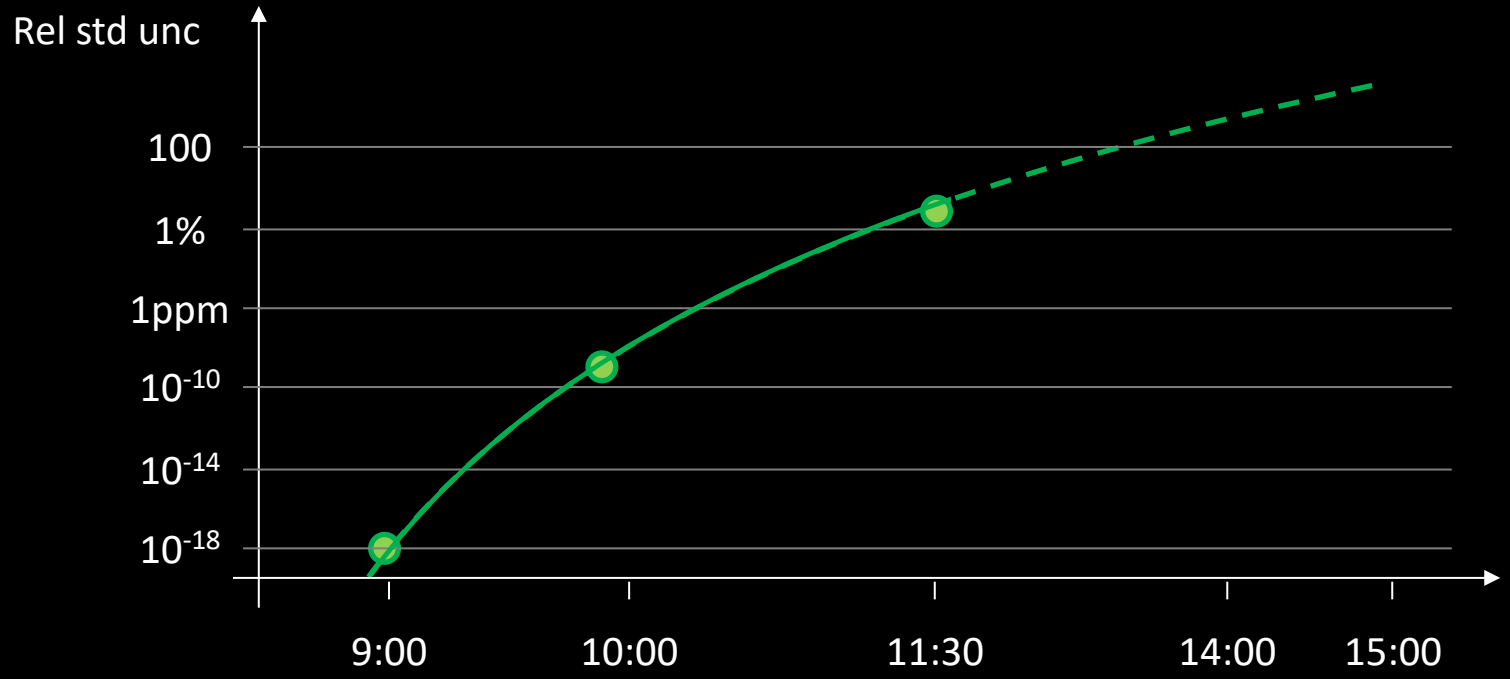
The measurement of appearance

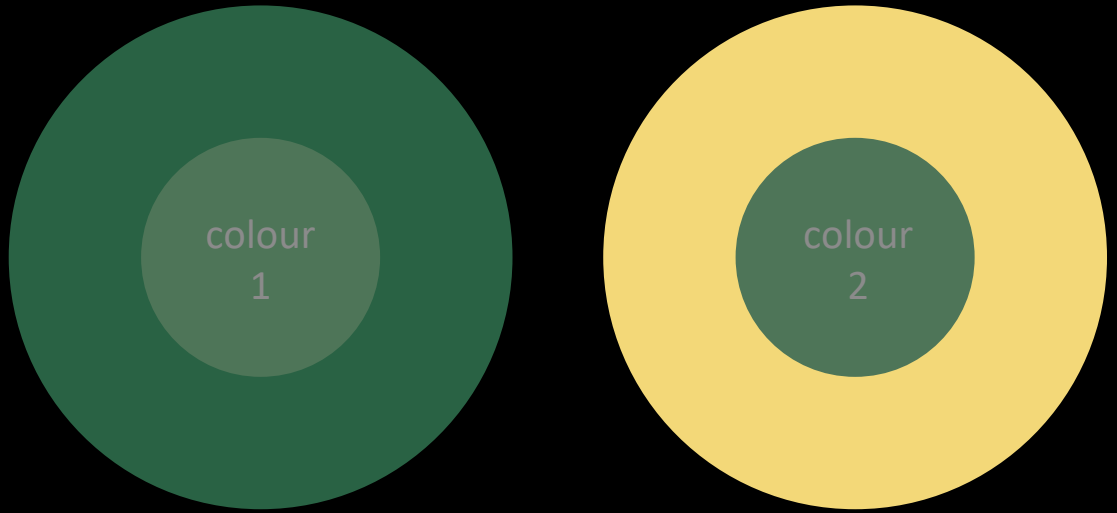
Evolution of the best uncertainty achieved at Varenna school at Day 2



Gaël Obein, LNE-CNAM

The measurement of appearance

Is colour 1 = colour 2 ?



Gaël Obein, LNE-CNAM

Metrology is the science of measurement

The metrologist defines principles and methods allowing to quantify the measurand

Mesurand

Diameter

Method

Caliper

Metrology is the science of measurement

The metrologist defines principles and methods allowing to quantify the measurand

Mesurand

Temperature

Method

Themometer

Metrology is the science of measurement

The metrologist defines principles and methods allowing to quantify the measurand

Mesurand

Appearance

Method

The measurand

What is appearance ?

« Aspect of the visual experience by which the things are recognized »

CIE, International Vocabulary of Lighting, 3rd edition

The measurand

« Aspect of the visual experience by which the things are recognized »

The measurand

« Aspect of the visual experience by which the things are recognized »

Visual attributes

- Colour
- Gloss
- Texture
- Transparency
- Sparkle

Visual attributes

- Enrich our perception of the world
- Provide to the object coherence and unicity
- Are linked to esthetic, sensation of quality and wish to buy

It is essential for the most of industrials to control these attributes

It is essential for the most of industrials to control these attributes

Food industry

It is essential for the most of industrials to control these attributes

Cosmetics

It is essential for the most of industrials to control these attributes

Packaging

It is essential for the most of industrials to control these attributes

Fashion and textile

It is essential for the most of industrials to control these attributes

Virtual reality

It is essential for the most of industrials to control these attributes

Architecture

It is essential for the most of industrials to control these attributes

High tech

It is essential for the most of industrials to control these attributes

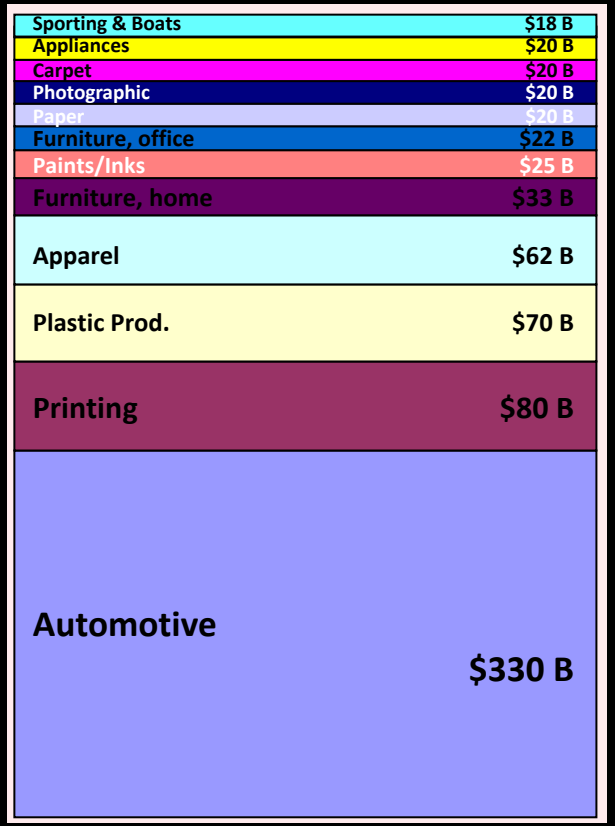
3D Printing

It is essential for the most of industrials to control these attributes

Automotive

It is essential for the most of industrials to control these attributes

$700 B is the estimated Value of Shipments in industries for which unacceptable appearance may result in “NO SALE”



From 1999 Annual Survey of Manufacturers, U.S. Census Bureau, 2001

Visual attributes

- Enrich our perception of the world
- Provide to the object coherence and unicity
- Are linked to esthetic, sensation of quality and wish to buy

It is essential for the most of industrials to control these attributes

Metrologist must provide to industry :

- Measurement solution to control appearance
- Stable standard artefacts traceable to national references
- Guidelines and measurement protocols to ensure measurement are performed in a correct way

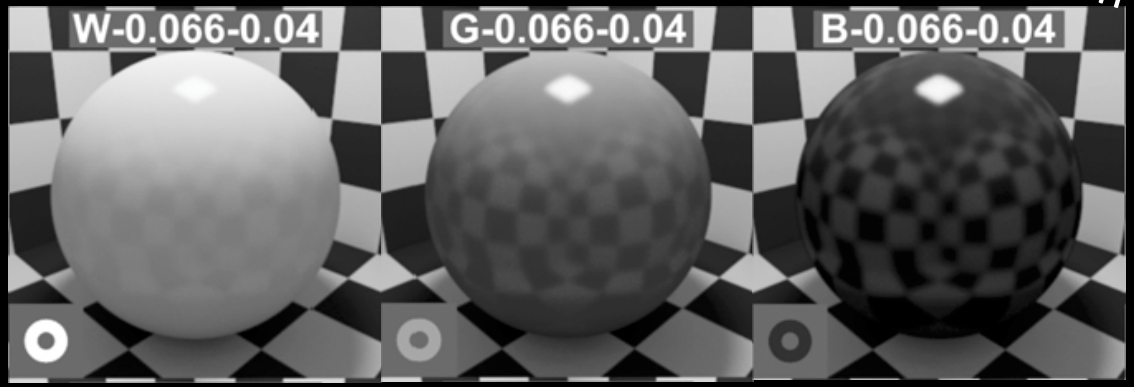
But how can we measure appearance ?

