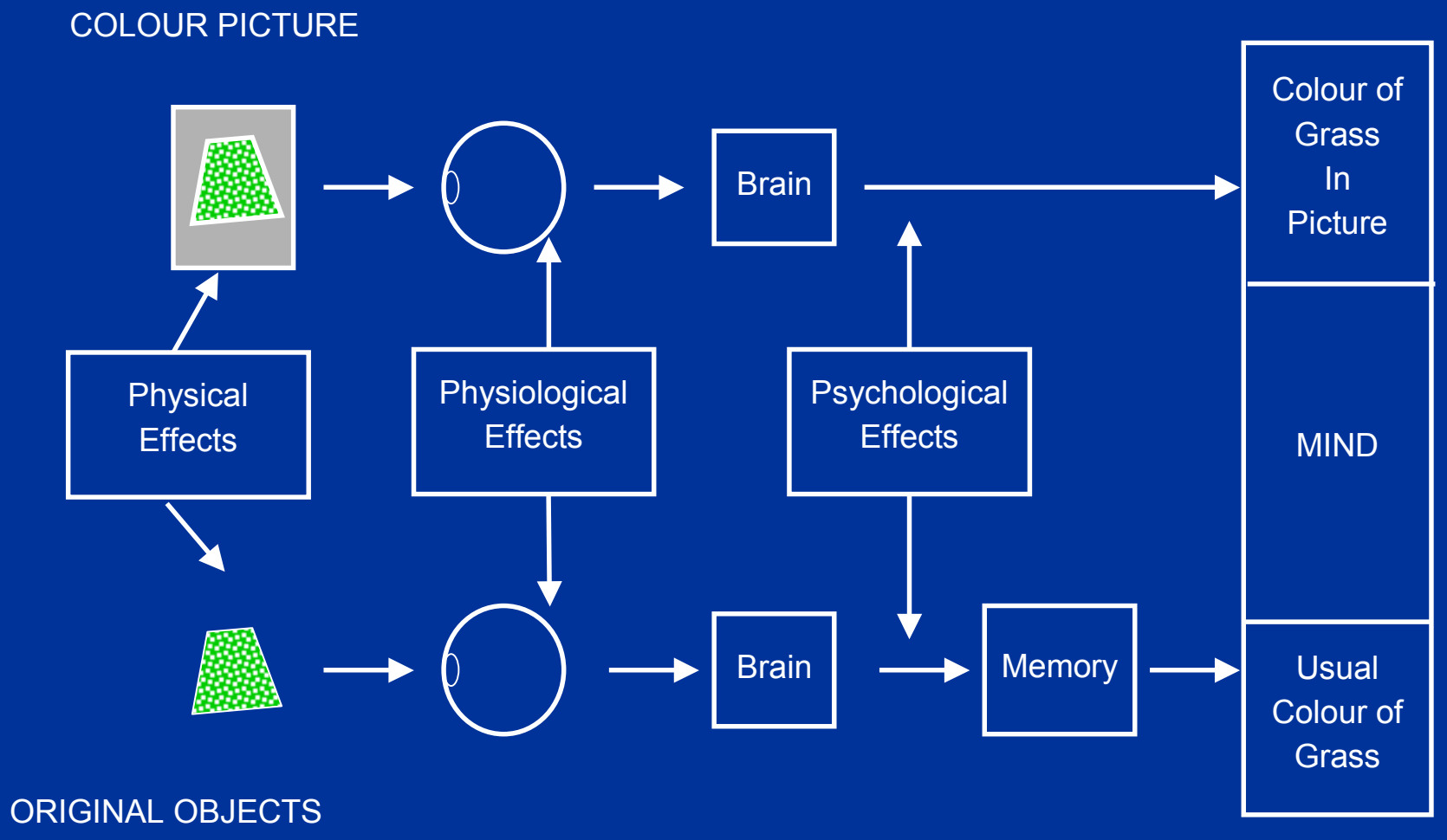
The ‘Nesses’

Proposed by Engledrum as a characteristics of images that we sense (see).

Perceptual attributes :

Brightness
Chromaness
Colorfulness
Contrastness
Fineness (detail)
Graininess (noisiness)
Hueness
Lightness
Naturalness
Sharpness
Textureness
Usefulness

Prototyping



Hunt, 1967

Prototyping

Subjective judgement made by a mental comparison of an external image with image impressions stored and remembered more or less distinctly by the observer, who allows for loss of detail in areas too small to be resolved by the eye.

Schade, 1975

Acceptability/Perceptibility

Quality (Acceptability):

Preference of one image over an other, or degree to which a factor is bothersome

Fidelity (Perceptibility):

Visibility of a factor, or

Discrimination between images

Klein, 1993, Farrell 1996

Acceptability/Perceptibility

Acceptability/Perceptibility

Naturalness

The degree of apparent match between the reproduced image and the internal references, e.g. memory prototypes

Endrikhovski, 2002

Naturalness

Colours shifted to yellow - Sunset

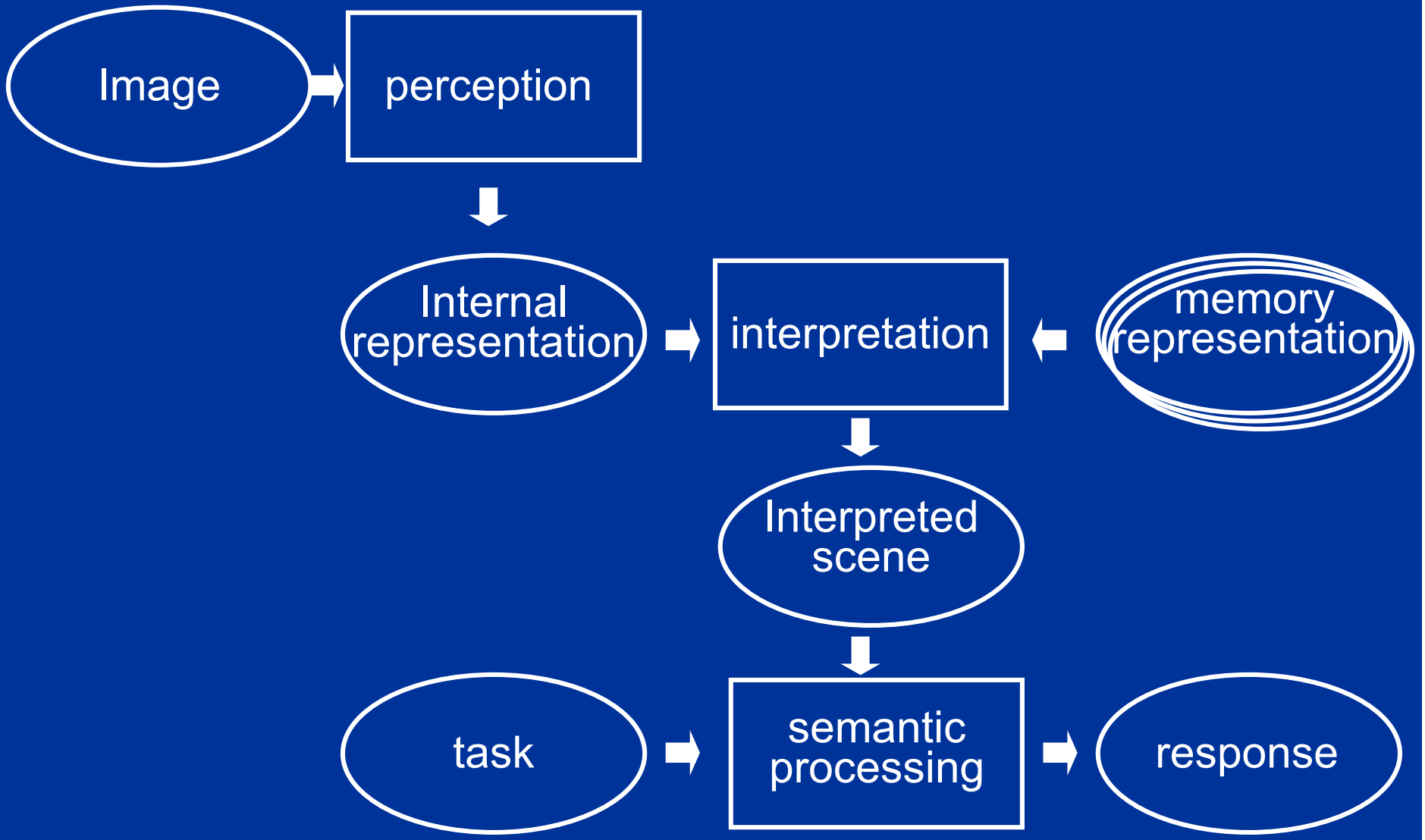
Original

Colours shifted to blue - Moonscape

Colours shifted to purple - Unnatural

Endrikhovski, 2002

Visuo-Cognitive Processing



Janssen, 2001

Usefulness

Requires modification according to application – *usefulness* or *fitness for purpose:*

The degree of apparent suitability of the reproduced image to satisfy the corresponding task.

Usefulness

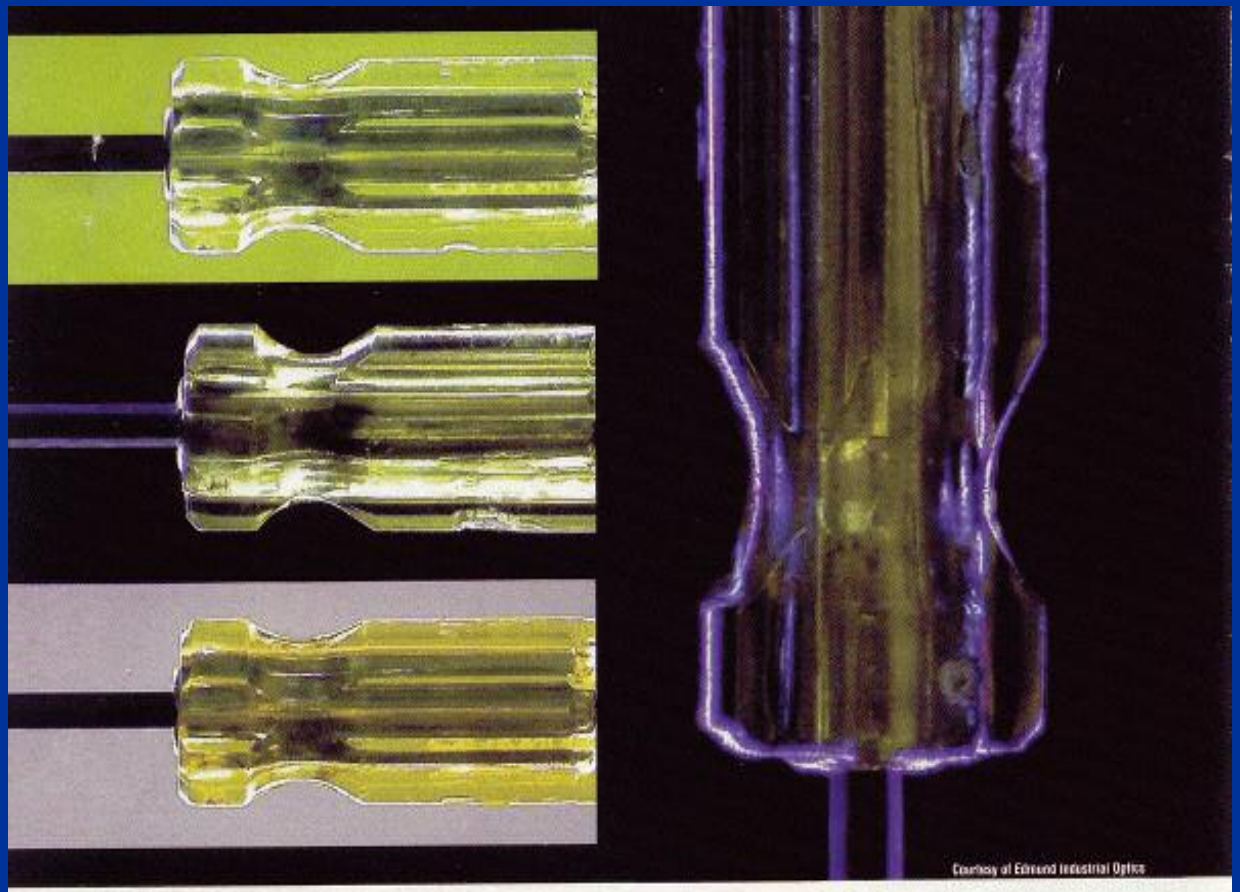
Examples of *usefulness* criteria might be the ability to:

- resolve a defined detail
- discriminate one area from another
- successfully diagnose or interpret

