

Metrology and standardization

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My profile

Luca Mari (M.Sc. in physics; Ph.D. in measurement science) is full professor of measurement science at the Cattaneo University – LIUC, Castellanza (VA), Italy, where he teaches courses on measurement science, statistical data analysis, system theory.

He is currently the chairman of TC1 (Terminology) and the secretary of TC25 (Quantities and Units) of the International Electrotechnical Commission (IEC), and an IEC expert in the WG2 (VIM) of the Joint Committee for Guides in Metrology (JCGM). He has been the chairman of the TC7 (Measurement Science) of the International Measurement Confederation (IMEKO).

He is the author or coauthor of several scientific papers published in international journals and international conference proceedings. His research interests include measurement science and system theory.

Some of my recent publications

- LM, *Evolution of 30 years of the International Vocabulary of Metrology (VIM)*, Metrologia (forthcoming)
- LM, D.Petri, *Measurement science: constructing bridges between reality and knowledge*, IEEE Instrumentation and Measurement Magazine (forthcoming)
- P.Micheli, LM, *The theory and practice of performance measurement*, Management Accounting Research, 2014
- LM, M.Wilson, *An introduction to the Rasch measurement approach for metrologists*, Measurement, 2014
- A.Frigerio, A.Giordani, LM, *On representing information: a characterization of the analog/digital distinction*, Dialectica, 2013
- LM, *A quest for the definition of measurement*, Measurement, 2013
- LM, A.Giordani, *Quantity and quantity value*, Metrologia, 2012
- LM, P.Carbone, D.Petri, *Measurement fundamentals: a pragmatic view*, IEEE Trans. Instr. Meas., 2012
- A.Giordani, LM, *Measurement, models, uncertainty*, IEEE Trans. Instr. Meas., 2012
- A.Giordani, LM, *Property evaluation types*, Measurement, 2012
- V.Lazzarotti, R.Manzini, LM, *A model for R&D performance measurement*, Int. J. Production Economics, 2011
- A.Frigerio, A.Giordani, LM, *Outline of a general model of measurement*, Synthese, 2010
- D.Macii, LM, D.Petri, *Comparison of measured quantity value estimators in nonlinear models*, IEEE Trans. Instr. Meas., 2010
- LM, V.Lazzarotti, R.Manzini, *Measurement in soft systems: epistemological framework and a case study*, Measurement, 2009
- LM, *A computational system for uncertainty propagation of measurement results*, Measurement, 2009
- LM, *On (kinds of) quantities*, Metrologia, 2009

This lecture

- Basic concepts
- In the last twenty years...

References [\[xyz\]](#) in the last slide

The critical importance of measurement: some examples

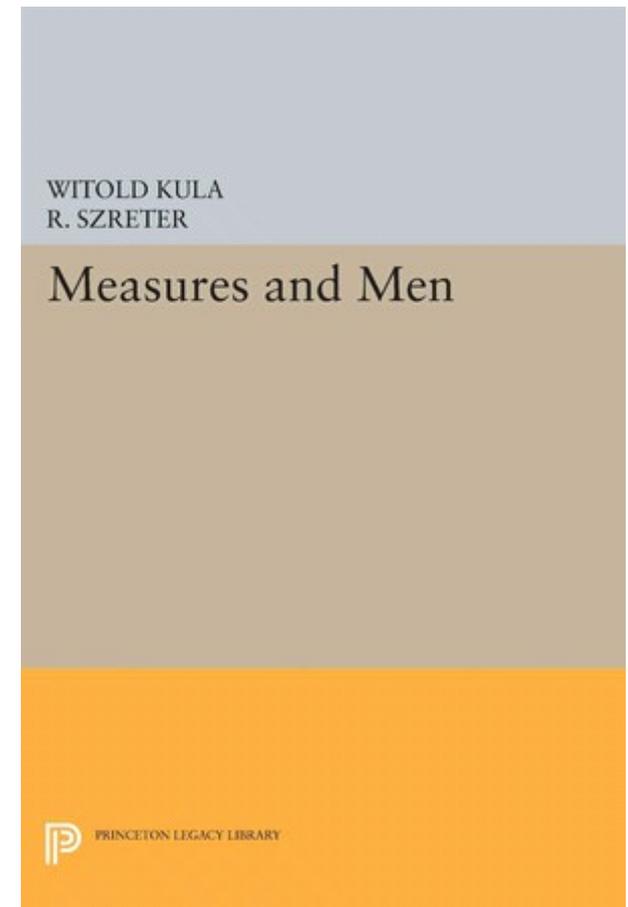
- Measuring the value of natural gas must be uniform and reliable throughout Europe in order to protect consumers and fiscal revenue
- Fundamental research in the measurement of electrolytic conductivity has direct impact on the quality of life for dialysis patients
- The measurement of airborne nanoparticles in the environment and workplace may help improve air quality and health
- Precise fertiliser spreaders reduce environmental impact and improve agricultural economy
- An intelligent solution for heat meters could reduce costs for the hundred million people in Northern Europe – and other cold parts of the world
- Are shrimps safe to eat? Understanding the measurements is important
- Measurements have a crucial role in cancer treatment
- Improved monitoring of the heat treatment of jet engine components could lead to reduced aircraft emissions