Good news

Appearance doesn’t have to be measured as a all.
The measurement can be split in different visual attributes.
One metrology can be developped per attribute

Good news

Although influence of attribute on others can't be ignored



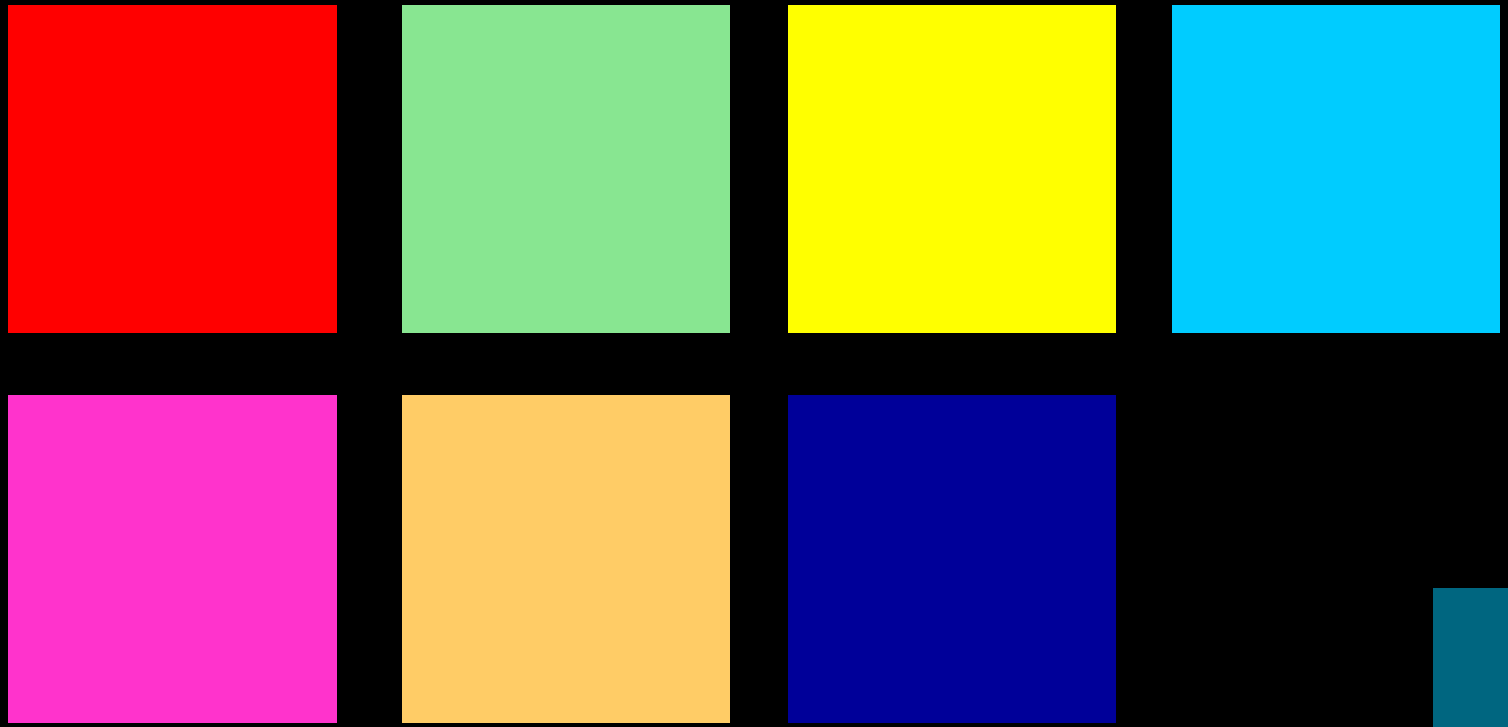
Ferwerda et al., 2001

Appearance doesn't have to be measured as a all.
The measurement can be split in different visual attributes.
One metrology can be developped per attribute

Bad news (1/2)

Appearance is a visual quantity.
The measurand is not accessible by the measuring instrument

Colour is not a reflectance spectrum



Colour is not a reflectance spectrum

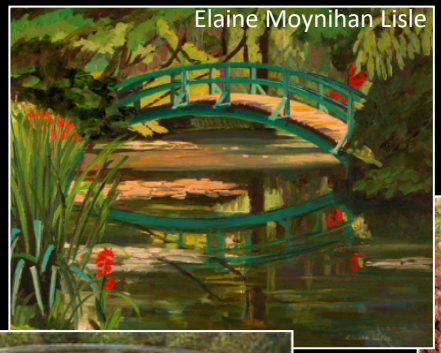
Bad news (2/2)

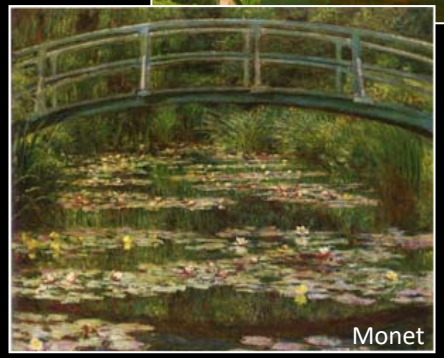
Appearance is a visual quantity.
The measurand is not accessible by the measuring instrument
The measurand may vary from an observer to another

Object

Appearance

The measurand may vary from an observer to an other





Strategy for the measurement of appearance

Step 1 : Segmentation

Total Appearance → Visual attributes → Component of visual attributes

- Colour
  - lightness
  - chroma
  - hue
- Gloss
  - contrast
  - Distincness of image
  - Haze
  - ⋮
- Sparkle
- Texture
- Transluscidity
  - blur
  - transparency
  - clarity

Strategy for the measurement of appearance

Step 2 : Development / assemble of samples

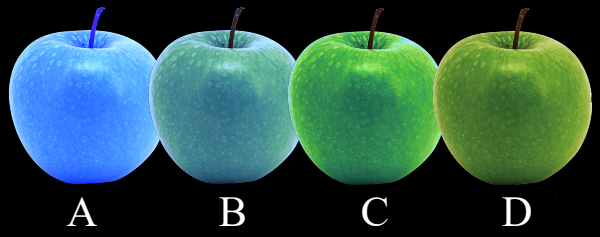
Component of visual attributes

lightness
chroma
hue

contrast
Distincness of image
Haze

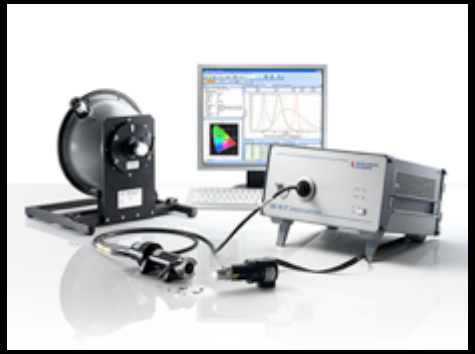
⋮

blur
transparency
clarity

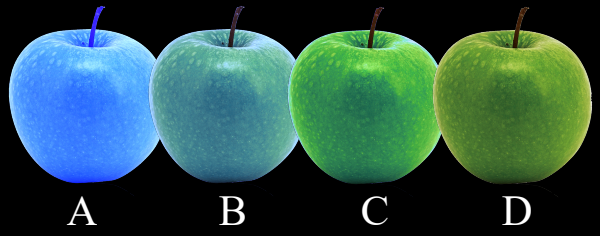


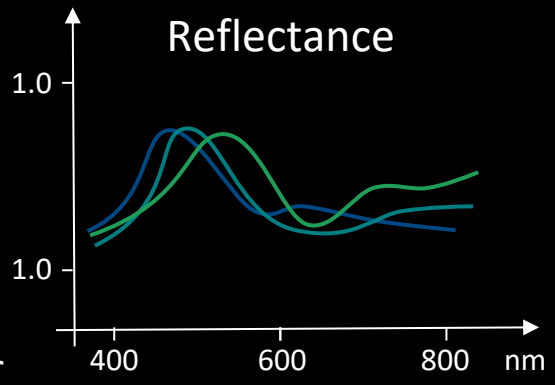
Strategy for the measurement of appearance