Usefulness

Dental X-ray

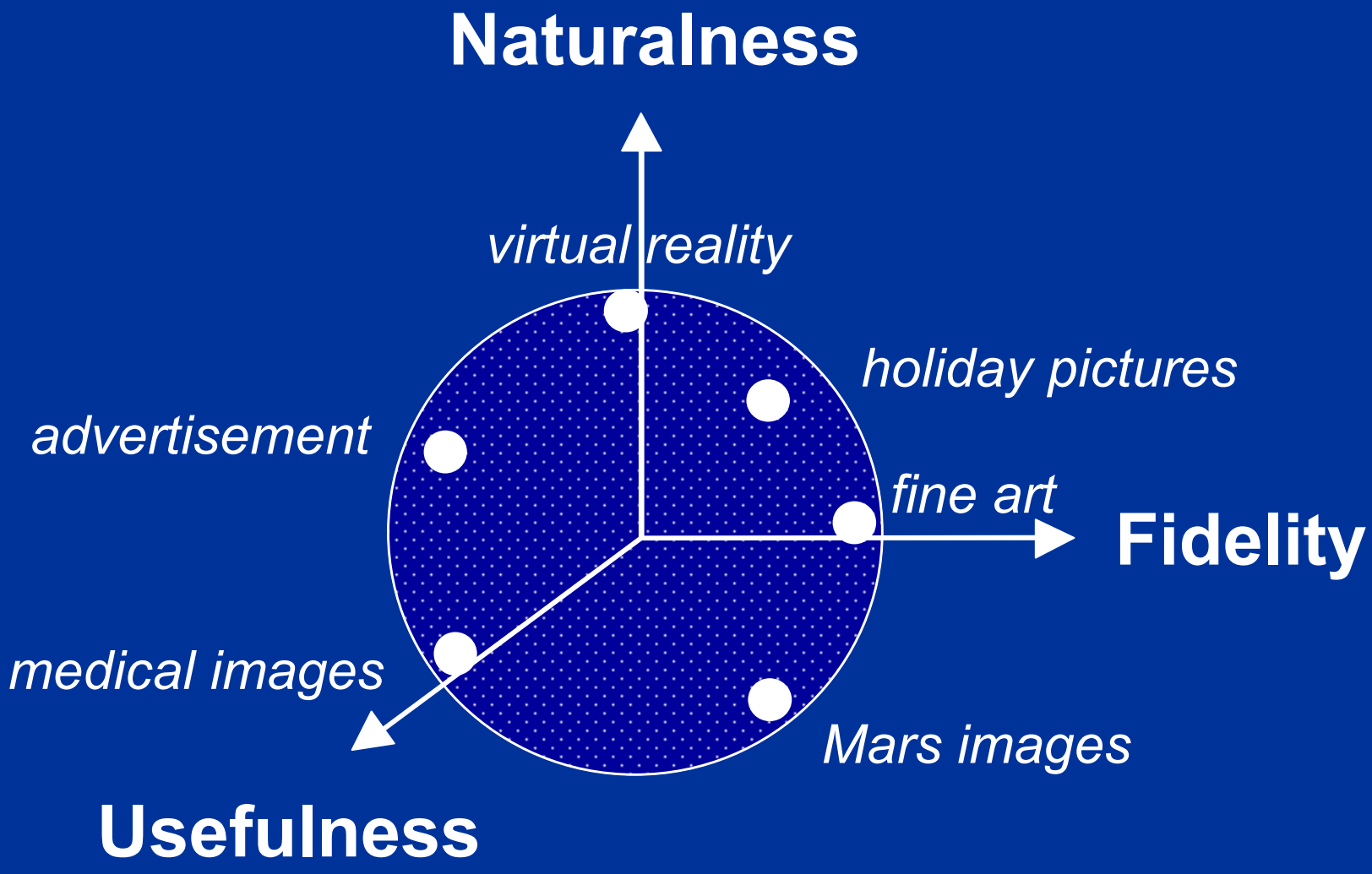
Usefulness



Machine Vision Lighting:
A Study in Contrast

Powell, May 2004

Image Quality Approaches



Endrikhovski, 2002

Problems

Multidimensional in character

Image quality has no single unique definition, yet as observers, we are able to decide almost instantly whether a particular image is of good or poor quality but for us to quantify how good an image is, and the scale of quality is far more difficult.

Additional ‘nesses’ for digital imaging

Digital ‘Nesses’ Artefacts

Effect	Possible Causes
Contouring	poor bit-depth
Blocking (Gibbs effects)	compression
Jaggies	inappropriate pixel size
Ringing	sharpening, compression
Aliasing	sampling
Streaking	pixel-to-pixel non uniformity
Patterning	poor spatial resolution, dithering
Colour misregistration	images from different channels not geometrically identical

Measurement

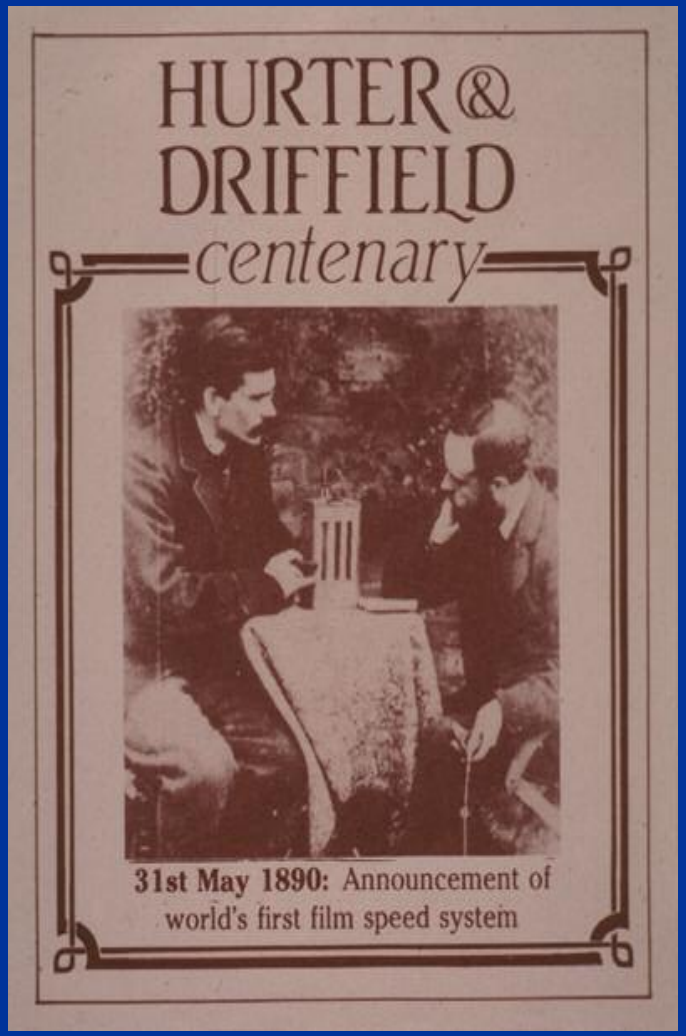
- Physical measures
- Psychophysical aspects
- Inter – relationships

Measurements

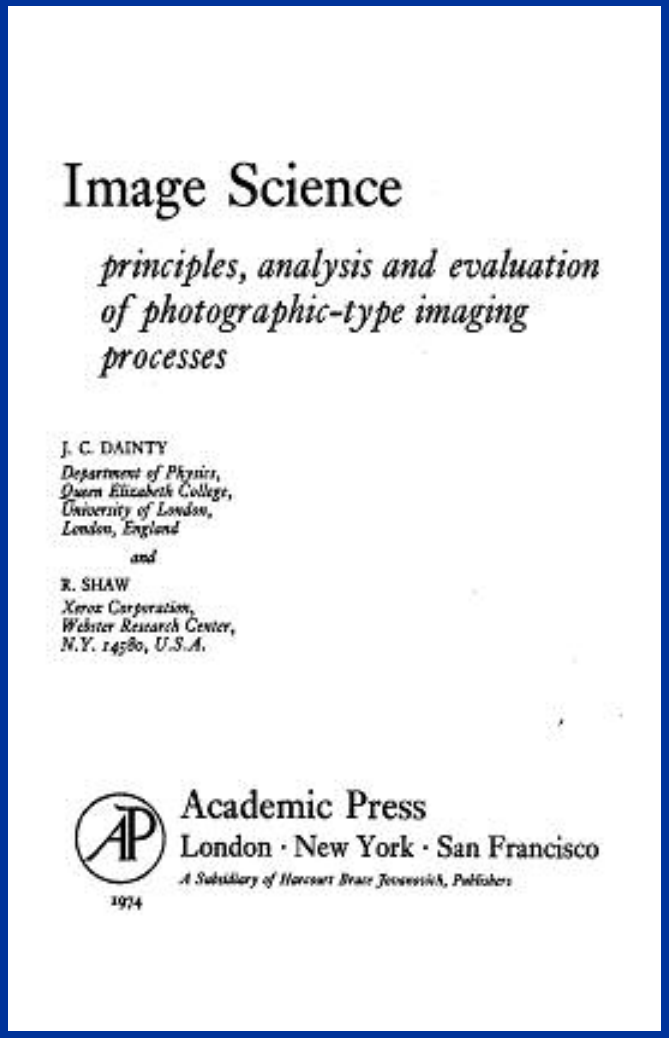
Attribute	Physical Measure
Colour	Spectral data, Chromaticities, Colour spaces etc.
Tone (contrast)	Gamma, Density, *PV*, Characteristic Curve, Tone Reproduction Curve, Density Histogram, *OECF*
Resolution (detail)	Resolving Power, l/mm, dpi, ppi
Sharpness (edges)	Acutance, *PSF, OTF, LSF, MTF, SFR*
Noise	Granularity, Standard Deviation (graininess, electronic noise) Noise-Power (Wiener) Spectrum
Information	Entropy, Information Capacity

Physical Measurements

Beginnings



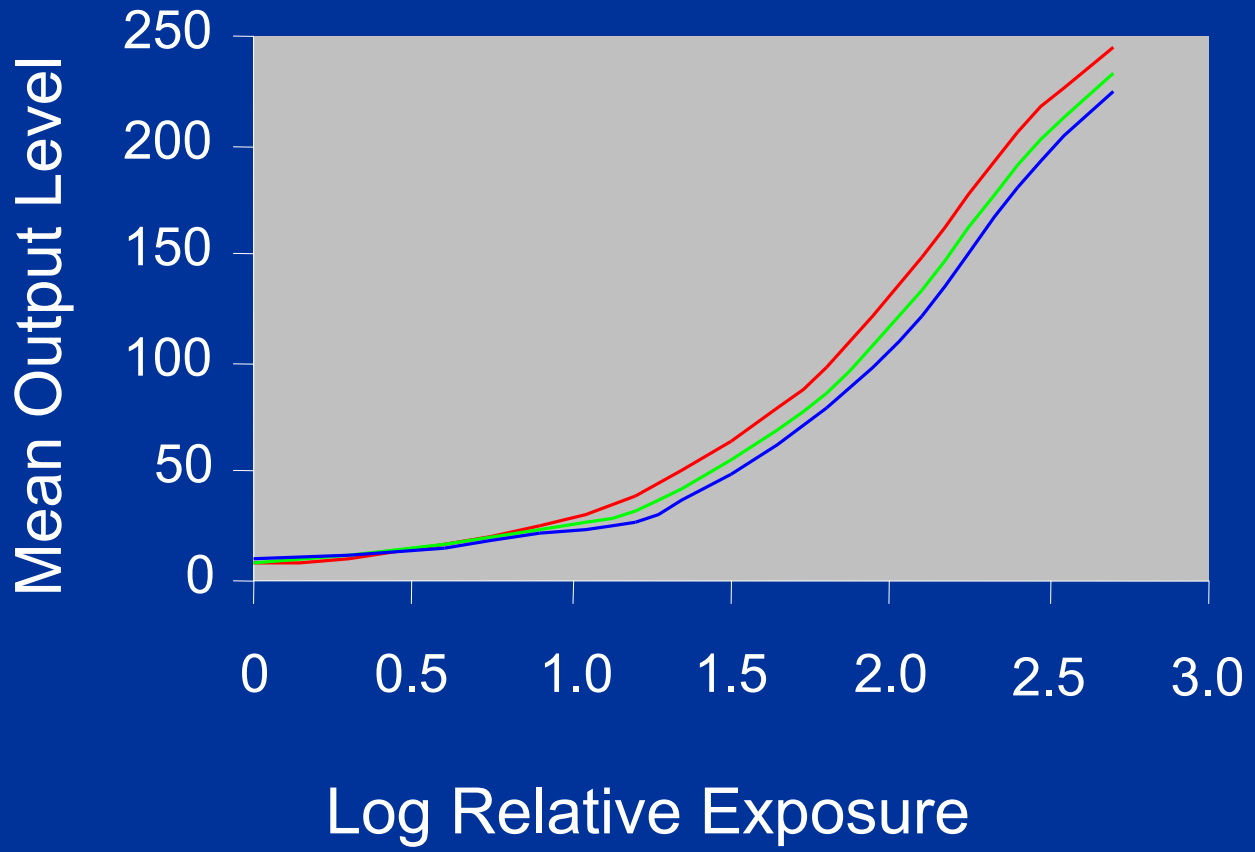
Fundamental Physical Measures



(1974)

(1975)

Opto-Electronic Conversion Function (OECF)

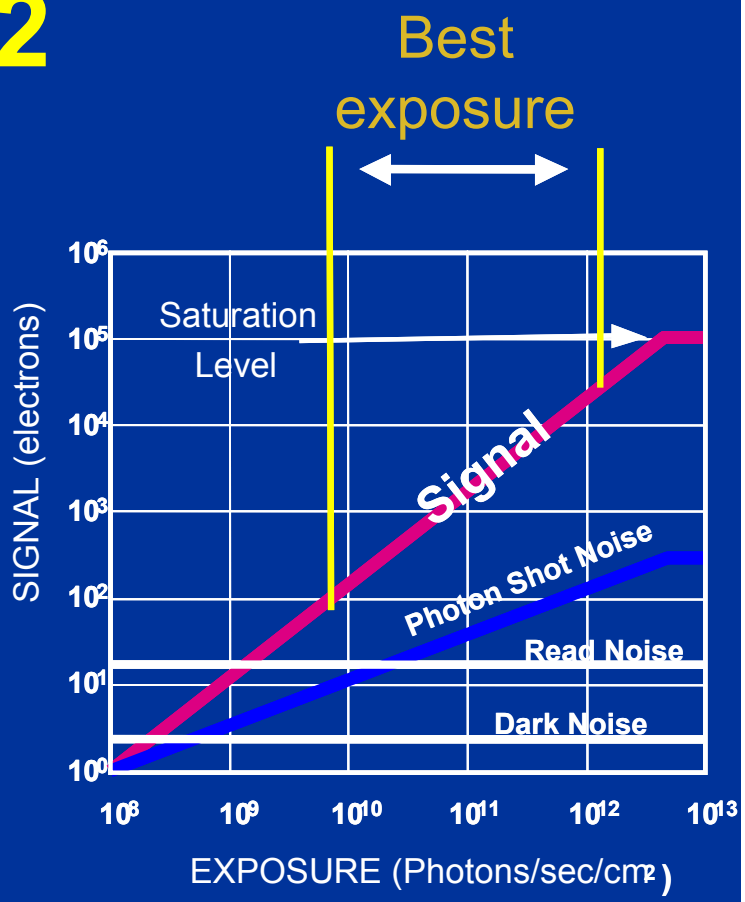


Methods for Measuring Opto-electronic Conversion Functions (OECF): ISO 14524

The standard describes methods for measuring and reporting the relationship between the input scene log luminance values and the digital output levels for a digital camera.

