Outline of the current status of measurement science: from the point of view of the International Vocabulary of Metrology (VIM)

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BEAR Seminar, University of California, Berkeley
Tuesday, November 19, 2013

Abstract

The *International Vocabulary of Metrology – Basic and General Concepts and Associated Terms* (VIM)

(JGCM 200:2012; http://www.bipm.org/en/publications/guides/vim.html)

is produced by the Joint Committee for Guides in Metrology (JCGM), which currently gathers eight international organizations working in the field of metrology and aimed at addressing the general metrological needs of science, technology, and society through the development of guidance documents (together with the VIM, the *Evaluation of measurement data – Guide to the expression of uncertainty in measurement* (GUM) (JCGM 100:2008)).

A comparison of the three editions of the VIM (published in 1984, 1993, 2007 respectively) highlights that measurement science is a moving target, and some of its foundational topics, such as the concepts of quantity, measurement result, and measurand, have significantly changed even in a relatively short time. With reference to some cogent examples, the seminar will emphasize the current understanding of measurement as a knowledge-based, pragmatic process, in which models play a primary role.

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 the TC1 (Terminology) and the secretary of the 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, **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

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

LM, **The problem of foundations of measurement**, *Measurement*, 2005

LM, **Epistemology of measurement**, *Measurement*, 2003

LM, **Beyond the representational viewpoint: a new formalization of measurement**, *Measurement*, 2000

The context: JCGM and its products

Some fundamental changes

- What is measurable?
- What is measured?
- What is measurement?

Towards the future...

Joint Committee for Guides in Metrology (JCGM)

(established in 1997)

(BIPM) Int.l Bureau of Weights and Measures
(IEC) Int.l Electrotechnical Commission
(IFCC) Int.l Federation of Clinical Chemistry and Laboratory Medicine
(ILAC) Int.l Laboratory Accreditation Cooperation
(ISO) Int.l Organization for Standardization
(IUPAC) Int.l Union of Pure and Applied Chemistry
(IUPAP) Int.l Union of Pure and Applied Physics
(OIML) Int.l Organization of Legal Metrology

The scope of JCGM

metrology: «science of measurement and its application»

… no principled constraints on the object of measurement...

JCGM guidance docs

the "VIM"

the "GUM"

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

1 Quantities and units

1.1 (1.1)
quantity

property of a phenomenon, body, or substance, where the property has a magnitude that can be expressed as a number and a reference

NOTE 1 The generic concept 'quantity' can be divided into several levels of specific concepts, as shown in the following table. The left hand side of the table shows specific concepts under 'quantity'. These are generic concepts for the individual quantities in the right hand column.

1 Grandeurs et unités

1.1 (1.1)
grandeur, f

propriété d'un phénomène, d'un corps ou d'une substance, que l'on peut exprimer quantitativement sous forme d'un nombre et d'une référence