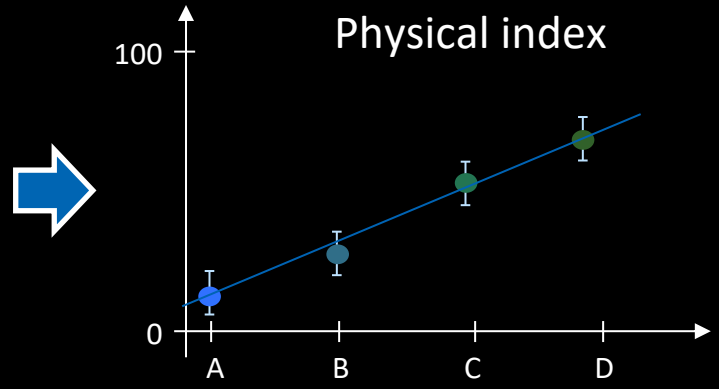
Step 3 : Physical characterization



Spectrophotometer
Glossmeter
Roughmeter
HDR Camera
Goniospectrophotometer

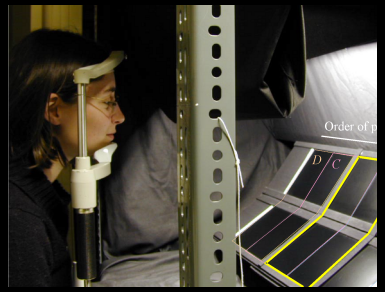


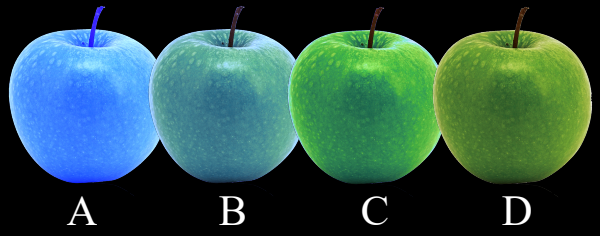




Strategy for the measurement of appearance

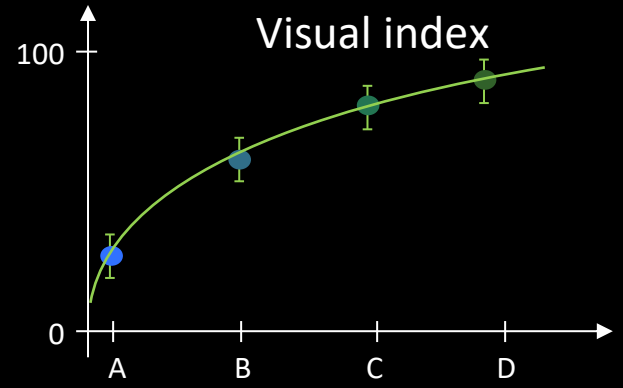
Step 4 : Visual characterization





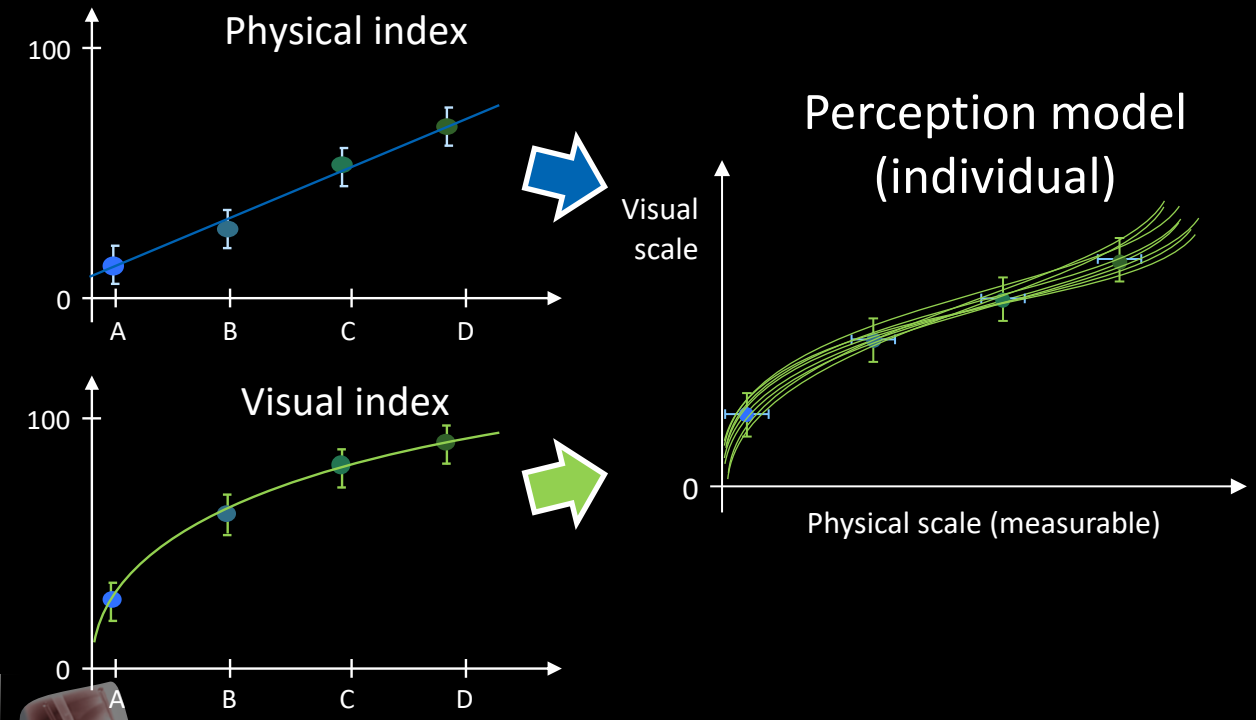
Light booth
Controlled environment
Observers
Questionnaires /Ranking

Psychophysic
&
Statistics



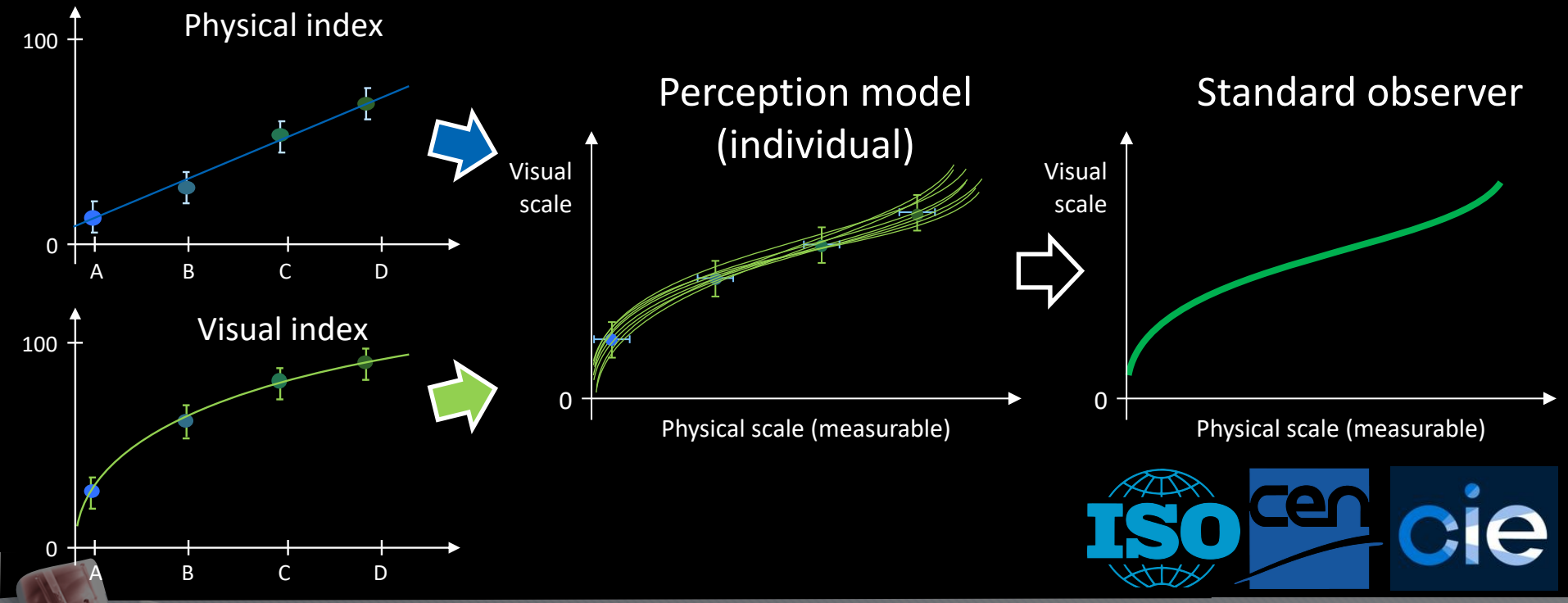
Strategy for the measurement of appearance

Step 5 : Perception model



Strategy for the measurement of appearance

Step 6 : Standardization (optional)

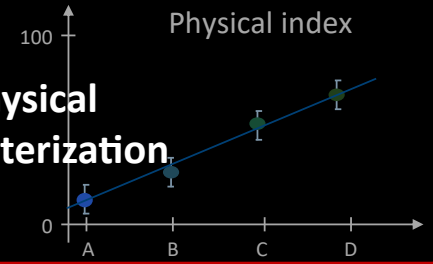


Strategy for the measurement of appearance

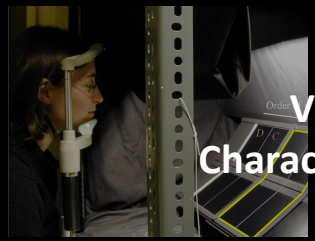
Role of NMIs

Definition measurand + Segmentation

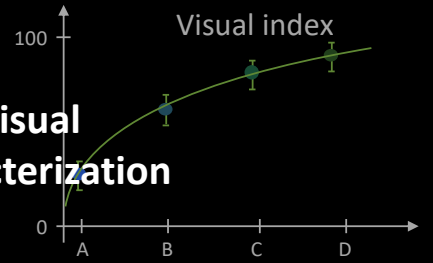
Physical characterization

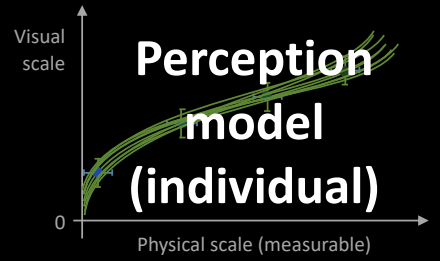


Development of samples



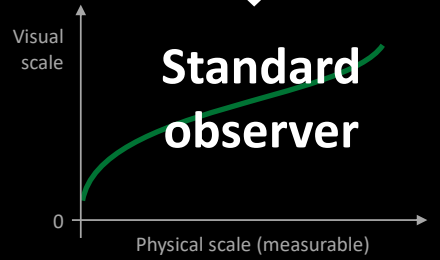
Visual Characterization





Perception model (individual)