Determination of ISO Speed ISO 12232

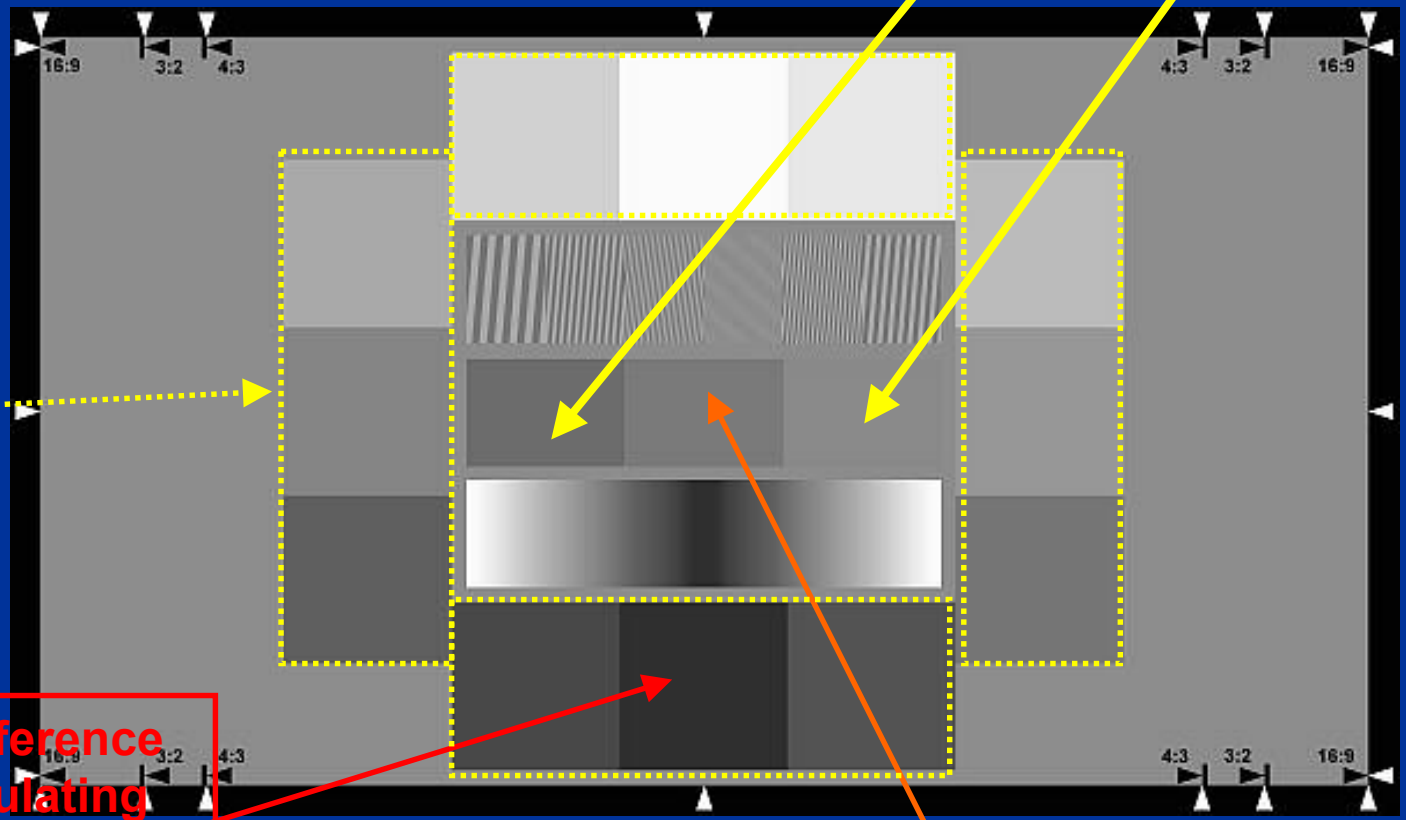
- ISO speed of a digital camera attempt to match ISO rating of film camera systems
- provides a method for measuring and reporting ISO speed metrics that correlate with image quality



(Saturation and noise based)

Muammar, 2008

ISO Test Chart ISO 15739



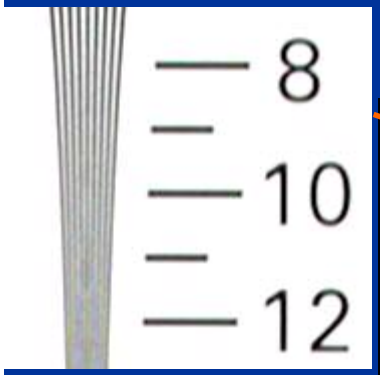
Patches used for calculating incremental gain

OECF

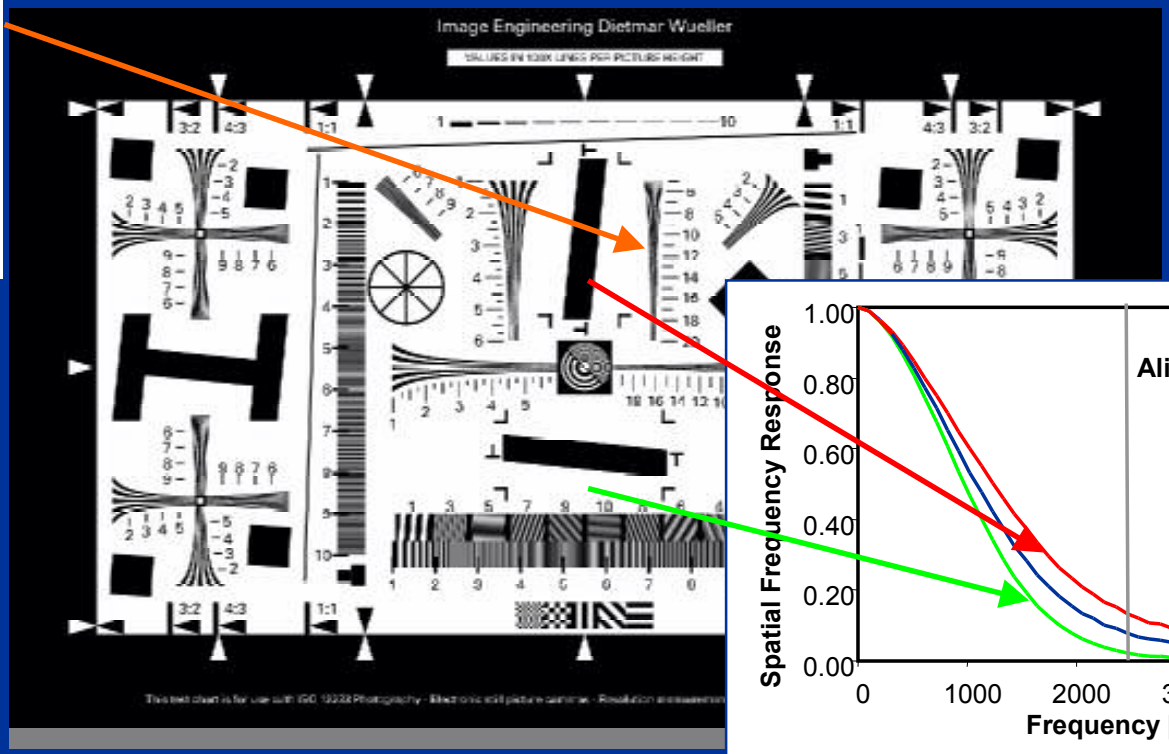
Black reference for calculating DSC dynamic range

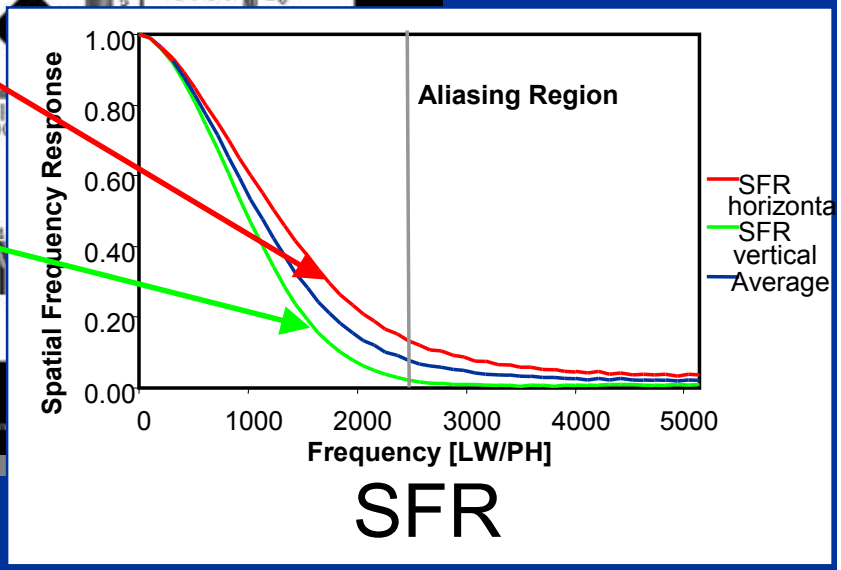
18% reflectance for calculating noise

Measurements of Visual Resolution & SFR: ISO 12233



Visual





SFR

Universal Test Target

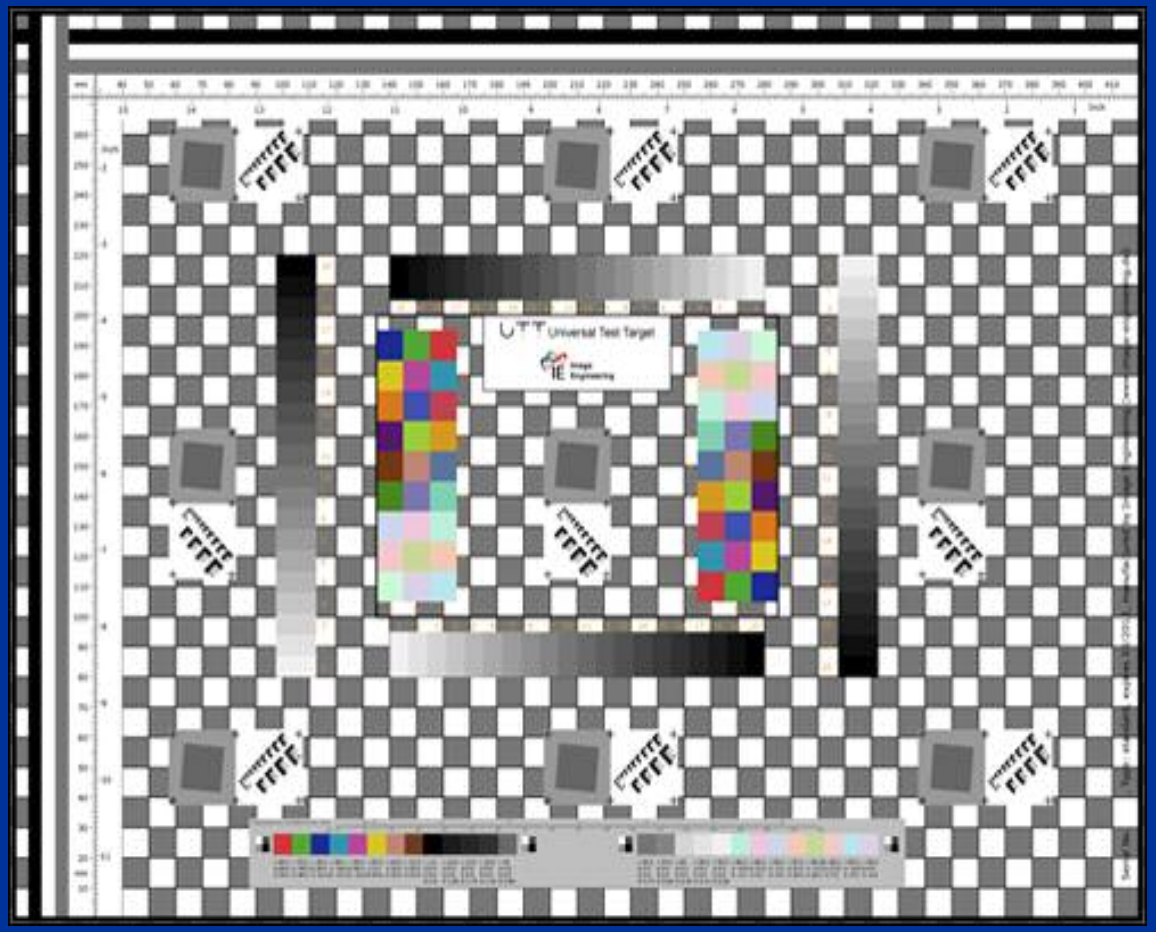


Image Engineering Dietmar Wueller , 1 Sep 2009

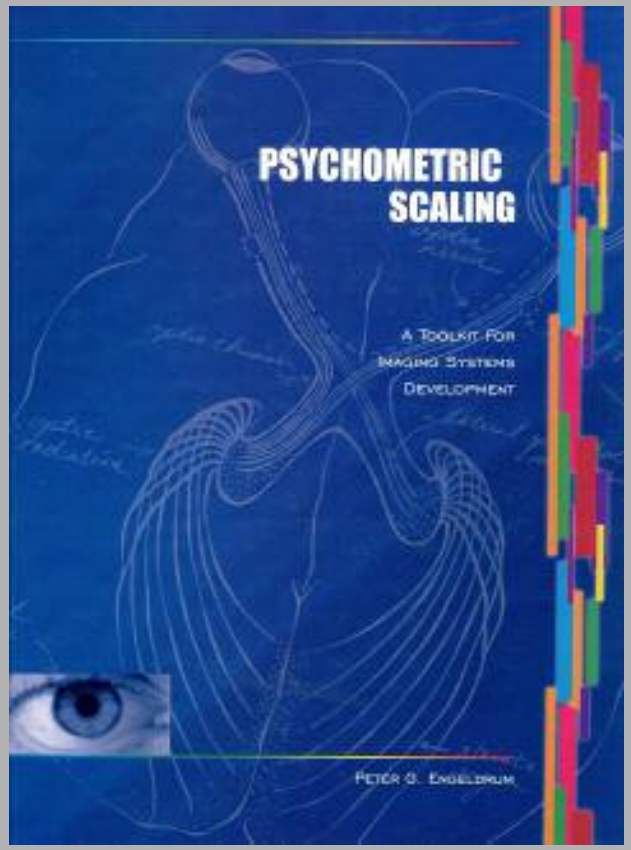
Psychophysics

Science of investigations of the quantitative relationships between physical events and the corresponding psychological events.