Measurement enables just society



The weight of an object is a fact that can be established independently of economical, political, religious, ... positions

“Measures and Men (1986, paperback 2014) considers times and societies in which weighing and measuring were ... weapons in class struggles.”



How can measurement have this role?
What is measurement?



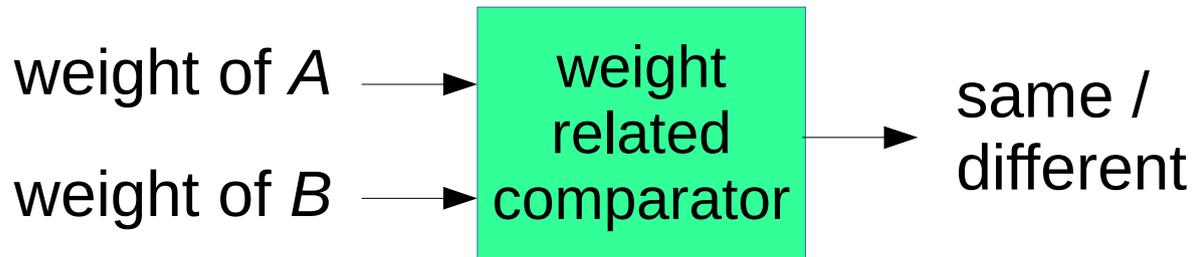
Backgrounder



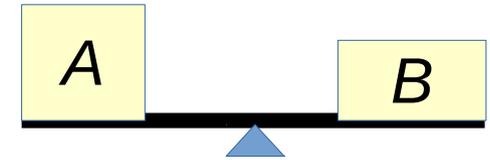
- Measuring systems are **information machines**
→ measurement results are pieces of information
- Measurement is based on **comparison**...
→ measuring instruments operate as comparators
- ... but **comparison is not enough for measurement**
→ a measurement result is not
 - (α) “the objects *A* and *B* have the same weight”
but
 - (β) “the weight of the object *A* is 2 kg”

Standardization in measurement is mainly related to what is required to obtain (β) from (α)

Comparison and beyond



if same, then $w(A) = w(B)$

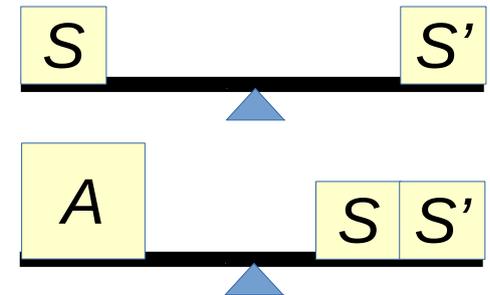


Let us choose two objects S and S' such that

$$w(S) = w(S')$$

and

$$w(A) = w(S \oplus S')$$



Then we can report

$$w(A) = 2 w(S)$$

or also

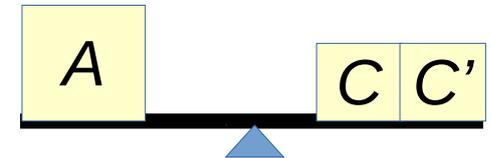
$$w(A) = 2 U$$

having introduced U , the quantity **unit**, as a shortcut for $w(S)$

Unit realization

In order to make comparisons leading to results such as

$$w(A) = 2 U$$



experimentally possible, an object C (or a phenomenon, ...) that **realizes the unit** must be available