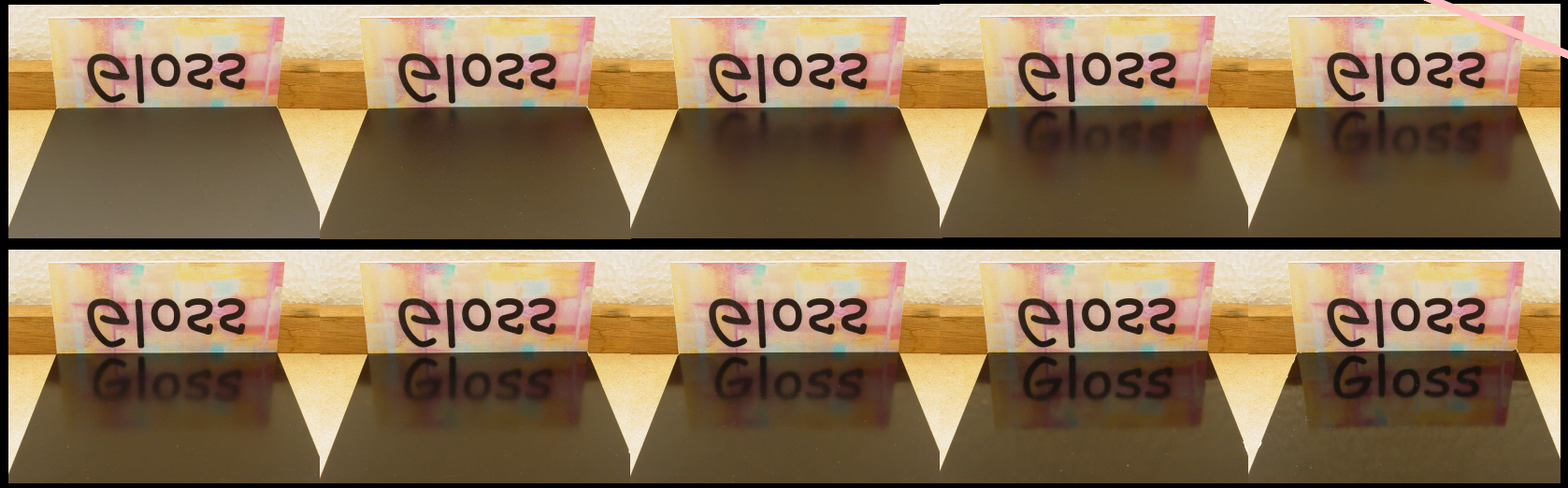
Standard observer



Measuring visual sensation of gloss

Development of samples

Example

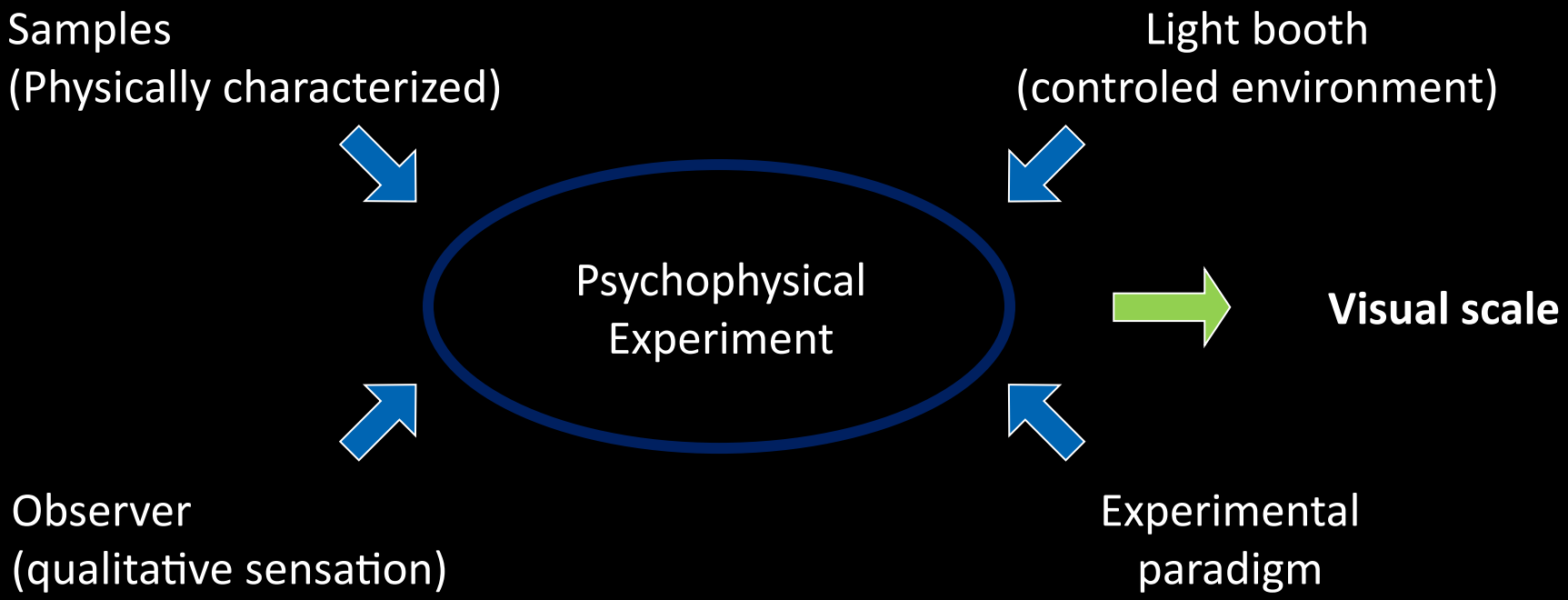


10 samples, rankable according to their gloss

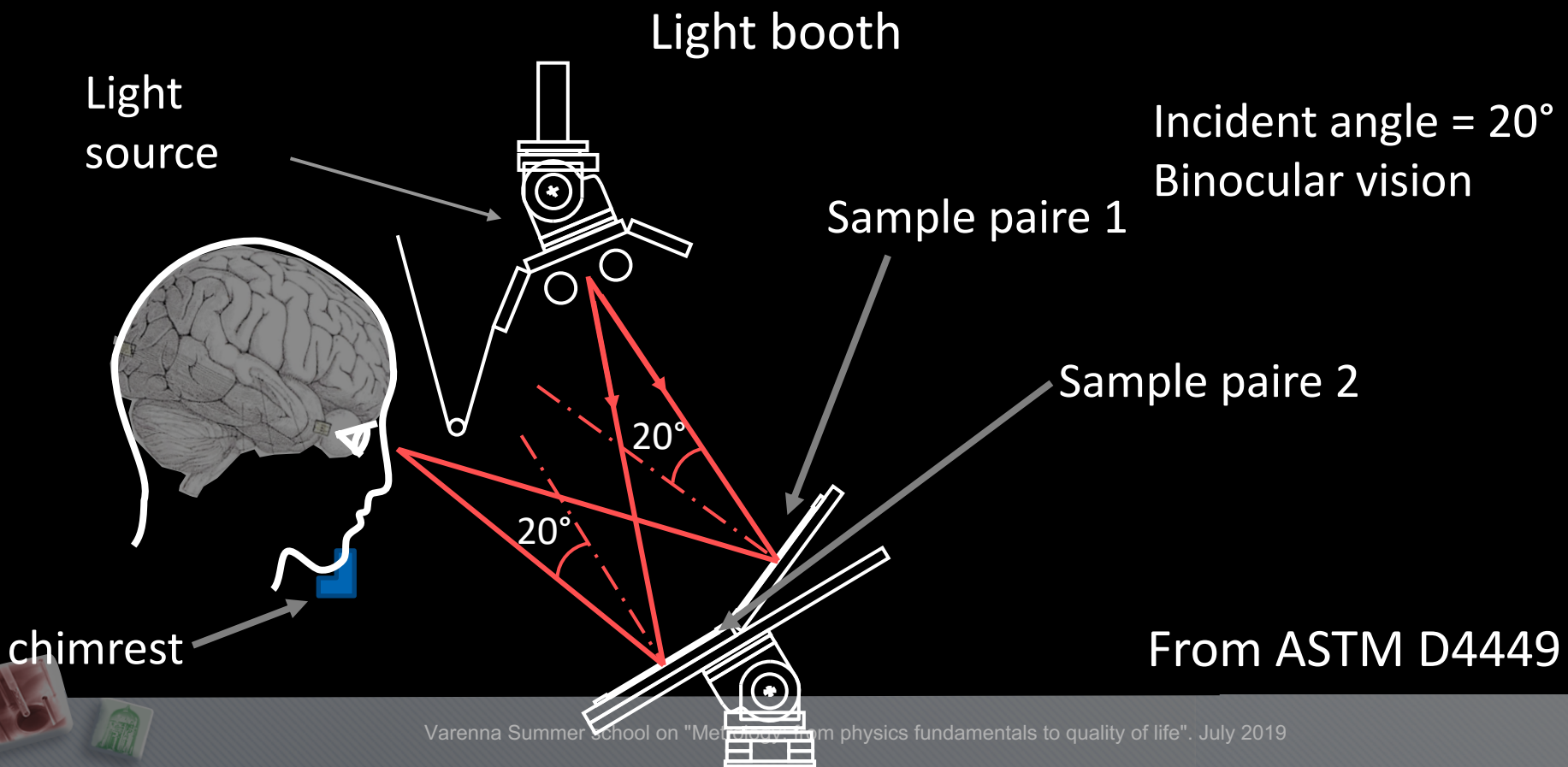
Black ink, A6 size(15 cm x 15,5 cm)

Measuring visual sensation of gloss

Set up of a psychophysical experiment



Measuring visual sensation of gloss



Measuring visual sensation of gloss

Observers

- ✓ Female / Male
- ✓ Young / Old
- ✓ Number
- ✓ Naïve / Expert
- ✓ Colour blind?
- ✓ Vision corrected
- ✓ Morning / Afternoon
- ✓ …..

Measuring visual sensation of gloss

Experimental paradigm

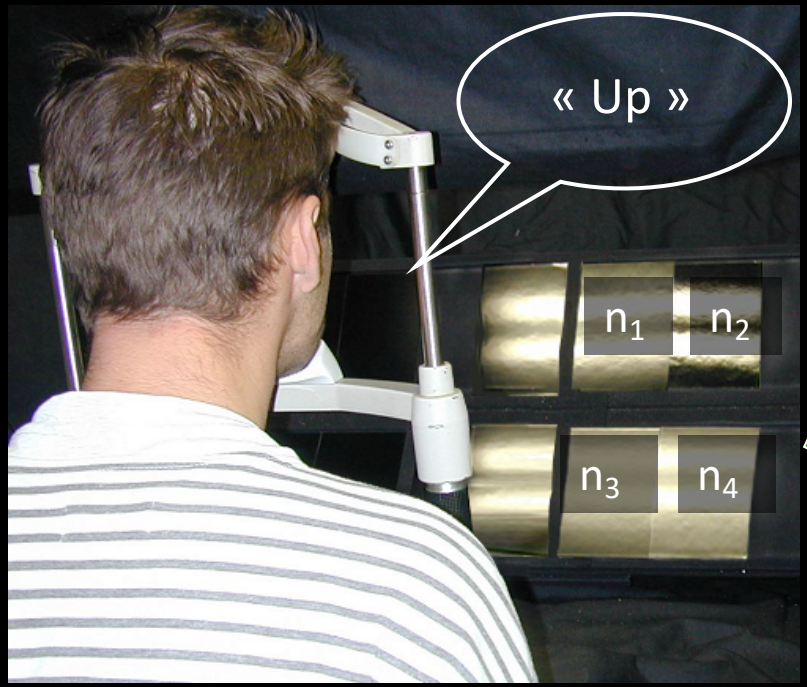
Adapted to the objective
Easy to perform
Clearly defined and strictly enunciated

Visual system is a bad absolute detector
Visual system is a accurate relative detector

Use comparisons

Measuring visual sensation of gloss

Experimental paradigm



Pairs comparison

Question:

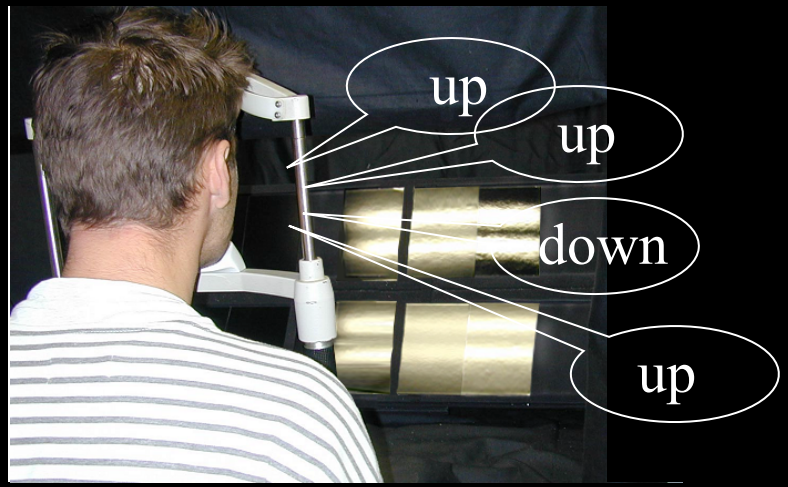
«On which pair the different is the highest?»

$$\psi_1 - \psi_2 > \psi_3 - \psi_4$$

Measuring visual sensation of gloss

Experimental paradigm

For 10 samples, we have **210** pair comparisons



ψ_1-ψ_2 > ψ_3-ψ_4
ψ_1-ψ_3 > ψ_6-ψ_8
ψ_1-ψ_3 < ψ_9-ψ_{10}
ψ_6-ψ_7 > ψ_9-ψ_{10}
ψ_1-ψ_2 < ψ_3-ψ_4

⋮

ψ_3-ψ_4 < ψ_5-ψ_6
ψ_2-ψ_3 > ψ_5-ψ_9
ψ_5-ψ_7 < ψ_8-ψ_{10}
ψ_4-ψ_5 > ψ_6-ψ_7
ψ_7-ψ_8 > ψ_9-ψ_{10}
ψ_5-ψ_6 > ψ_7-ψ_9

210

Measuring visual sensation of gloss

Experimental paradigm

Introduction of a « variable of decision »

$$\psi_1 - \psi_2 > \psi_3 - \psi_4$$

Pair 1

Pair 2

$$D(n_1, n_2 ; n_3, n_4) = (\psi_1 - \psi_2) - (\psi_3 - \psi_4) + \varepsilon > 0$$