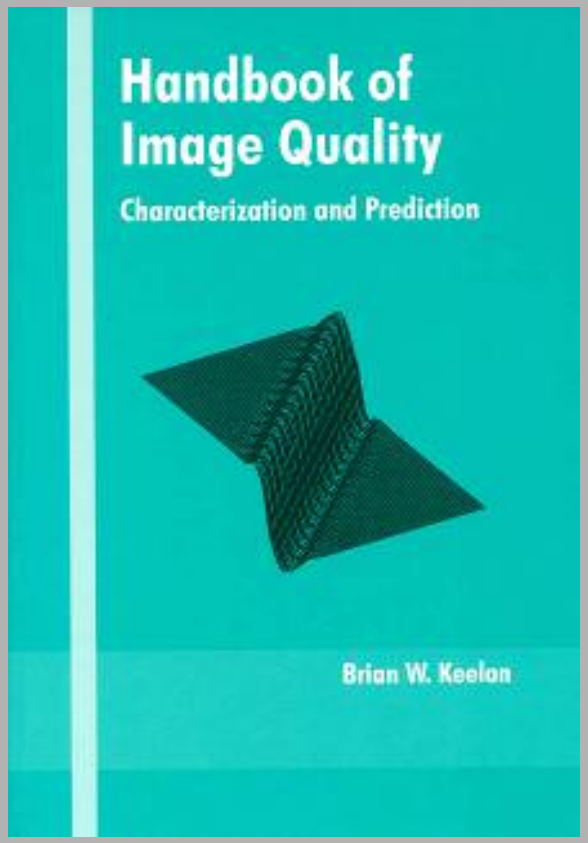
i.e., quantitative relationships between stimuli and responses

Psychometrics

Provide quantification of qualitative attributes



2000



2002

Scaling Methods

- Pair Comparisons
- Categorical Methods
- Rank Order
- Interval Judgment
- Ratio Judgment
- Magnitude Estimation
- Pass/fail

Psychophysical Experimental Method to Estimate Image Quality: ISO 20462

Part 1: Overview of psychophysical elements Describes how the standard could be extended to include other psychometric techniques.

Part 2: Triplet comparison method Method for subjective image quality assessment

Part 3: Quality Ruler Method Describes a method for generating quality rulers varying in sharpness.

Just Noticeable Difference (JND)

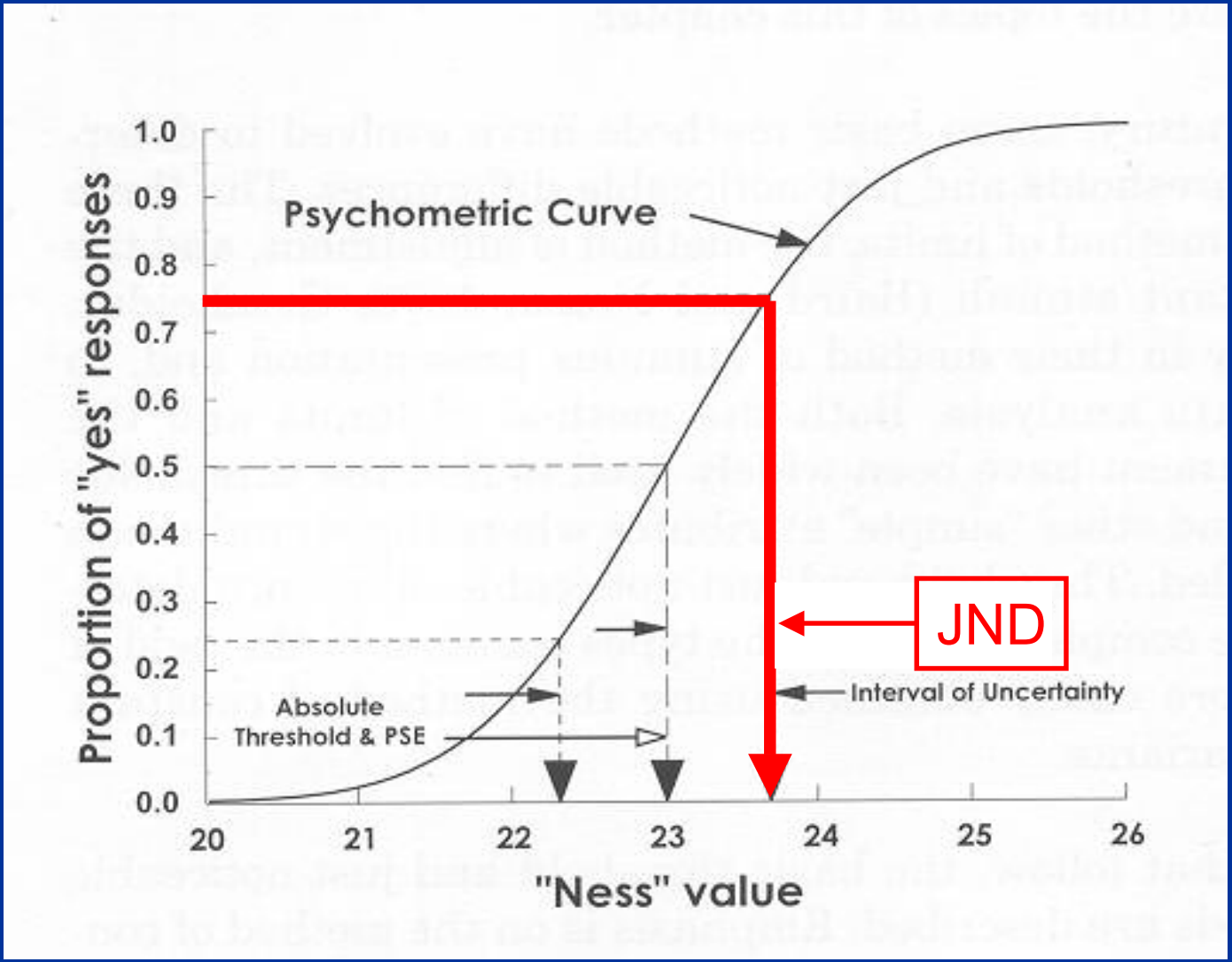
Attribute JND

measure of the detectability of appearance variations, corresponding to a stimulus difference that leads to a 75:25 proportion of responses in a paired comparison

Quality JND

measure of the significance or importance of quality variations, corresponding to a stimulus difference that leads to a 75:25 proportion of responses in a paired comparison task in which multivariate stimuli pairs are assessed in terms of overall image quality

Just Noticeable Difference (JND)



Engledrum, 2000

Metrics

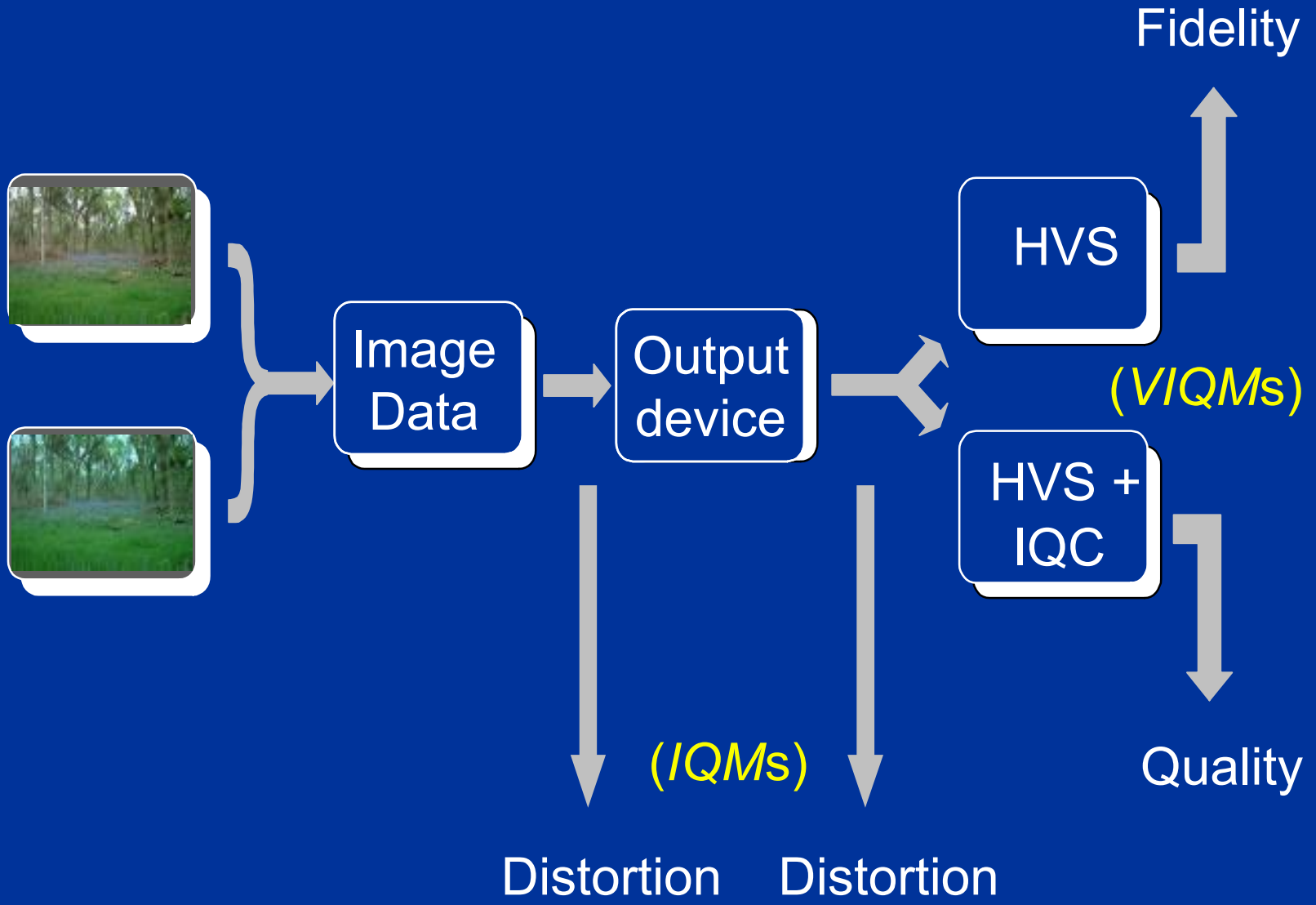
Image Quality Metric *(IQM):*

Single numbers (figures of merit) derived from physical measurements for the system which relate to perceptions of image quality

Visual Image Quality Metric *(VIQM):*

Single numbers (figures of merit) derived from physical measurements for the system and the eye which relate to perceptions of image quality

Image Quality Metrics



Multivariate Metric (Minkowski)

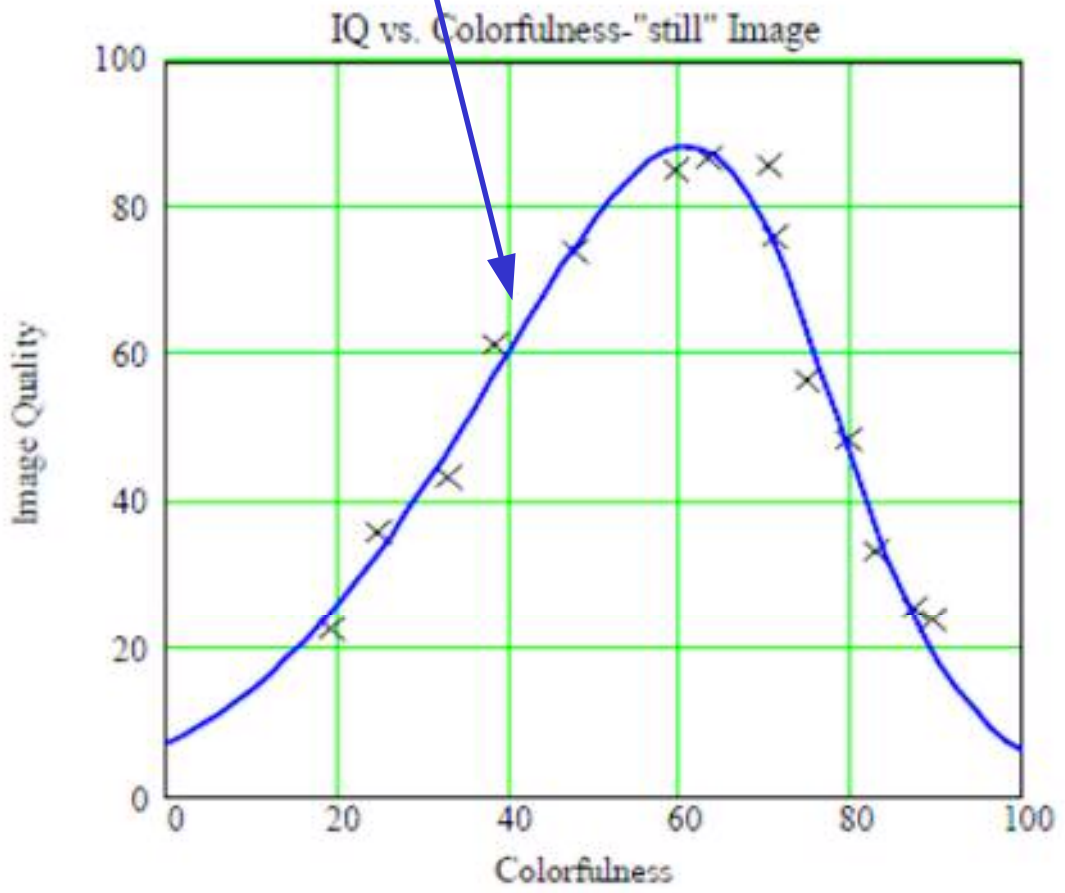
IQM given by:

$$[0.413(sharpness)^{-3.14} + 0.422\,(10\text{-}graininess)^{-3.4}]^{-1/3.4} - 0.532$$