C is called a **measurement standard**

- “standard” has (at least) two meanings:**
- a document such that...
 - an entity that realizes a reference quantity

Intersubjectivity

The fundamental claim of measurement is that a sentence such as

$$w(A) = 2 U$$

must have **the same meaning everytime and everywhere**,
so that **its interpretation is subject-independent**

(2 metres, today and tomorrow, in Geneva and New York, must be the same quantity)

This implies that the quantity unit U must be:

- **stable** (“everytime” constraint)
- **accessible** (“everywhere” constraint)

A strategic solution to this problem requires scientific, technological, organizational, and political means:

the metrological system

Unit definition



A significant example, the metre:

1. the distance between the axes of two lines marked on a given bar in given conditions
2. a given fraction of the length of a given earth meridian from pole to the equator
3. the length of the path traveled by light in vacuum during a given time interval

1.
low stability
no theory

2.
fair stability
almost no theory

3.
maximum stability
theory-laden

Extreme (current!) cases

In the International System of Units (Système International d’Unités, SI):

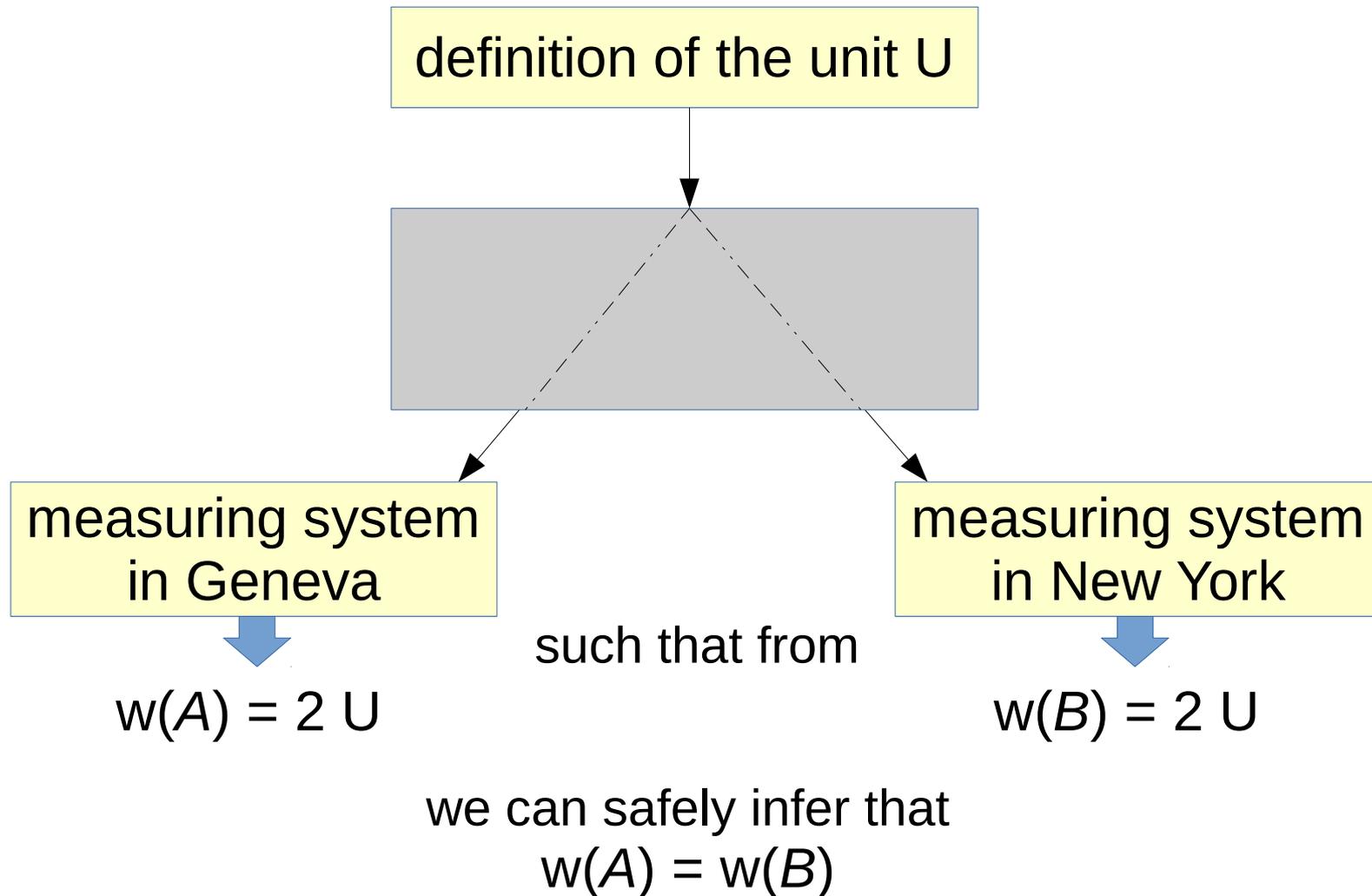
“The kilogram is the unit of mass; it is equal to the mass of the international prototype of the kilogram.”