Uncertainty

ψ_1-ψ_2 > ψ_3-ψ_4
ψ_1-ψ_3 > ψ_6-ψ_8
ψ_1-ψ_3 < ψ_9-ψ_{10}
ψ_6-ψ_7 > ψ_9-ψ_{10}
ψ_1-ψ_2 < ψ_3-ψ_4

⋮

ψ_3-ψ_4 < ψ_5-ψ_6
ψ_2-ψ_3 > ψ_5-ψ_9
ψ_5-ψ_7 < ψ_8-ψ_{10}
ψ_4-ψ_5 > ψ_6-ψ_7
ψ_7-ψ_8 > ψ_9-ψ_{10}
ψ_5-ψ_6 > ψ_7-ψ_9

210

Measuring visual sensation of gloss

Experimental paradigm

Introduction of a « variable of decision »

$$D(n_1, n_2 ; n_3, n_4) = (\psi_1 - \psi_2) - (\psi_3 - \psi_4) + \varepsilon > 0$$

ε ⇨ Gaussian N (0, σ)

$\psi_1, \psi_2, \ldots, \psi_{10}$ ⇨ Visual sensation of glossy samples

⇨ 11 unknown ⇐ $\psi_1, \ldots, \psi_{10}$, σ

ψ_1-ψ_2 > ψ_3-ψ_4
ψ_1-ψ_3 > ψ_6-ψ_8
ψ_1-ψ_3 < ψ_9-ψ_{10}
ψ_6-ψ_7 > ψ_9-ψ_{10}
ψ_1-ψ_2 < ψ_3-ψ_4
⋮
ψ_3-ψ_4 < ψ_5-ψ_6
ψ_2-ψ_3 > ψ_5-ψ_9
ψ_5-ψ_7 < ψ_8-ψ_{10}
ψ_4-ψ_5 > ψ_6-ψ_7
ψ_7-ψ_8 > ψ_9-ψ_{10}
ψ_5-ψ_6 > ψ_7-ψ_9

210

Measuring visual sensation of gloss

Experimental paradigm

Solvable

Introduction of a « variable of decision »

$$D(n_1, n_2 ; n_3, n_4) = (\psi_1 - \psi_2) - (\psi_3 - \psi_4) + \varepsilon > 0$$

ε ⇨ Gaussian N (0, σ)

$\psi_1, \psi_2, \ldots, \psi_{10}$ ⇨ Visual sensation of glossy samples

⇨ 11 unknown ⇐ $\psi_1, \ldots, \psi_{10}$, σ

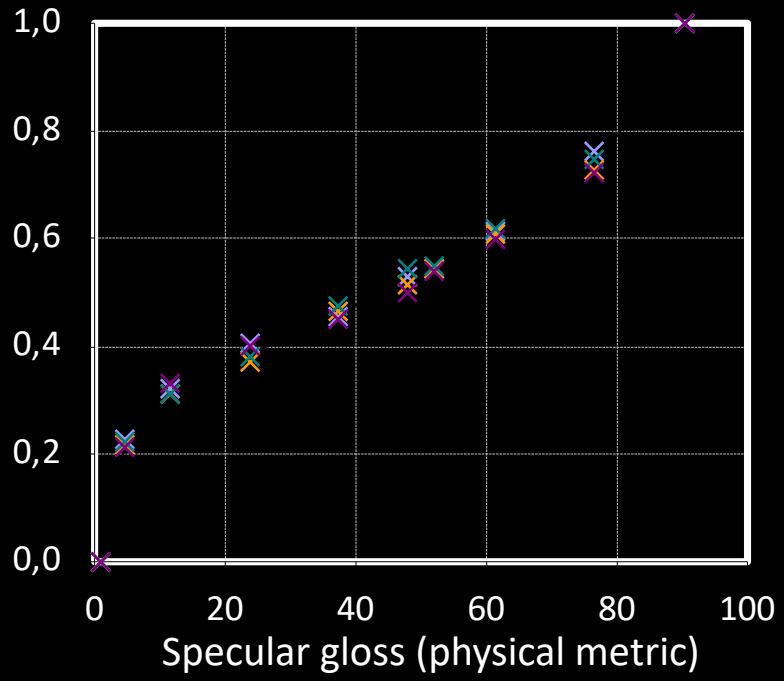
$\psi_1-\psi_2 > \psi_3-\psi_4$
$\psi_1-\psi_3 > \psi_6-\psi_8$
$\psi_1-\psi_3 < \psi_9-\psi_{10}$
$\psi_6-\psi_7 > \psi_9-\psi_{10}$
$\psi_1-\psi_2 < \psi_3-\psi_4$
⋮
$\psi_3-\psi_4 < \psi_5-\psi_6$
$\psi_2-\psi_3 > \psi_5-\psi_9$
$\psi_5-\psi_7 < \psi_8-\psi_{10}$
$\psi_4-\psi_5 > \psi_6-\psi_7$
$\psi_7-\psi_8 > \psi_9-\psi_{10}$
$\psi_5-\psi_6 > \psi_7-\psi_9$

210

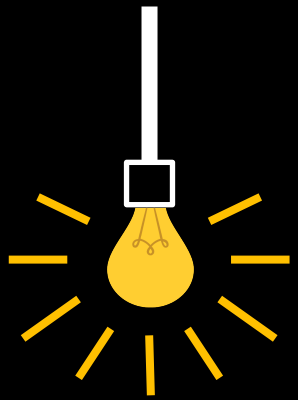
Measuring visual sensation of gloss

We obtain vector : $[\hat{\psi}_1; \hat{\psi}_2; \ldots ; \hat{\psi}_{10}]$, « visual scale » for samples $[n_1, n_3, \ldots, n_{10}]$

Visual scale
(perceptive metric)

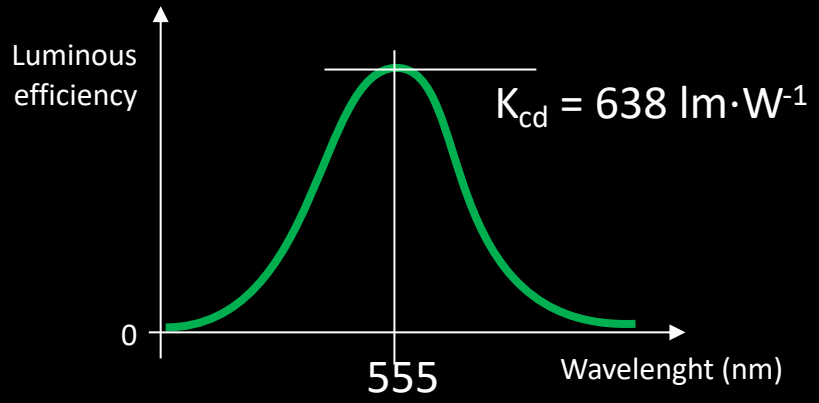


Success story : Photometry



Luminous intensity
(visual)

Standard Photopic observer
(CIE 1924)

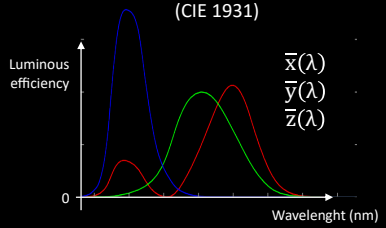


SI brochure
Principle governing photometry

Success story : Colorimetry

Measurand : Colour (visual)

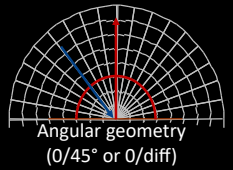
Standard Colorimetric observer (CIE 1931)



ISO 18314

CIE 015.x

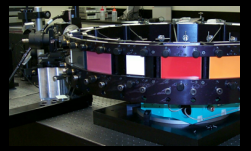
Standard measurement geometries



Portable commercial spectrophotometer

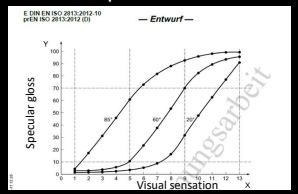
Commercial standard calibration tiles

Primary spectrophotometer at NMI level



Measurand : Gloss (visual)

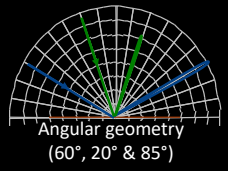
Perception model



ISO 2813

ASTM 512

Standard measurement geometries



Commercial Glossmeter

Commercial standard calibration tiles

Primary glossmeter at NMI level

Colorimetry – Glossmetry
XX^{e} century

Colorimetry
XXI^{e} century

Goniochromatism

Glossmetry
XXI^{e} century

Satin & mattes

Texture
XXI^{e} century

Sparkle & Anisotropy

Translucency
XXI^{e} century

Translucency
XXI^e century

Functionality

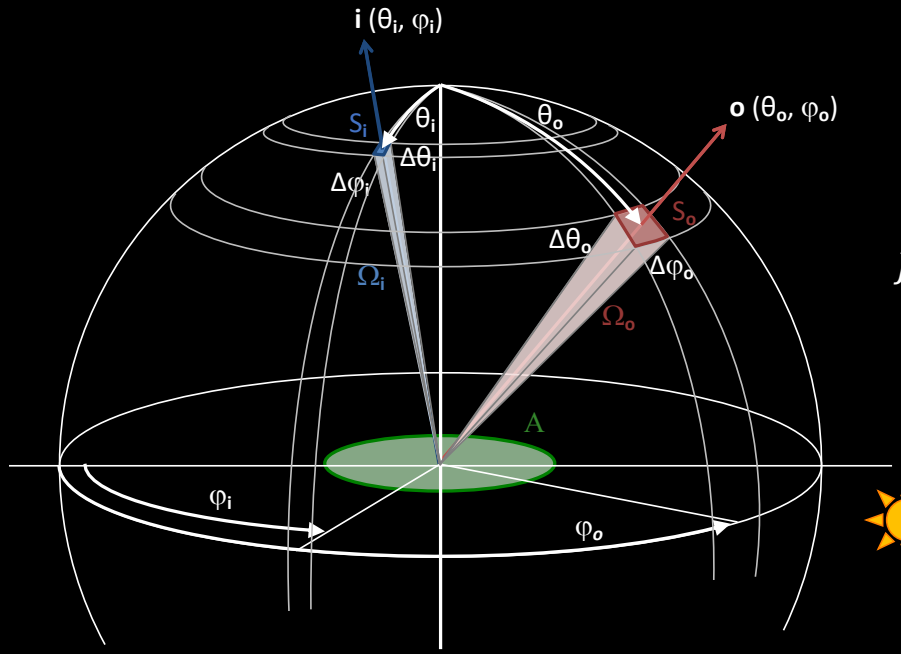
All these effects are strongly bi-directionnal