Bartleson, 1982

Minkowski Metric

$$IQ = \left(a1 * ness1^{p} + a2 * fw(a,b,c,d,x0,x1)^{p}\right)^{1/p}$$



Engledrum, 2002

Image Quality Metric (IQM)

Colour Difference:

CIE 1976 CIELAB Colour Difference:

$$\Delta E^*_{ab} = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2}$$

- Does not take viewing conditions into account

Later colour difference formulae (CIE94, CIEDE2000) do include viewing conditions

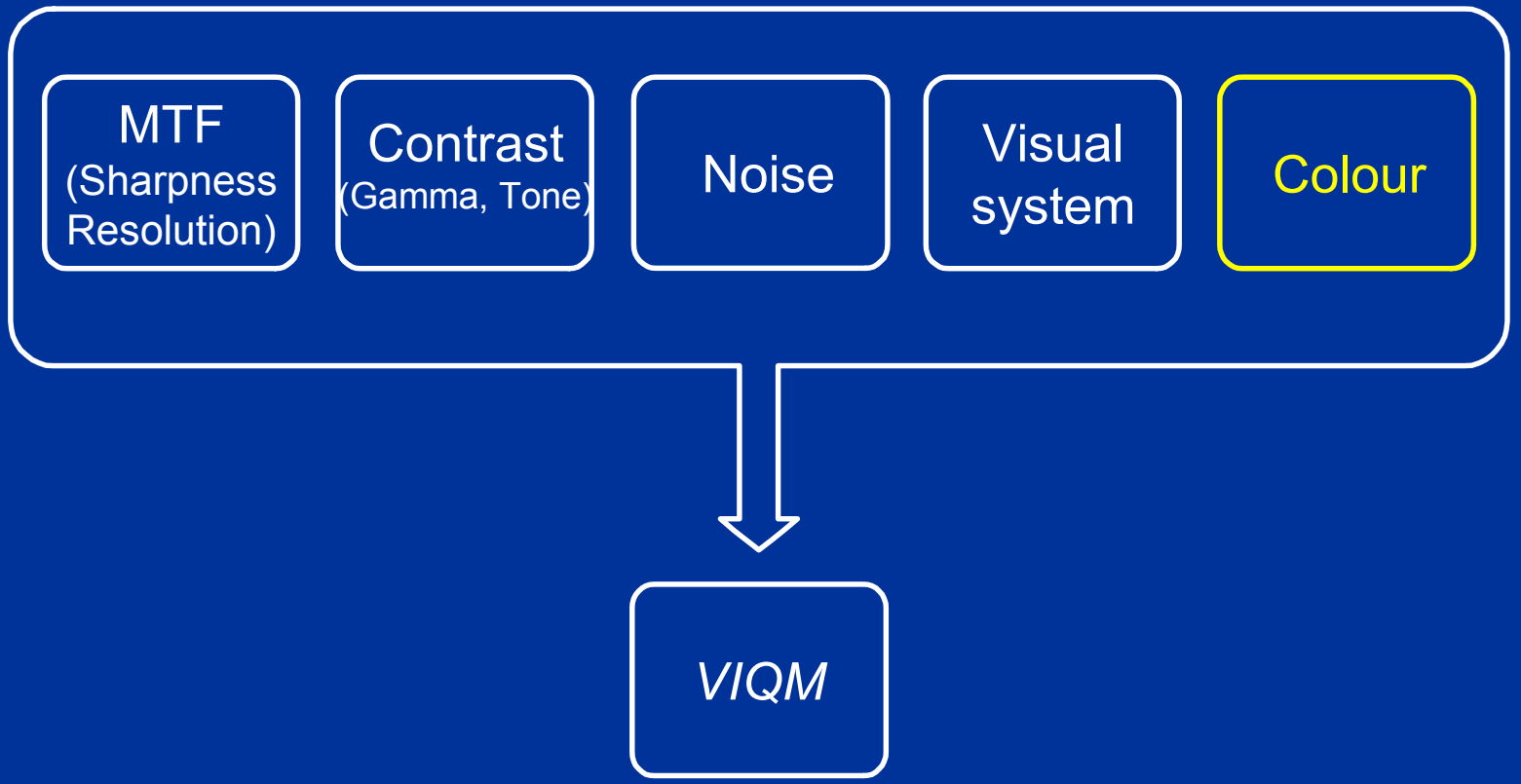
Variable Exponent Minkowski Metric

$$\Delta Q = (\Sigma \Delta Q^{\varepsilon})^{1/\varepsilon}$$

In JNDs of quality change

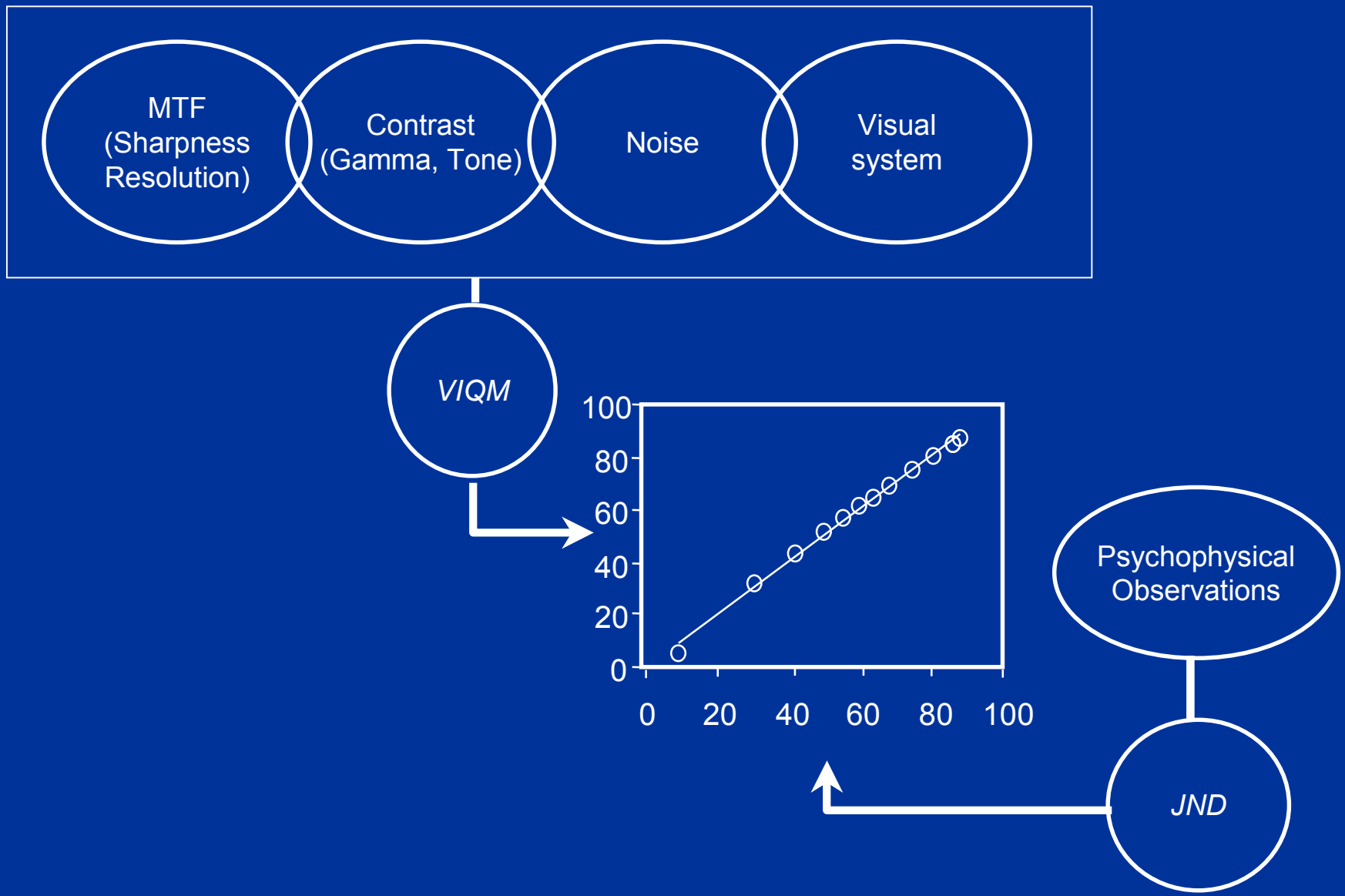
Keelan, 2000

Visual Image Quality Metrics
(VIQMs)

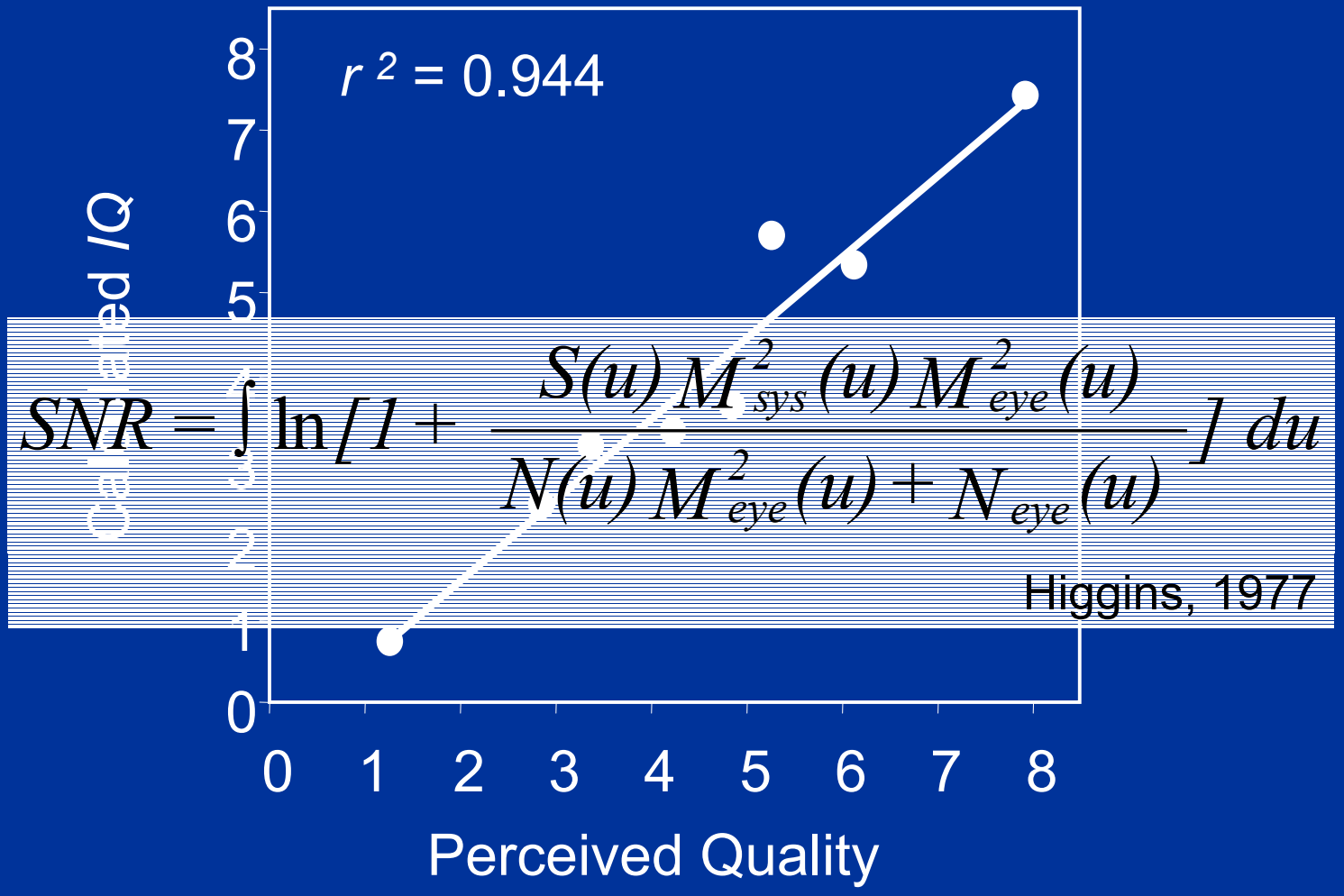


Generally are based on some form of signal to noise ratio

VIQM Approach



Sharpness and Noise Multivariate *IQ*



$$SNR = \int \ln\left[1 + \frac{S(u)\,M_{sys}^2(u)\,M_{eye}^2(u)}{N(u)\,M_{eye}^2(u) + N_{eye}(u)}\right] du$$

Higgins, 1977

Stone, Jacobson & Attridge 1994

Visual Image Quality Metric

Barten's Square Root Integral (*SQRI*):

$$J = \frac{1}{\ln(2)} \int_{u_{\min}}^{u_{\max}} \sqrt{\frac{M(u)}{m_t(u)}}\, \mathrm{d}(\ln u)$$