(a definition referring to a concrete, individual object)

“The ampere is that constant current which, if maintained in two straight parallel conductors of infinite length, of negligible circular cross-section, and placed 1 metre apart in vacuum, would produce between these conductors a force equal to 2×10^{-7} newton per metre of length.”

(a definition referring to an abstract, ideal phenomenon)

Metrological traceability



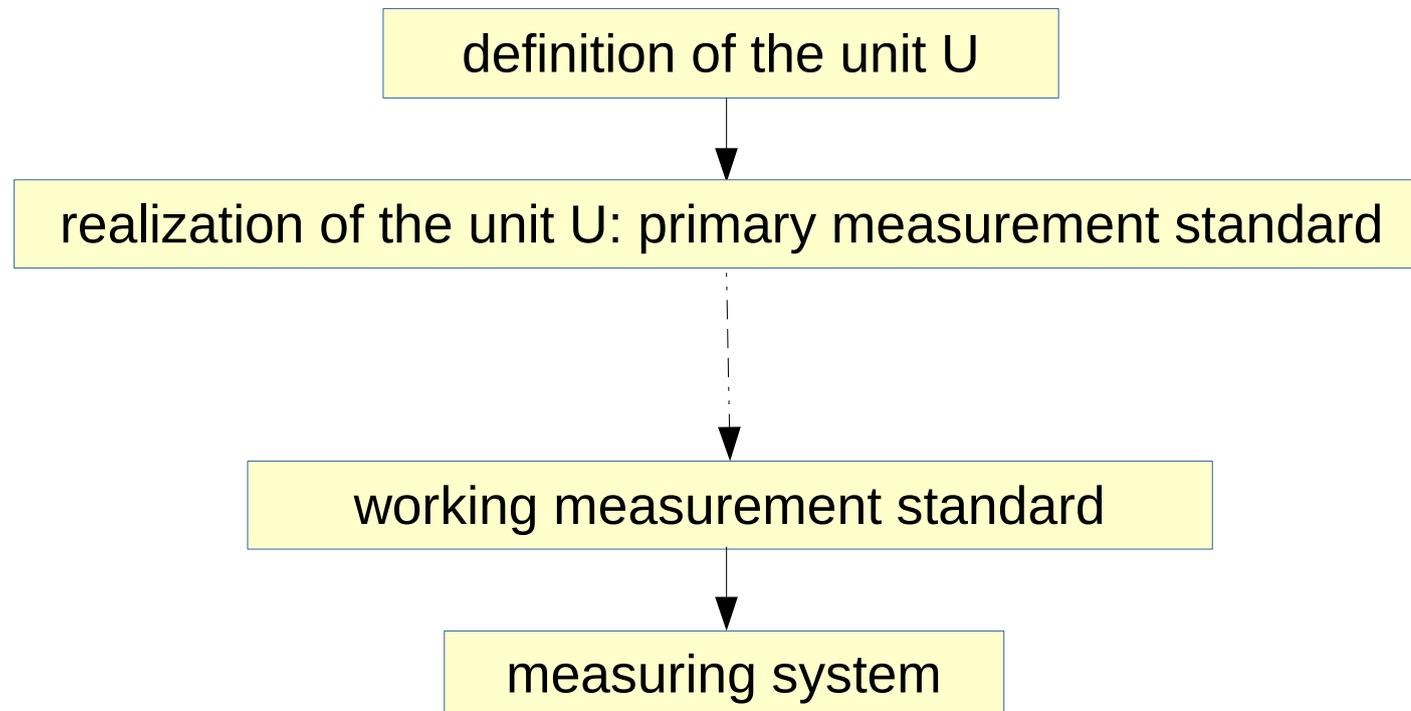
metrological traceability: “property of a measurement result whereby the result can be related to a reference through a documented unbroken chain...”