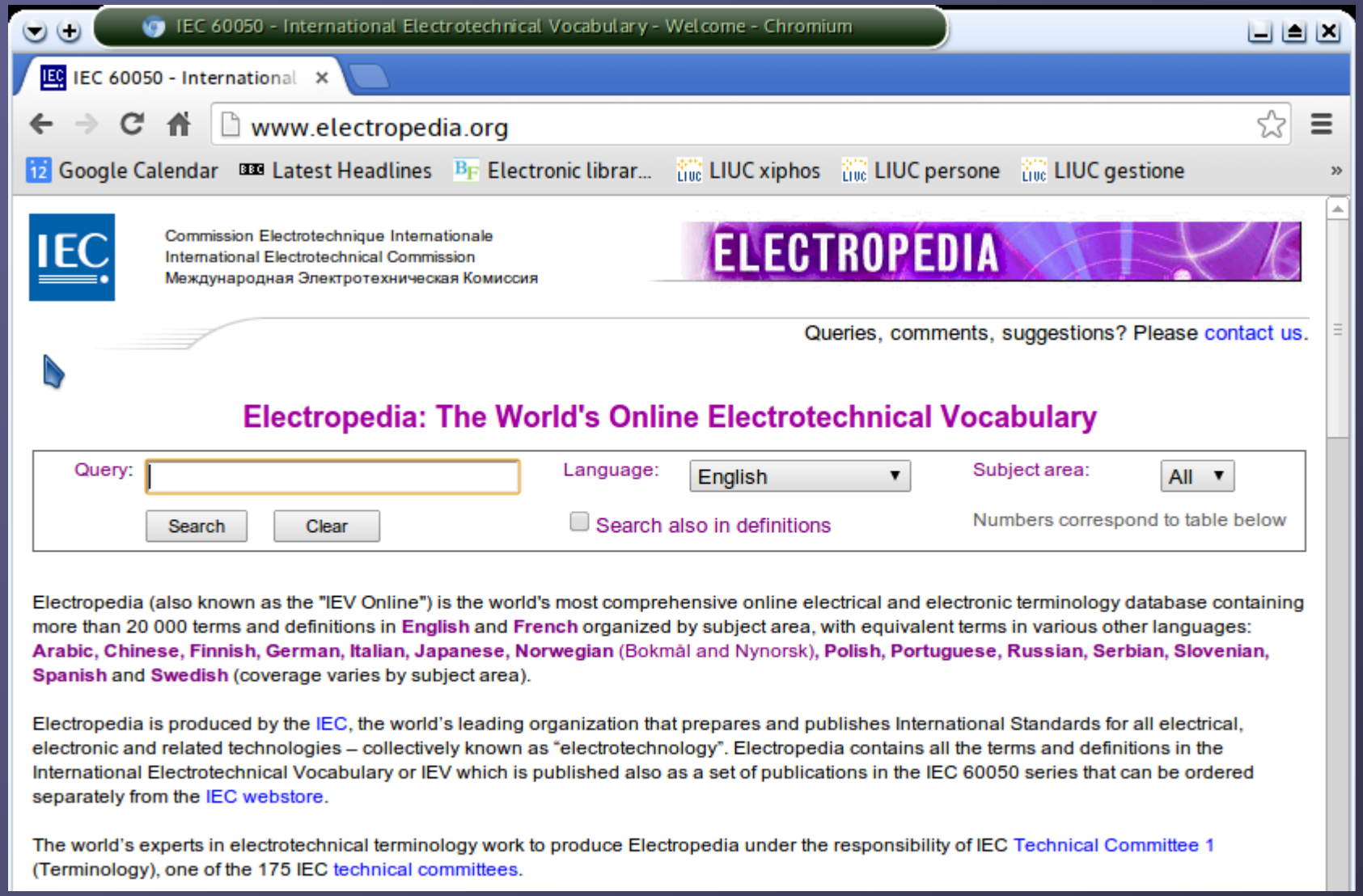
NOTE 1 Le concept générique de grandeur peut être subdivisé en plusieurs niveaux de concepts spécifiques, comme indiqué dans le tableau suivant. La moitié gauche du tableau présente des concepts spécifiques du concept de grandeur. Ce sont des concepts génériques pour les grandeurs individuelles de la moitié droite.

length, l longueur, l	radius, r rayon, r	radius of circle A, r_A or r(A) rayon du cercle A, r_A ou r(A)
	wavelength, λ longueur d'onde, λ	wavelength of the sodium D radiation, λ_D or λ(D; Na) longueur d'onde de la radiation D du sodium, λ_D ou λ(D; Na)
energy, E	kinetic energy, T	kinetic energy of particle i in a given system, T_i

→ a live demo

It is only a vocabulary...

Yes... but compare, e.g., with



Searching Electropedia for “sensitivity”:

Search results (52 hits)

311-03-11	sensitivity (of a measuring instrument)	[311 - Electrical and electronic measurements]
351-47-44	parameter sensitivity	[351 - Control technology]
394-38-11	photocathode sensitivity	[394 - Nuclear instrumentation]
394-38-62	light sensitivity (of a photomultiplier)	[394 - Nuclear instrumentation]
394-38-63	spectral sensitivity (of a photomultiplier)	[394 - Nuclear instrumentation]
394-38-64	light sensitivity non-uniformity (of a photomultiplier)	[394 - Nuclear instrumentation]
394-39-07	sensitivity (of a measuring assembly)	[394 - Nuclear instrumentation]
521-09-12	magnetic sensitivity (of a Hall probe)	[521 - Semiconductor devices and integrated circuits]
521-09-13	control current sensitivity (of a Hall probe)	[521 - Semiconductor devices and integrated circuits]
521-09-20	magnetoresistive sensitivity	[521 - Semiconductor devices and integrated circuits]
531-14-14	deflection sensitivity (electrostatic)	[531 - Electronic tubes]
531-14-15	deflection sensitivity (magnetic)	[531 - Electronic tubes]
531-41-32	tuning sensitivity	[531 - Electronic tubes]
531-44-21	radiant sensitivity	[531 - Electronic tubes]
531-44-22	absolute spectral sensitivity	[531 - Electronic tubes]
531-44-23	relative spectral sensitivity	[531 - Electronic tubes]
531-44-24	luminous sensitivity	[531 - Electronic tubes]
531-44-25	dynamic sensitivity	[531 - Electronic tubes]
531-44-26	spectral-sensitivity characteristic	[531 - Electronic tubes]
531-44-27	absolute-spectral-sensitivity characteristic	[531 - Electronic tubes]
531-44-28	relative-spectral-sensitivity characteristic	[531 - Electronic tubes]
531-45-10	knee sensitivity	[531 - Electronic tubes]
531-45-13	sensitivity	[531 - Electronic tubes]
531-47-09	radiation sensitivity	[531 - Electronic tubes]