MTF display system

modulation threshold function of the eye

Barten, 1990

Visual Image Quality Metric

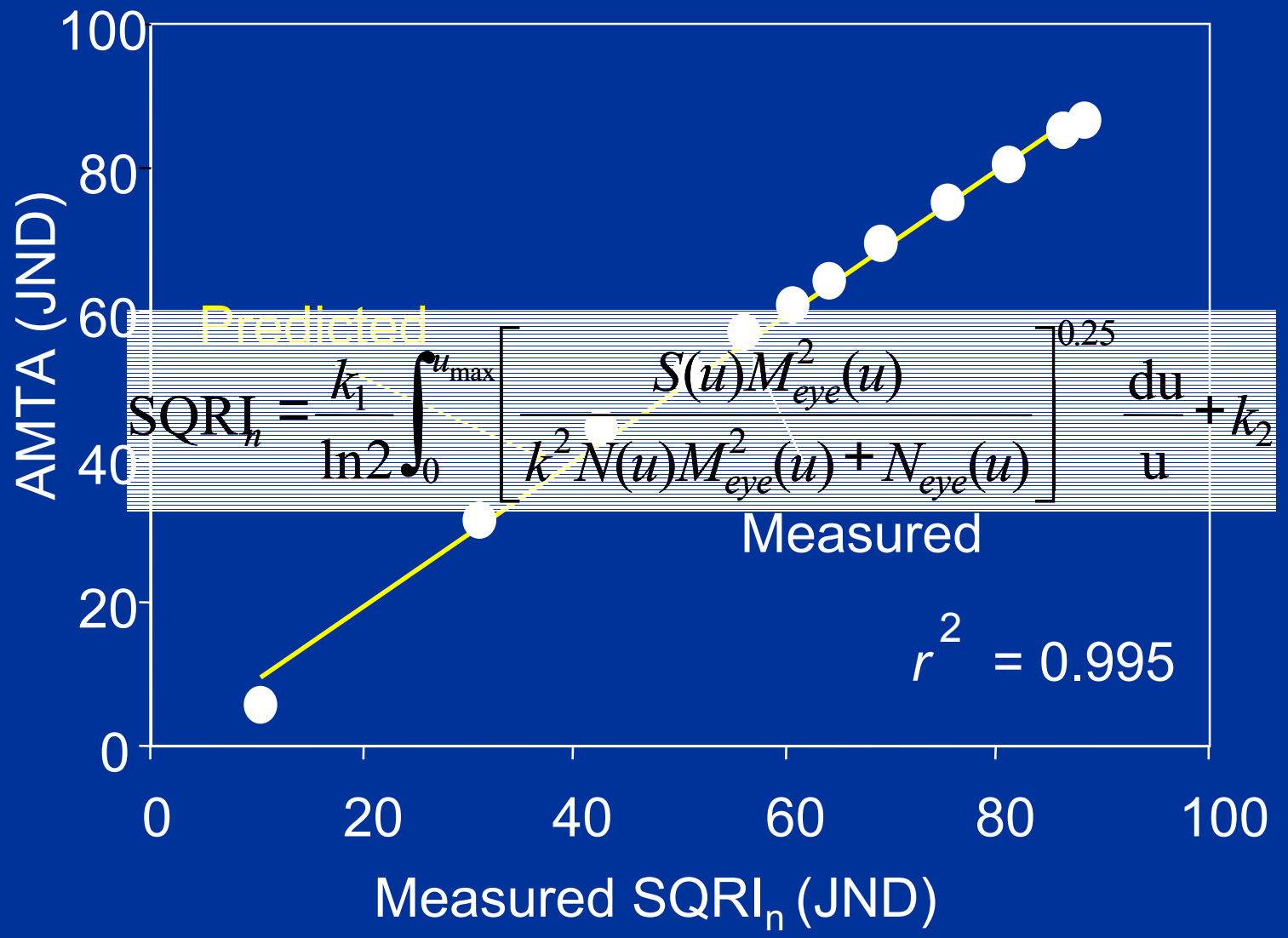
Square Root Integral with Noise ($SQRI_n$)

$$SQRI_n = \frac{k_1}{\ln 2}\int_0^{u_{\max}} \left[\frac{S(u)M_{eye}^2(u)}{k^2 N(u)M_{eye}^2(u) + N_{eye}(u)}\right]^{0.25} \frac{\mathrm{du}}{\mathrm{u}} + k_2$$

$$\{S(u) = S_0(u)M_1^2(u).....M_n^2(u)\}$$

(Barten's $SQRI_n$ reformulated by Töpfer & Jacobson, 1993)

VIQM ($SQRI_n$) and Sharpness



Töpfer & Jacobson, 1993

Examples of *VIQMs*

MTFs, Signals, Sharpness, Noise etc: Schade, 1950+
System Modulation Transfer Acutance (*SMTA*) : Crane, 1964
Signal-to-Noise Ratio (*SNR*) : Nelson, 1973
Modulation Transfer Acutance (*AMTA*): Crane, 1983
(Quality: graininess and sharpness (*Qg/s*) : Bartleson, 1982
Square-root Integral (*SQRI*) : Barten, 1990+
Perceived Information Capacity (*PIC*) : Töpfer & Jacobson, 1993

Visible Differences Predictor (*VDP*) : Daly, 1992
Visual information and processing: Janssen & Blommaert, 1997+
Effective Pictorial Information Capacity (*EPIC*) : Jenkin et al., 2005

Colour Reproduction Index (*CRI*) : Pointer, 1986+
Colour Difference: CIE,1976, CIECAM97s :CIE, 1997, CIEDE2000
R-LAB: Fairchild and Berns, 1993
S-CIELAB:Zhang et al., 1996
Cognition: Usefulness, Naturalness: Endrikhovski et al, 1999+
CSF/CIEDE2000, Colour Image Difference Metric:
Johnson and Fairchild , 2002

Metrics Applied to Digital Images

Mean-Square-Error (*MSE, RMSE*)
Mean-Square-Error after Non-Linearity (*MSENL*)
Mannos-Sakrison (*MANNOS*)
Logarithmic Image Processing (*LIP*)
Distortion Contrast (*DCON*)
Bit Rate (*BITS*)
Mean Intensity (*MI*)
Spectrum Slope (*SS*)
Spectrum Slope over Mean Intensity (*SS/MI*)
Local Contrast (*LCON*)

Root Mean Square Error *(RMSE)*

$$RMSE = \sqrt{\frac{1}{XY}\sum_{x=0}^{X-1}\sum_{y=0}^{Y-1}\left|f(x,y) - f'(x,y)\right|^2}$$

(f, f' are original and changed images at spatial locations x,y, X *and* Y are total number of horizontal and vertical pixels)

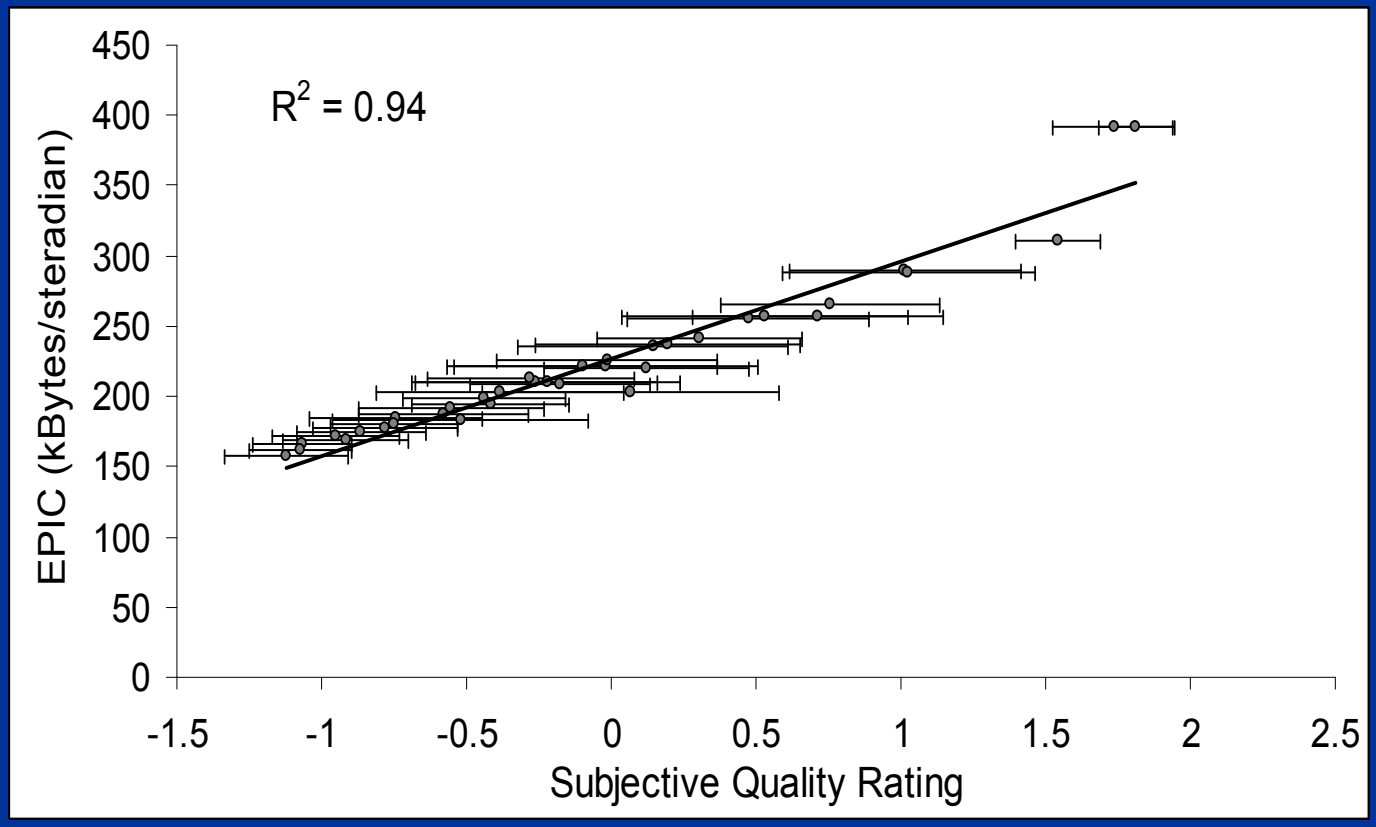
- No account of visual significance
- Output device not considered
- Cognitive aspects not considered

Effective Pictorial Information Capacity (EPIC)

1. Determine total *MTF* of system components and the eye
2. Inverse Fourier transform to find effective pixel size
3. Determine total noise using effective pixel size as aperture, including scene dependent noise for distorted (e.g. blurred) images
4. Find Information capacity ($I = n \log_2 m$) in bits
5. Convert to bits/steradian from image size and viewing distance

Jenkin, Triantaphillidou and Richardson, 2007

Effective Pictorial Information Capacity (EPIC)



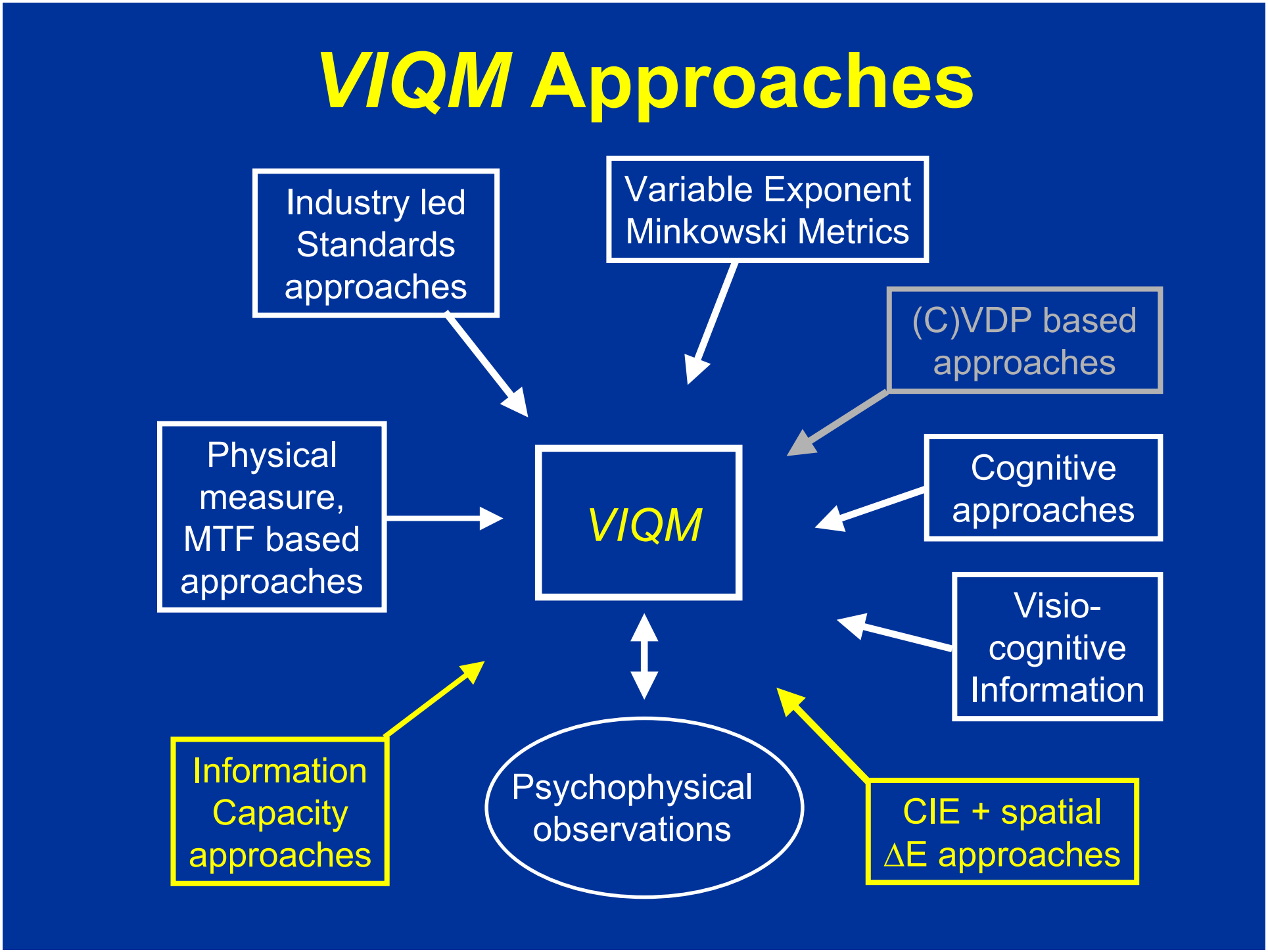
Jenkin, Triantaphillidou and Richardson, 2007