accessibility (“everywhere”)

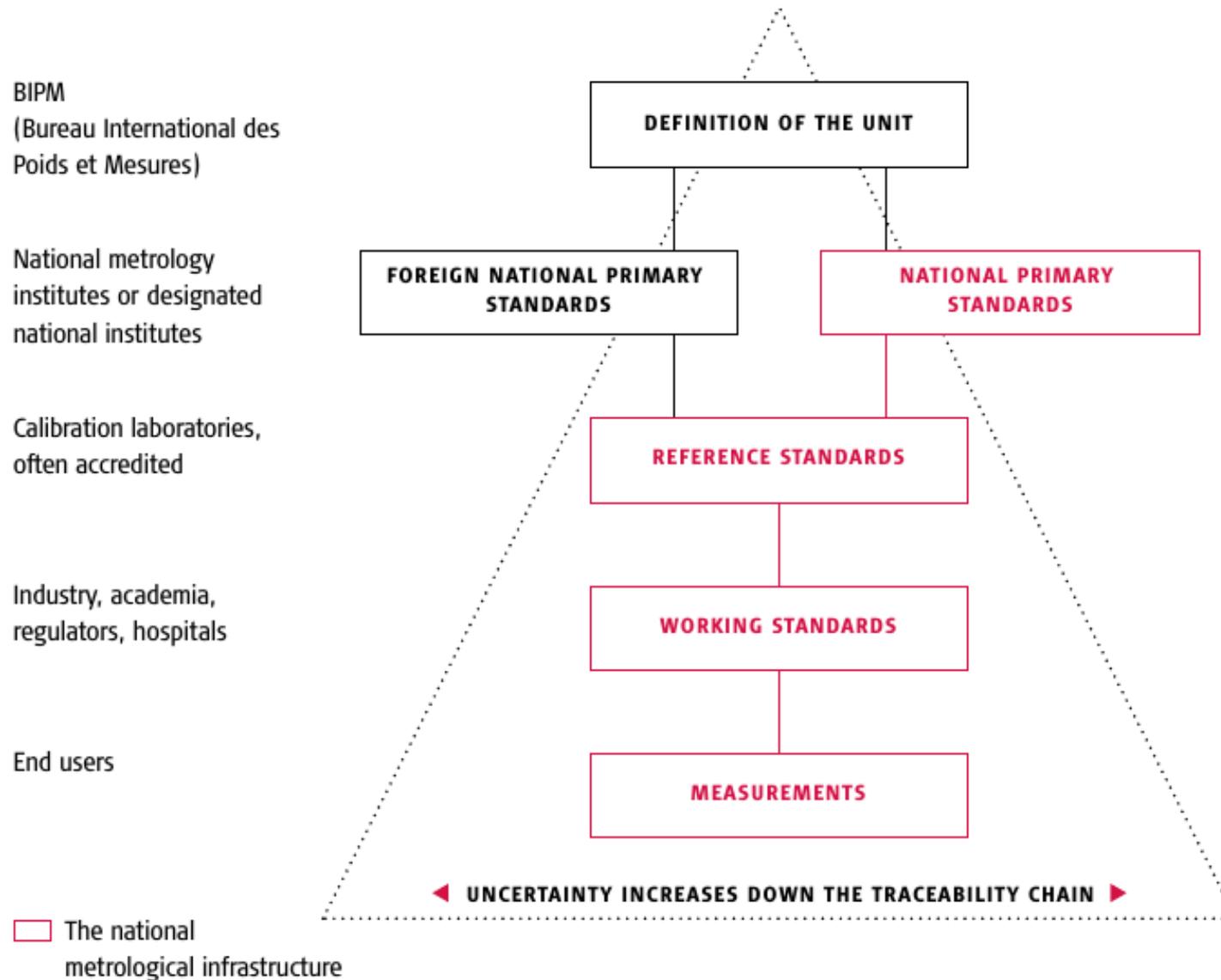
Calibration

metrological traceability: “property of a measurement result whereby the result can be