Development of new radiometric quantities to answer the industrial need

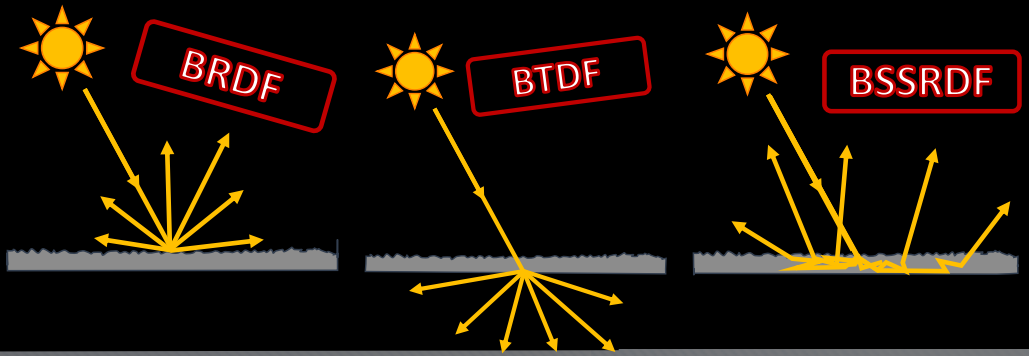
- BRDF (Bidirectional Reflectance Distribution Fct)
- BTDF (Bidirectional Transmittance Distribution Fct)
- BSSRDF
  (Bidirectional Surf ace Scattering Distribution Fct)

Nicodemus, 1979

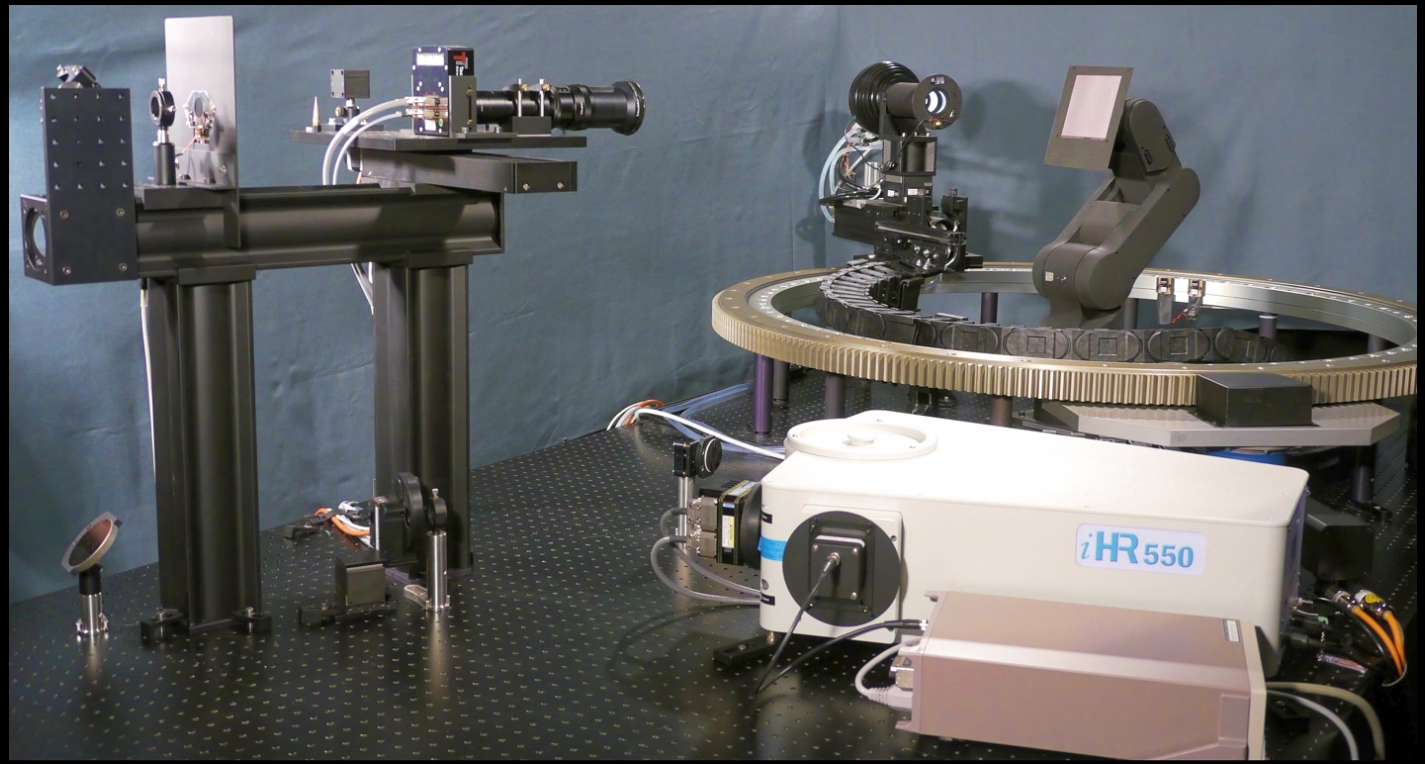
BRDF, BTDF, BSSRDF



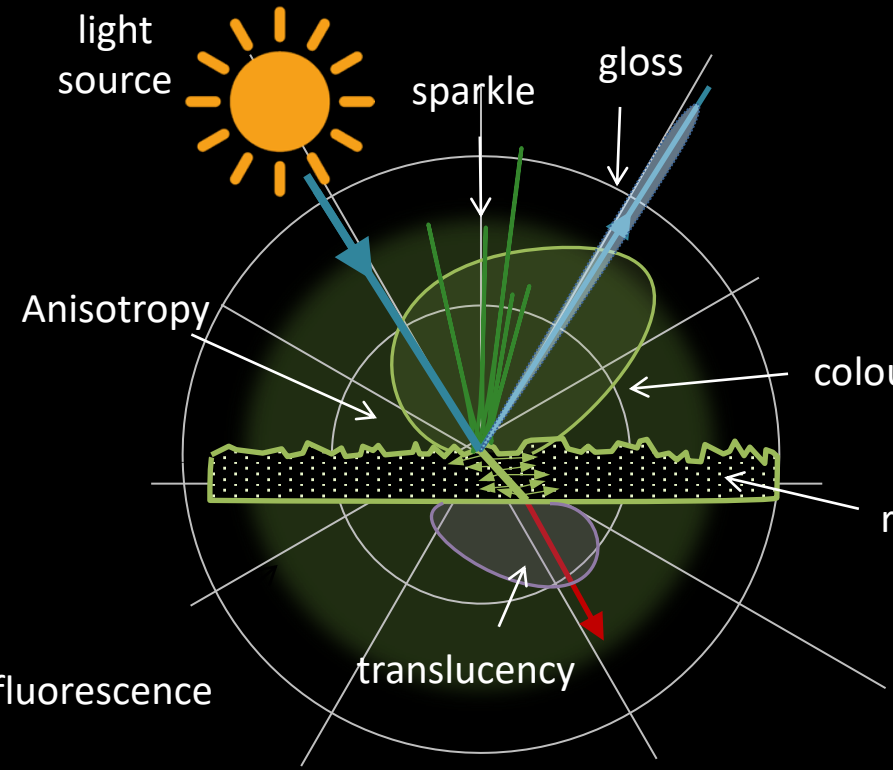
$$f = \frac{radiance(\theta_I, \varphi_I, \theta_R, \varphi_R, \Omega_R, \lambda, \sigma)}{Irradiance(\theta_I, \varphi_I, \lambda, \sigma)} \qquad [sr^{-1}]$$

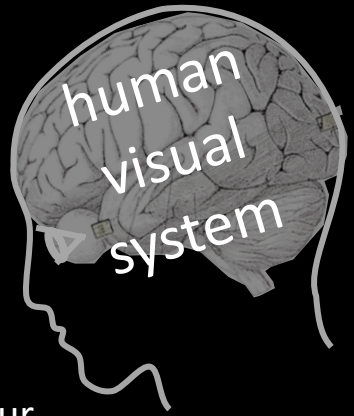


Goniospectrophotometer

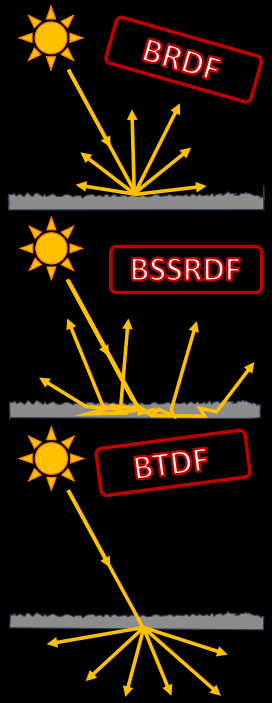


BRDF, BTDF, BSSRDF





BRDF, BTDF, BSSRDF



All these measurements can't be performed at the highest level with a single equipment

Coordinated effort at the European metrological level

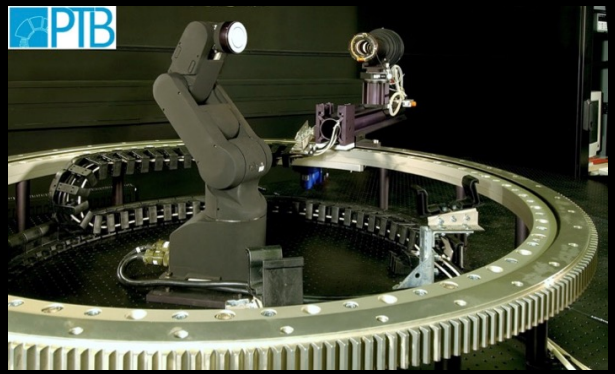
EMPIR

EURAMET

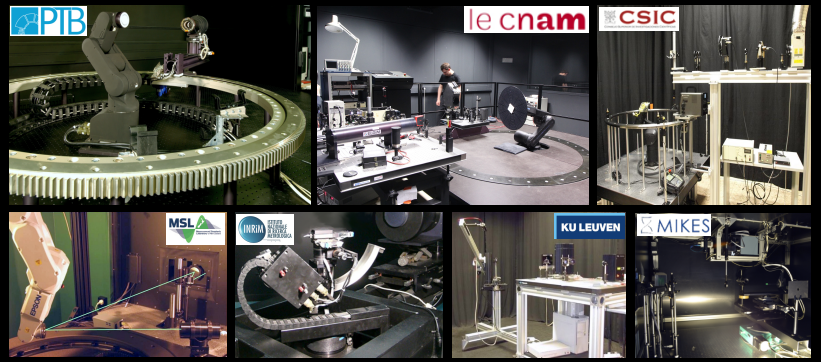
The EMPIR initiative is co-funded by the European Union's Horizon 2020 research and innovation programme and the EMPIR Participating States

Ongoing coordinated action at EU level

PTB



CMI (CZ), CNAM (FR), CSIC (ES), INRIM (IT), Aalto (FI), MSL (NZ), PTB x2 (GE), METAS (CH), CMI (CZ)



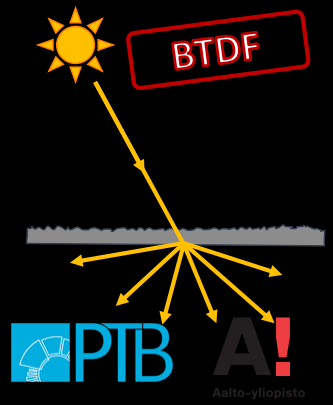
2005 — 2013 — 2016 — 2017 — 2019 — 2020 — 2022