Specific approaches

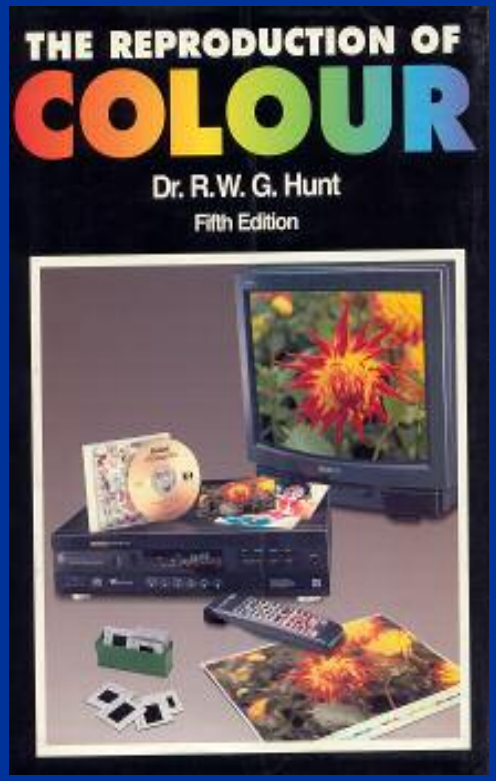
Standards : e.g. NCITS W1.1
Image Quality for Printer Systems –

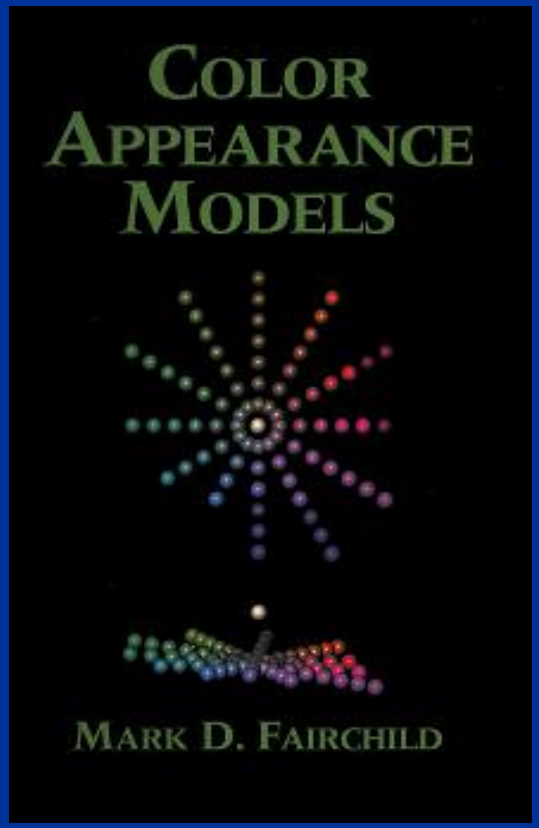
Considerations of:
Text and Line quality, Micro uniformity, Macro uniformity, Gloss/Gloss uniformity,
Color rendition, Effective tone levels,
Effective resolution in pictorials, Adjacency

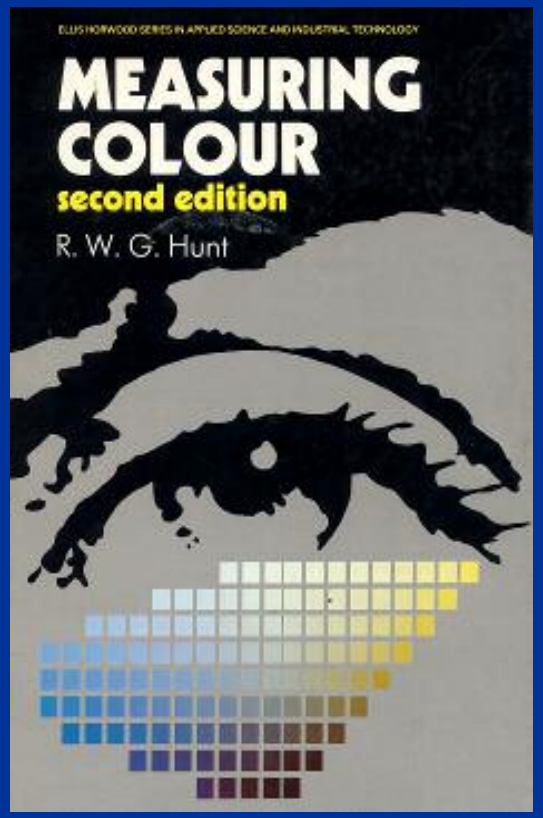
VIQM Approaches



Colour Principles and Measurement





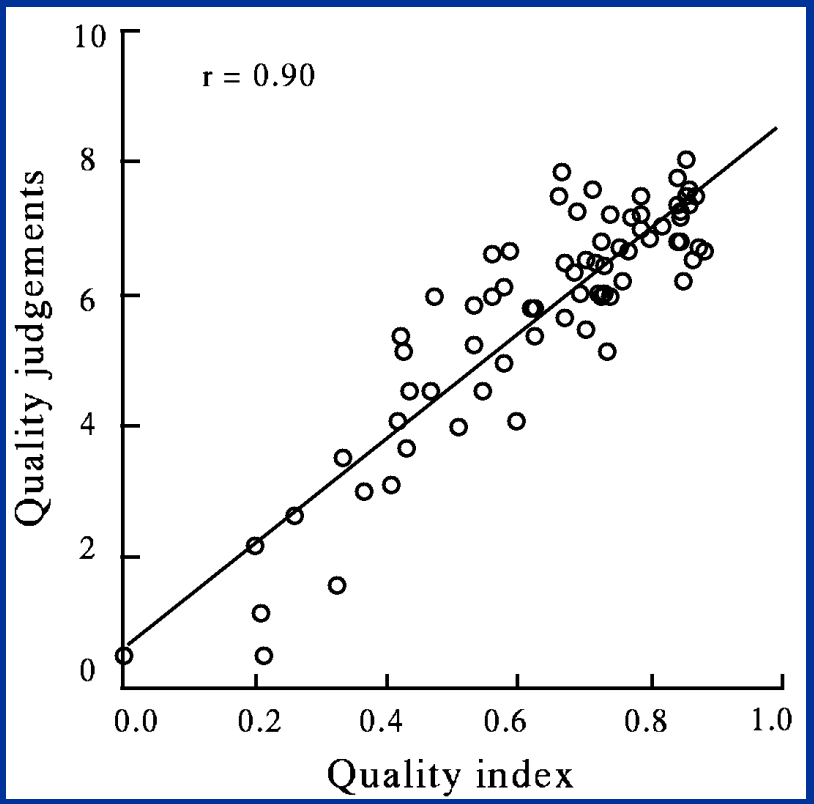


Colour Reproduction Index (*CRI*)

- For determinations of absolute colour appearance
- Based on Hunt model for colour vision
- Includes viewing conditions
- Excludes spatial aspects

Pointer, 1986

Image Quality Index



For prediction of colour reproduction perceived as natural, unnatural, pleasant or unpleasant for an average observer.

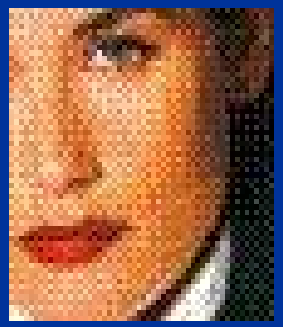
Endrikhovski, 1999

Enhancing Perceived Quality

Original **Processed**

Endrikhovski, 2002

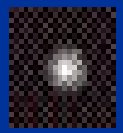
S-CIELAB



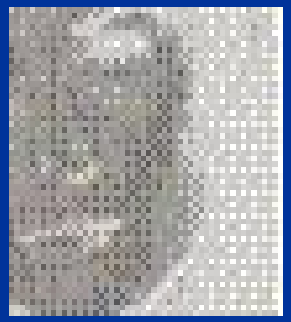
Colour Image

Lum

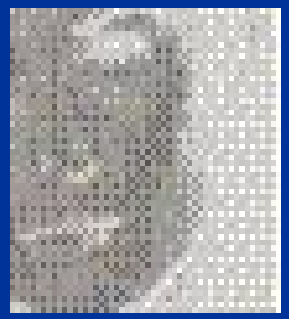
Spatial filter

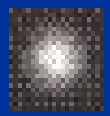


R/G



B/Y

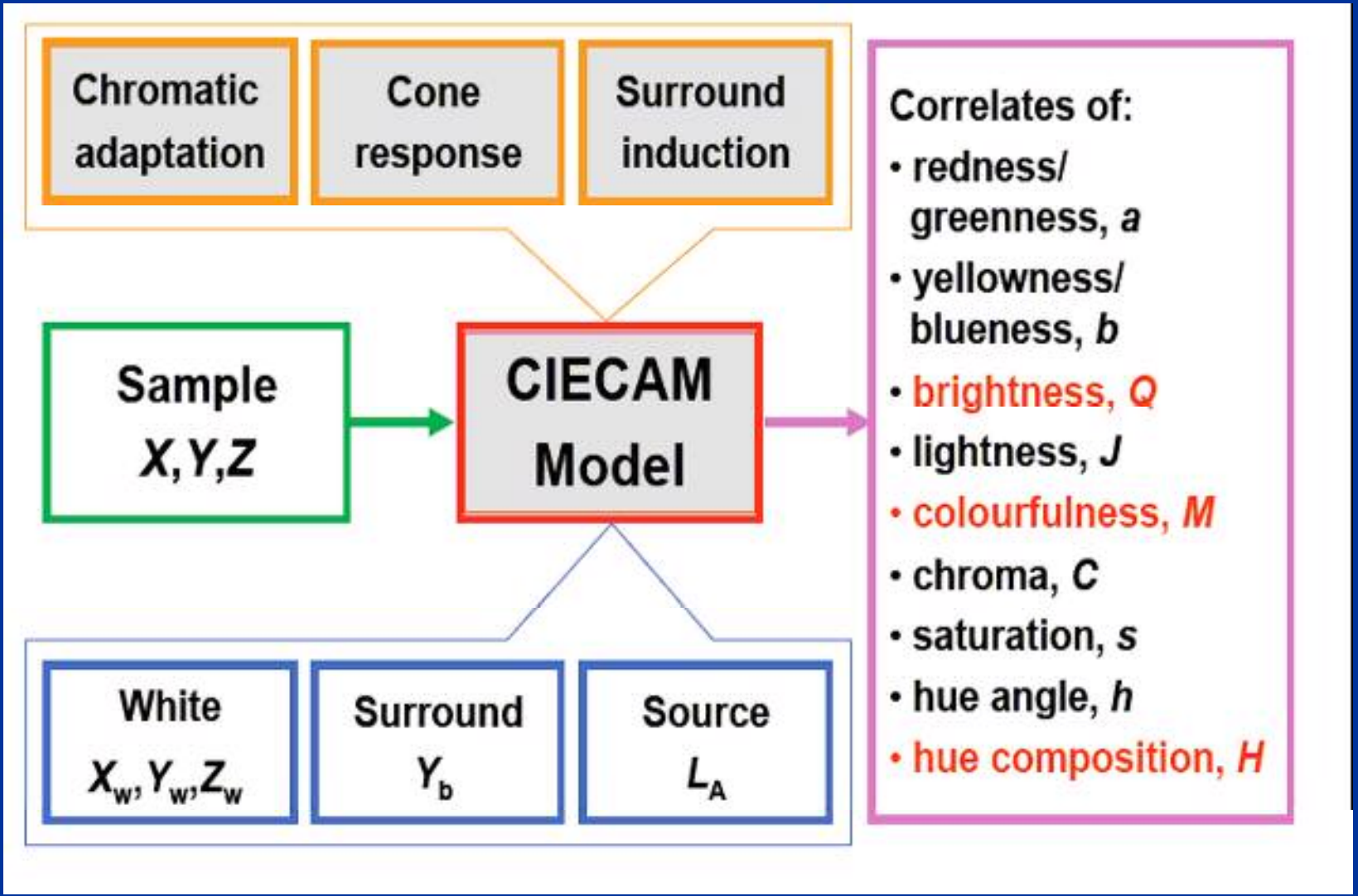




XYZ → S-CIELAB

Zhang & Wandell, 1997

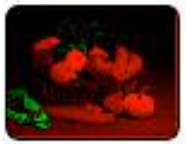
CIECAM02



Pointer 2009

i-CAM

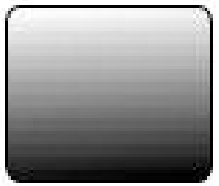

Two input images are given: an original and a reproduction

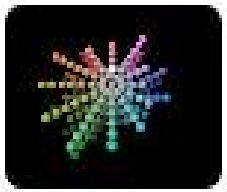

The input images are transformed into an opponent colour space



The opponent channels are filtered using contrast sensitivity functions which are adapted based on the spatial information in the image. The filtering decreases information that is not visible and increases information that is most visible