related to a reference through a documented unbroken chain of calibrations, each contributing to the measurement uncertainty”

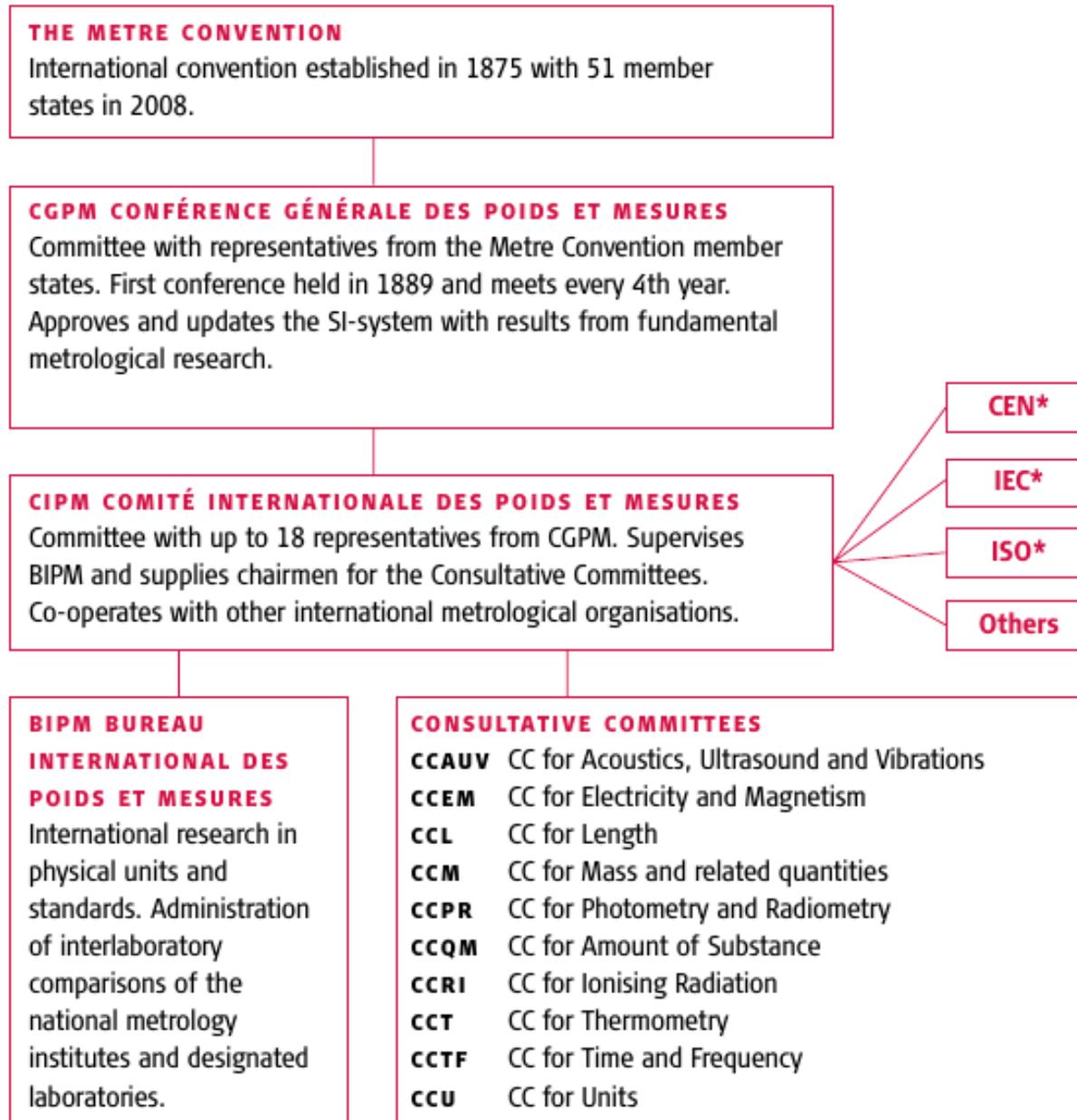
[VIM]