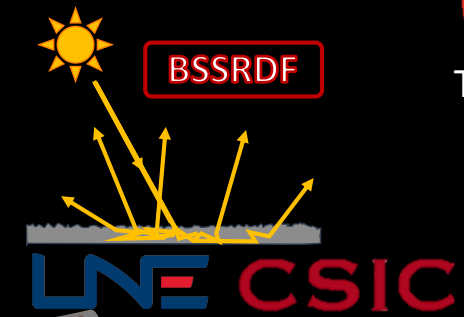
EReflect (IRP – IND 52)

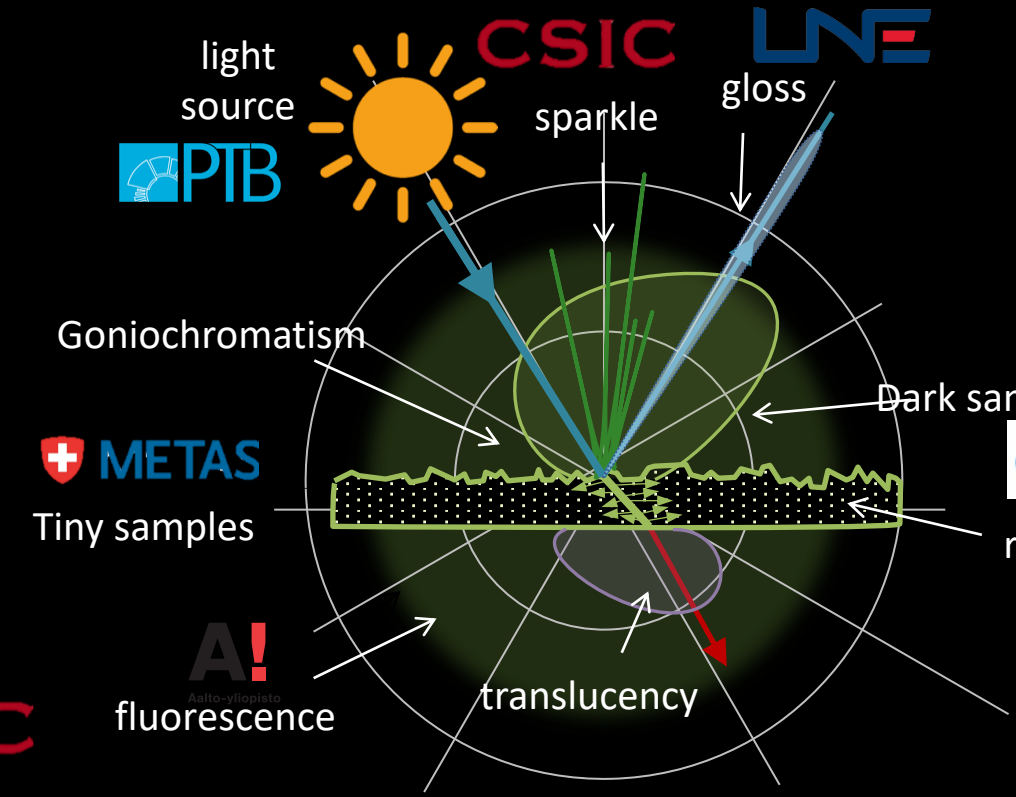
BiRD Bidirectional Reflectance Definitions JRP 16NRM08

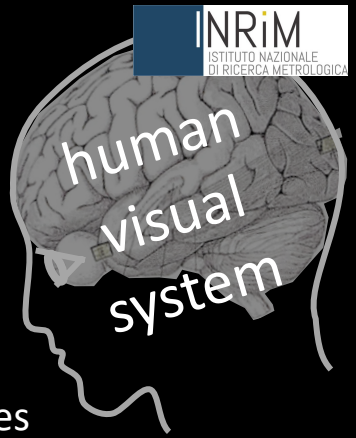
BxDiff JRP 18SIB03

Ongoing coordinated action at EU level







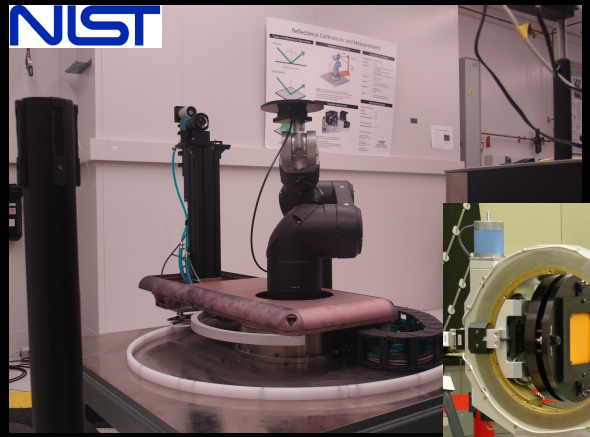


CZECH METROLOGY INSTITUTE

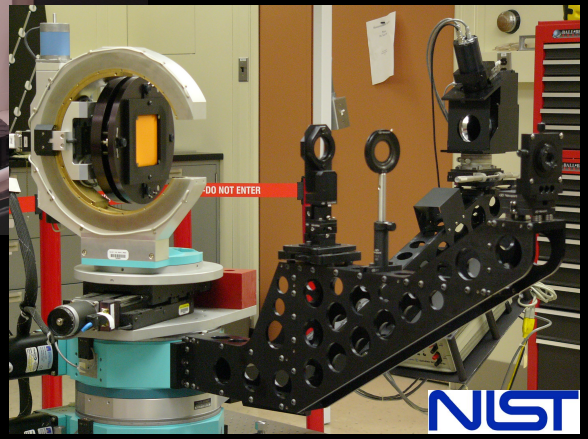
MSL Measurement Standards Laboratory of New Zealand

RISE

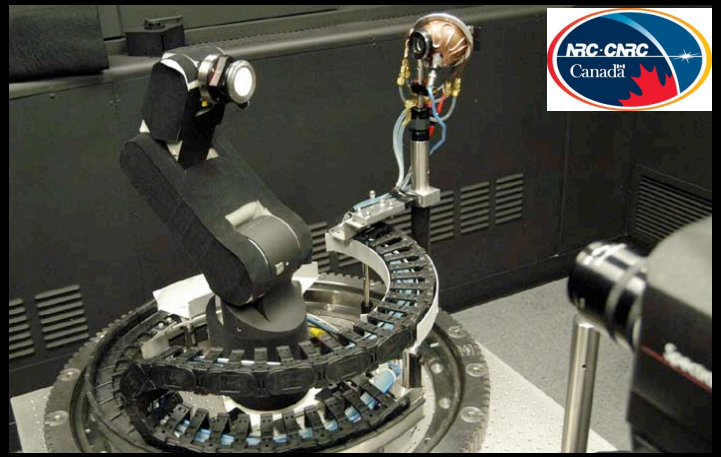
Ongoing actions out of Europe



2015



2005



2007

Developments at NIM, KRISS

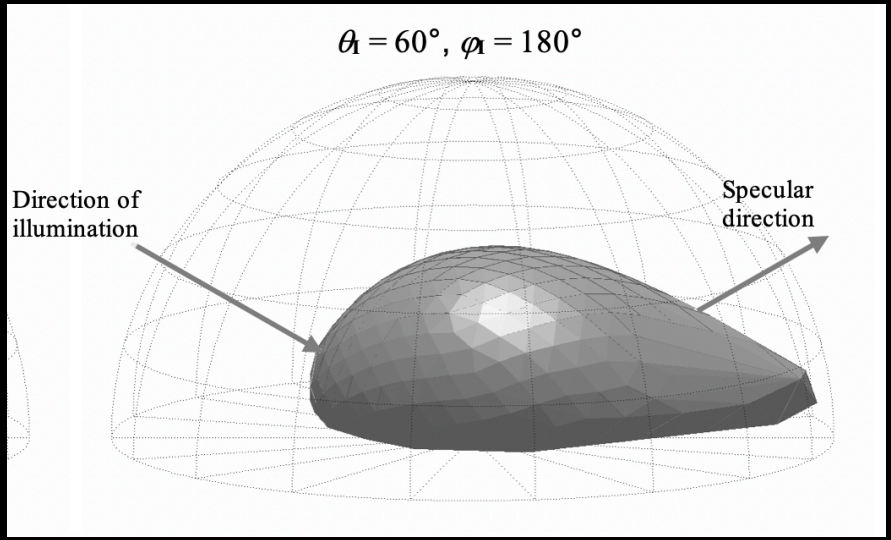
(last update June 2019)

Example of results

Lambertian sample

Spectralon® (labsphere)

Full hemisphere, $\theta_I = 60°$

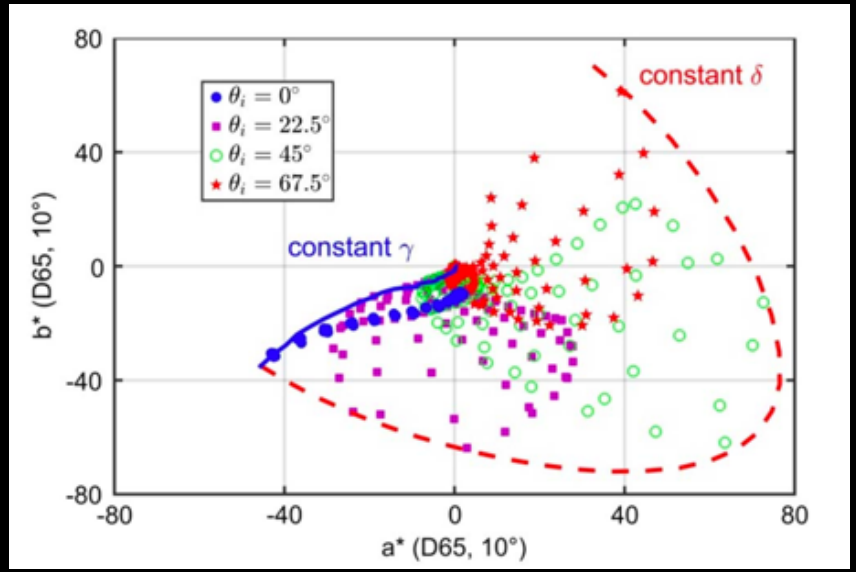


Sphere represents 0.56 sr^{-1}

Obein, 2005, SPIE

Example of results

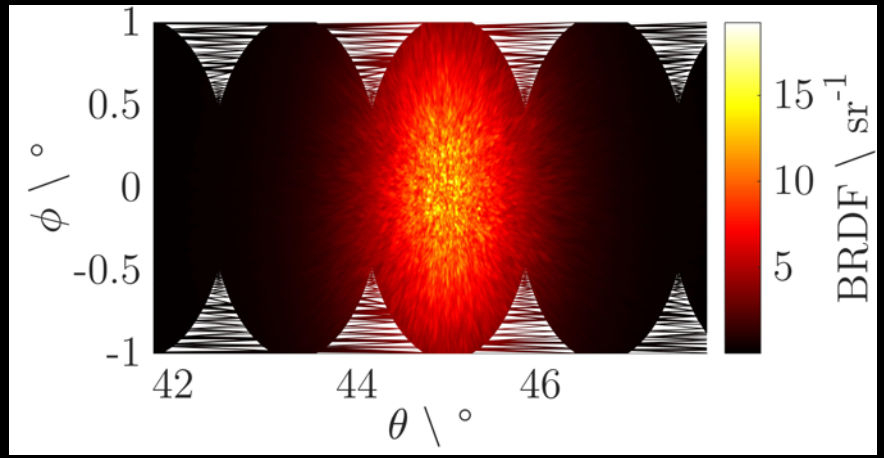
Goniochromatism (interferencial)