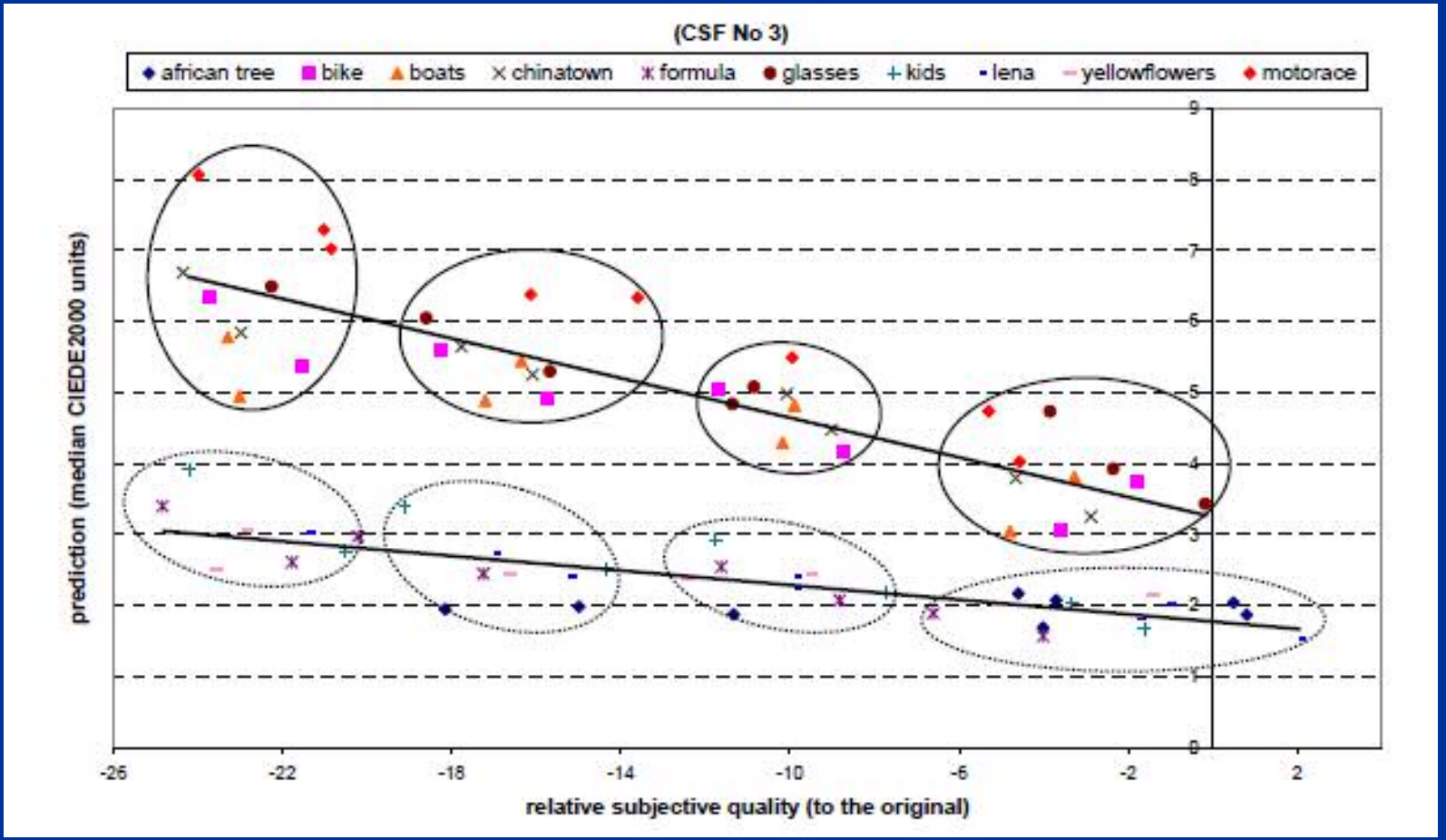

Models of local attention and local contrast are applied to the filtered images




The filtered images are then converted into CIELAB coordinates and a Pixel-by Pixel colour difference calculated

Johnson and Fairchild, 2002

iCAM



Orfanidoua, Triantaphillidou and Allen, 2008

The '…..ishes'

More than 50 VIQMs have been proposed

Signal to noise will always give good correlations!

Use of charts in *VIQM* measurements

Observers

Question asked of Observers

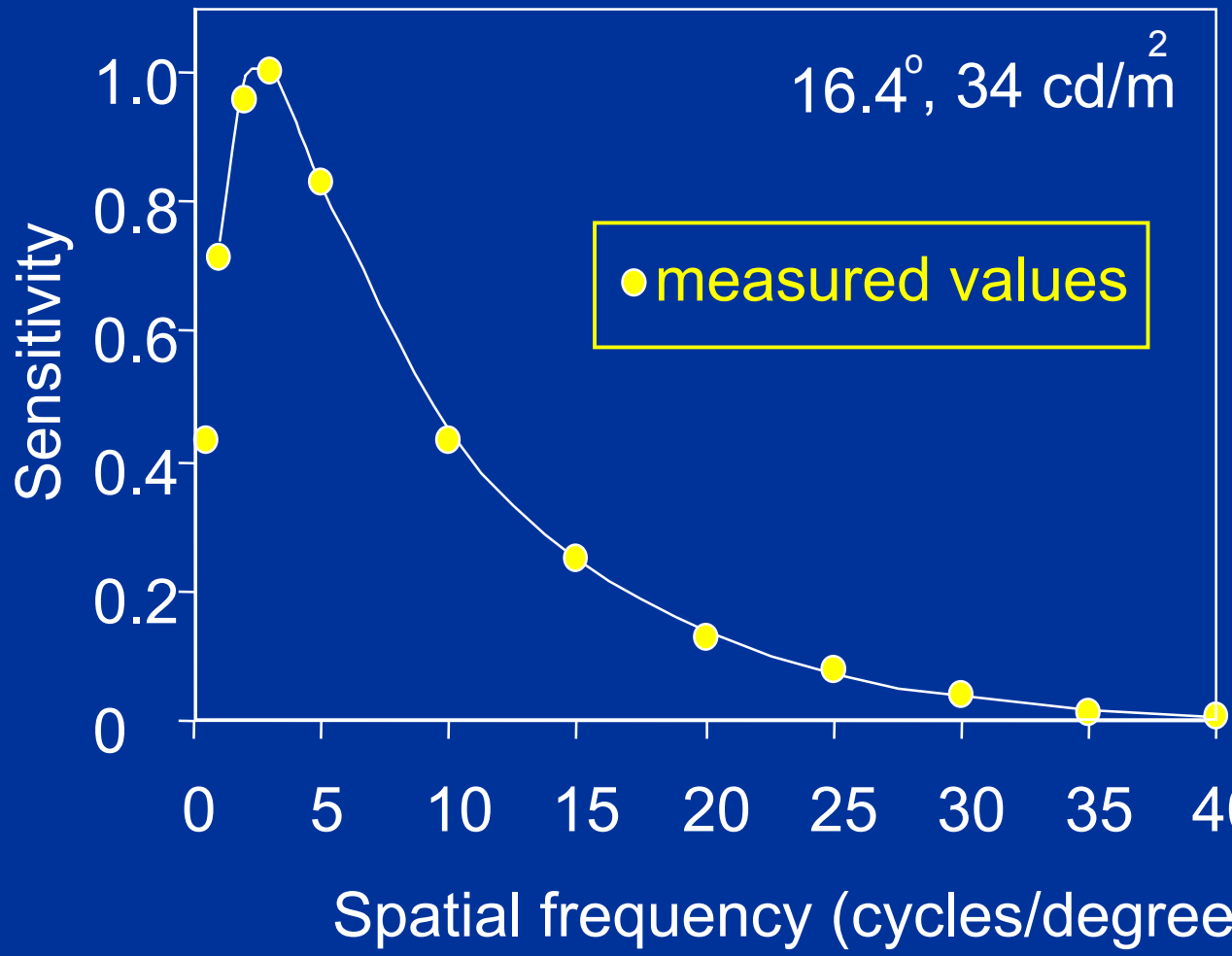
Standard observer

Scenes, Scene Dependency, ROI(salience)

Spatial and colour approaches

Traditional to digital transfers

Contrast Sensitivity of the Human Eye



Barten, 1992

The Standard Observer

TC1-60 of Division 1 of the CIE terms of reference:

1) To specify a baseline achromatic CSF with its reference conditions and reference observer.

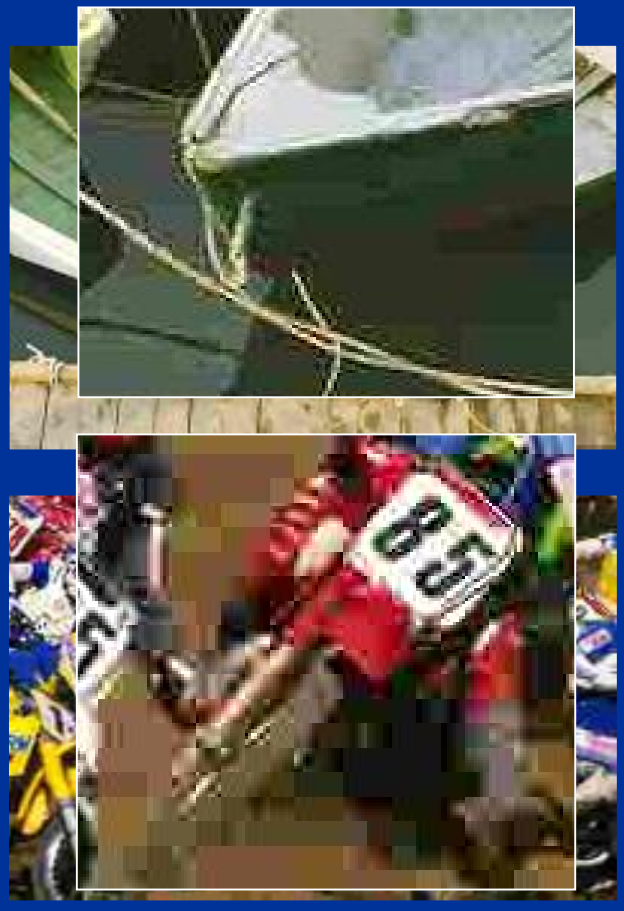
2) To specify CSF extensions based on discrimination thresholds, as well as chromatic CSFs for both detection and discrimination.

Chairman: Eugenio Martinez-Urigas

Scene Dependency and Compression

Non-compressed

JPEG 60:1



JPEG2000 60:1

S. Triantaphillidou, E. Allen, R.E. Jacobson and G.G. Attridge, 2002

Standard Images

Lena

ISO 12640-3: 2007

8 natural scenes

a) N1 Bride and groom

b) N2 People

e) N5 Mandolin

f) N6 Tailor scene

c) N3 Cashew nuts

d) N4 Meal

g) N7 Wool

h) N8 Fruits

Importance of Lightness in Image Quality

Original

Lightness sharp

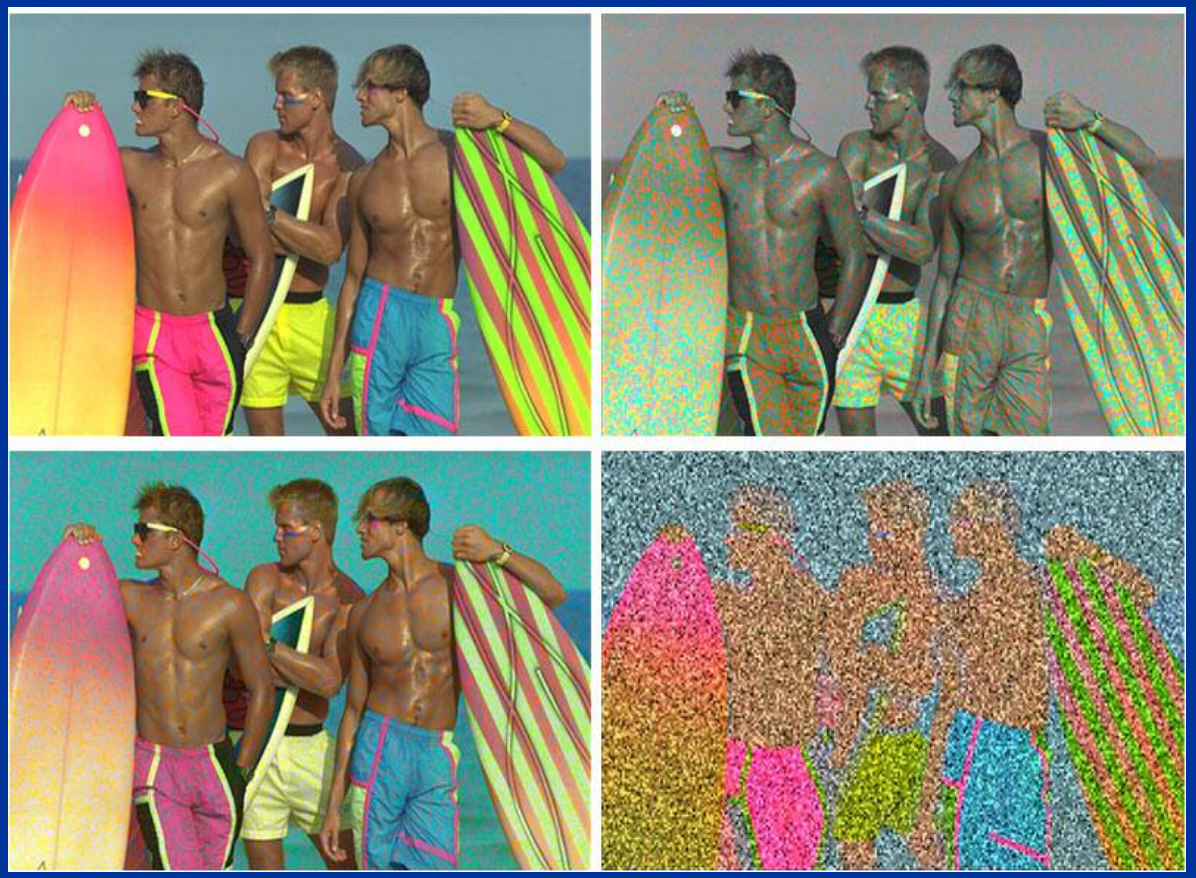
Hue sharp

Saturation sharp

All unsharp

Importance of Lightness in Image Quality

Original



Scrambled for HUE

Scrambled for CHROMA

Scrambled for LIGHTNESS

Endrikhovski, 2002

Digital Transfer Difficulties

Digital systems are difficult to deal with using conventional mathematical processes

- Artefacts
- Anisotropy
- Non-linearity
- Non-stationary

Conclusions *VIQMs*

- Some success in relating complex physical measures to perceptions of image quality
- Provide modelling approach
- Require extensive validation
- Research & development tool
- Move away from *VIQM* single number approach to determining metrics by process steps (e.g.*EPIC, S-CIELAB, i-CAM*)

General Conclusions

- All approaches work and are applied!
- Provide useful data for modelling system changes, benchmarking and improvements
- Lead to determination of fundamental parameters
- Used by all manufacturers and system developers
- Are providing new insights and impetus in perception and measurement of image quality