The metrological system



The (political and) scientific side



The (political and) legal side



Organisation Internationale de Métrologie Légale

International Organization of Legal Metrology

ABOUT

PUBLICATIONS

STRUCTURE

CERTIFICATES

EVENTS

TECHNICAL WORK



Legal metrology
and trade



What is legal metrology?

Legal metrology is the application of legal requirements to measurements and measuring instruments...

[More info](#)



Publications and Bulletin

The OIML develops model regulations, standards and related documents...

[More info](#)

[<https://www.oiml.org>]

For Your Information...

29.3.2014

EN

Official Journal of the European Union

L 96/149

DIRECTIVE 2014/32/EU OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL

of 26 February 2014

on the harmonisation of the laws of the Member States relating to the making available on the market of measuring instruments (recast)

an update of

DIRECTIVE 2004/22/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL

of 31 March 2004

on measuring instruments

[MID]

- Basic concepts
- **In the last twenty years...**
 - MRA
 - (expected) SI reform
 - JCGM: the GUM and the VIM

Traceability again

If the unit U is defined through its realization (“case 1”, e.g., metre as length of an object), the “owner” of the primary measurement standard is the top layer of the metrological system:

→ this is the role traditionally played by the BIPM

But if the unit U is defined in reference to a universal phenomenon (“case 3”, e.g., metre from speed of light), there can be multiple ways to realize it, and none of them is in principle privileged

→ what can be the role of BIPM in this case?

→ towards a “Do It Yourself” metrological system?

Mutual Recognition Arrangement

For each quantity:

1. two or more NMIs, independently of one another, realize the unit
2. then compare their measurement standards
3. and together establish the value of the quantity of each standard

This is the core content of the Mutual Recognition Arrangement (MRA), signed in 1999, which creates a **“federated” metrological system**

BIPM has the role of coordinating steps 2 and 3, and of publishing their results in the Key Comparison Database

[<http://kcdb.bipm.org>]

The current state...

All three cases of unit definition

1. the distance between the axes of two lines marked on a given bar in given conditions
2. a given fraction of the length of a given earth meridian from pole to the equator
3. the length of the path traveled by light in vacuum during a given time interval)

share the same pattern:

1. Physics provides a **system of quantities**: “set of quantities together with a set of noncontradictory equations relating those quantities”
2. on this basis, a set of independent **base quantities** is decided (in the **International System of Quantities**, ISQ: length, mass, time, electric current, thermodynamic temperature, amount of substance, luminous intensity), such that each non-base quantity is derived from base quantities through such equations
3. for each base quantity a **base unit** is defined; the same equations applied to such base units define derived units, thus obtaining a **system of units** (the ISQ is the basis of the **International System of Units**, SI, in which base units are metre, kilogram, second, etc)