Strothkämper 2016, JOSA A, **33**(1)

Example of results

Gloss



Black samples from 3C® gloss scale (75 gu)

Specular Peak

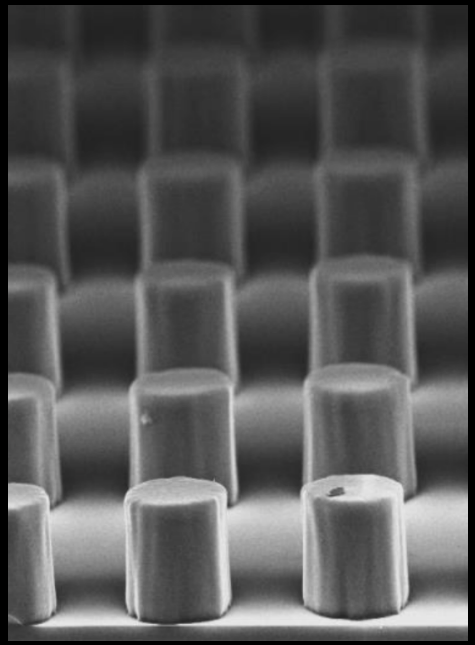
Cut plane of incidence

$\theta_I = 45°$, $42 < \theta_R < 48°$

Rabal 2019, CIE session

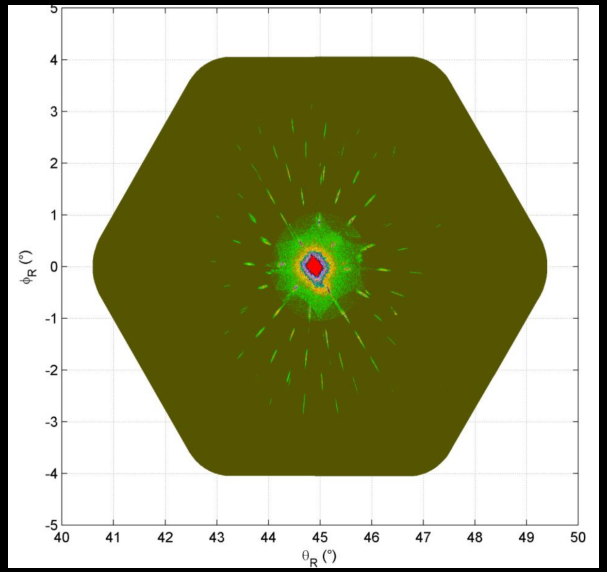
Example of results

Functionnal surfaces



Pilar distance = 80 µm

$\theta_I = 45°$, $42 < \theta_R < 48°$, $-4 < j_R < 4°$



Diffraction = 0,4°

Turbil & al, CIE 2016

Example of results

Sparkle

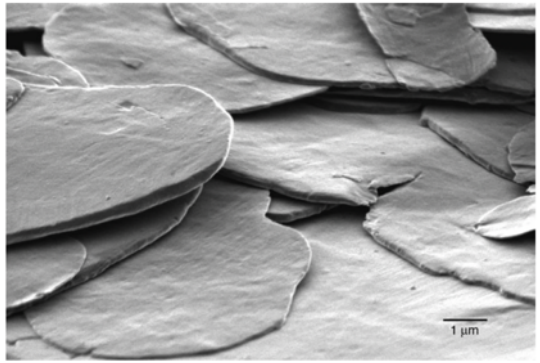
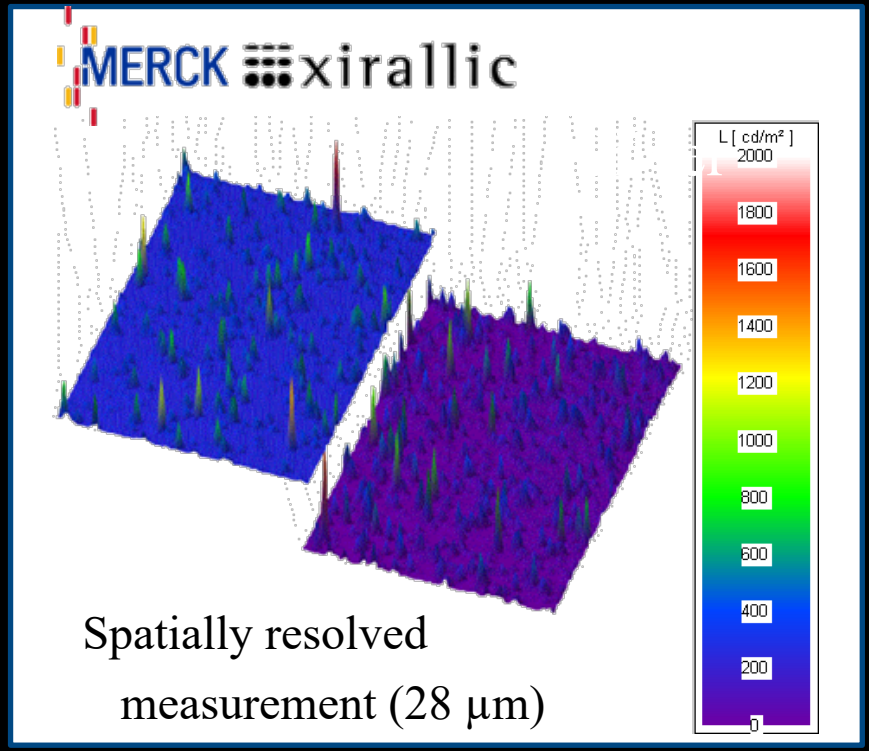


Fig. 2.33 SEM picture of silver dollar pigments of aluminum (source: Eckart Werke GmbH, Velden, Germany)



Ferrero, 2015, Metrologia

Stakeholders

Instrumentation & standard artefacts

Pulp and Papers

Materials, pigments & coatings

Automotive

Others

Measurement of appearance

Control of appearance is essential for industrials because appearance is linked to esthetic & quality

Metrologist must provide to industry :

- Measurement solution to control appearance
- Stable standard artefacts traceable to national references
- Guidelines and measurement protocols to ensure measurement are performed in a correct way

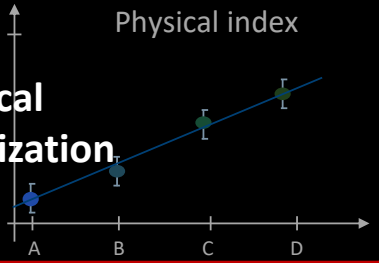
Measurand is not accessible and not stable

Measurement of appearance

But it is possiblie to provide measurement using strict protocols

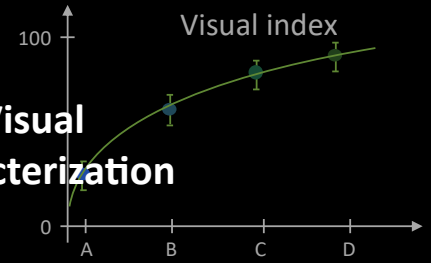
Definition measurand + Segmentation

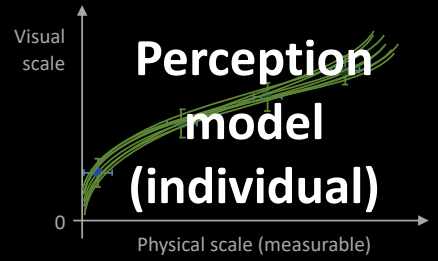
Physical characterization



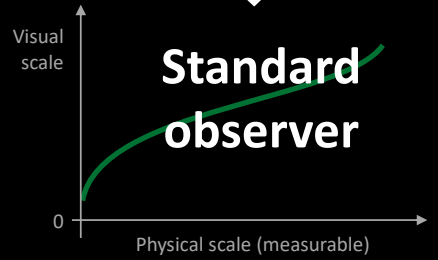
Development of samples

Visual Characterization





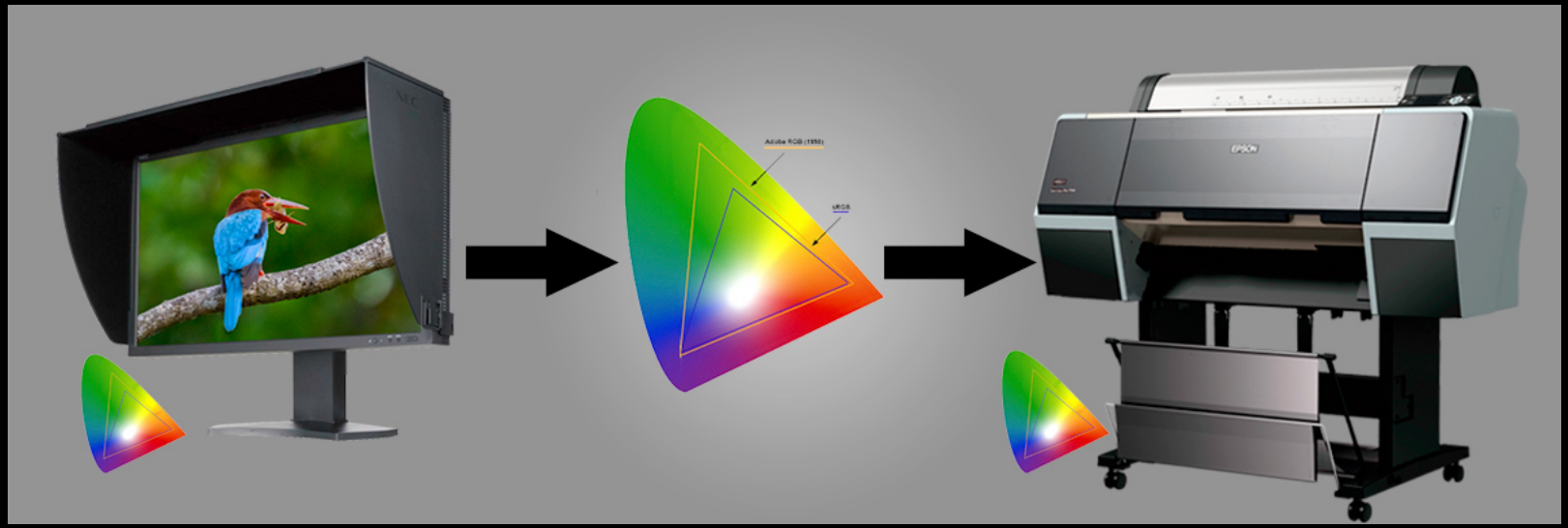
Perception model (individual)



Standard observer

Measurement of appearance

Photometry, Colorimetry and colour management have shown the way



Measurement of appearance

New developments are ongoing at NMIs to provide references, traceability and measurement protocols to characterize and control the full appearance

Thank you