... and a possible new vision

From the same system of quantities (of course...) a set of universal constants (speed of light, charge of electron, etc) is identified and:

- **the value of each of such constants is assigned**
- **each unit is defined as the quantity that if assumed as unitary is compatible with the assigned values of the constants**

Consequences:

- all unit definitions have the same structure
- unit definitions derive from previous definitions (“the constant x has numerical value y in the given units”)
- this assumes “bootstrap” definitions: each unit is defined in reference to values of constants, and the numerical value of each constant is defined in reference of such units
- the distinction between base quantities/units and derived quantities/units
- each unit can be realized in different ways
- unit definitions are much harder to explain...

Measurement is everywhere

... and several institutions are interested in standardizing it

“In 1997 the Joint Committee for Guides in Metrology (JCGM) was formed

...

- to develop and maintain, at the international level, guidance documents addressing the general metrological needs of science and technology, and to consider arrangements for their dissemination
- to promote worldwide adoption and implementation of the results of its work;
- to provide advice, when requested, on questions related to the implementation of its guidance documents”

JCGM

The current membership of the Joint Committee:

- the two inter-governmental organizations concerned with metrology:
 1. the Bureau International des Poids et Mesures (**BIPM**)
 2. the Organisation Internationale de Métrologie Légale (**OIML**)
- the two principal international standardization organizations:
 3. the International Organization for Standardization (**ISO**)
 4. the International Electrotechnical Commission (**IEC**)
- three international unions:
 5. the International Union of Pure and Applied Chemistry (**IUPAC**)
 6. the International Union of Pure and Applied Physics (**IUPAP**)
 7. the International Federation of Clinical Chemistry and Laboratory Medicine (**IFCC**)
- one international accreditation organization
 8. the International Laboratory Accreditation Cooperation (**ILAC**)



Decision making principle

Decisions of the Joint Committee shall be by **consensus**, bearing in mind the following definition:

consensus: General agreement characterized by the absence of sustained opposition to substantial issues by any important part of the concerned interests and by a process that involves seeking to take into account the views of all parties concerned and to reconcile any conflicting arguments.
Note Consensus need not imply unanimity

[ISO/IEC Guide 2:2004, Standardization and related activities – General vocabulary, ISO, IEC, 2004]



JCGM guidance docs

the “VIM”



International vocabulary of metrology — Basic and general concepts and associated terms (VIM)

Vocabulaire international de métrologie — Concepts fondamentaux et généraux et termes associés (VIM)

the “GUM”



JCGM 100:2008
GUM 1995 with minor corrections

Evaluation of measurement data — Guide to the expression of uncertainty in measurement

Evaluation des données de mesure — Guide pour l'expression de l'incertitude de mesure

<http://www.bipm.org/en/publications/guides/>

[vim.html](http://www.bipm.org/en/publications/guides/vim.html)
[gum.html](http://www.bipm.org/en/publications/guides/gum.html)

References

[GUM] JCGM 100:2008, Evaluation of measurement data – Guide to the expression of uncertainty in measurement (GUM), Joint Committee for Guides in Metrology, 1993 upd 2008

<http://www.bipm.org/en/publications/guides/gum.html>

[MID] Directive 2014/32/EU of the European Parliament and of the Council of 26 February 2014 on the harmonisation of the laws of the Member States relating to the making available on the market of measuring instruments

<http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32014L0032>

[MIS] Metrology in short, 3rd ed, Euramet, 2008

<http://www.euramet.org/index.php?id=mis>

[SIB] SI Brochure: The International System of Units (SI), 8th ed, BIPM, 2006 upd 2014

<http://www.bipm.org/en/publications/si-brochure>

[VIM] JCGM 200:2012, International Vocabulary of Metrology – Basic and general concepts and associated terms (VIM), 3rd ed, Joint Committee for Guides in Metrology, 2008 upd 2012

<http://www.bipm.org/en/publications/guides/vim.html>

Thanks for your kind attention

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