The structure of the VIM

1. Quantities and units
2. Measurement
3. Devices for measurement
4. Properties of measuring devices
5. Measurement standards (Etalons)

about 150 concepts defined

VIM1

International vocabulary of basic and general terms in metrology

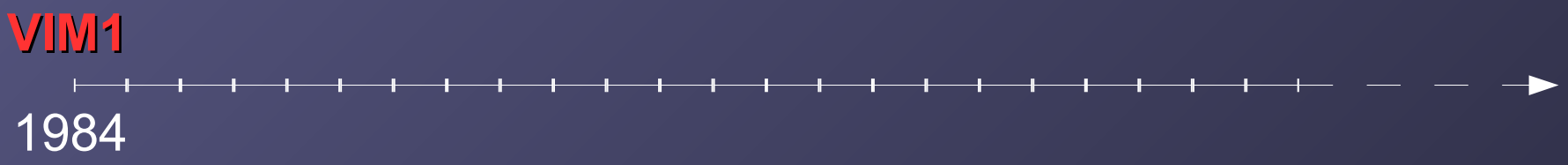
1984 (with corrections: 1987)

ISO: standardization

IEC: standardization

BIPM: fundamental metrology

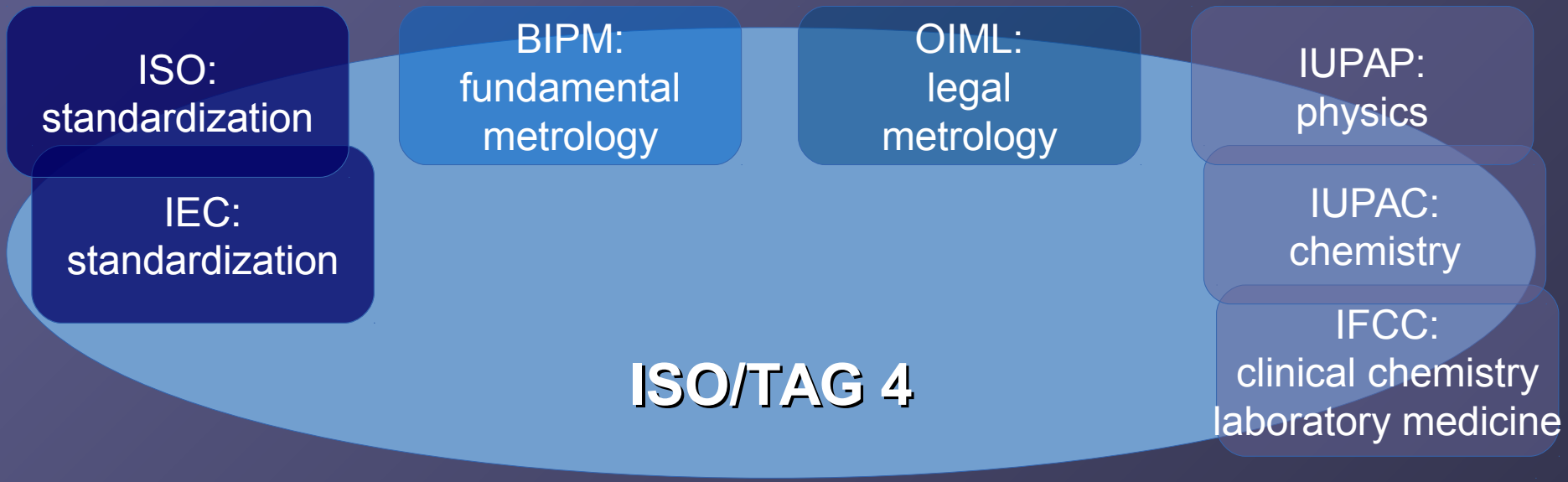
OIML: legal metrology

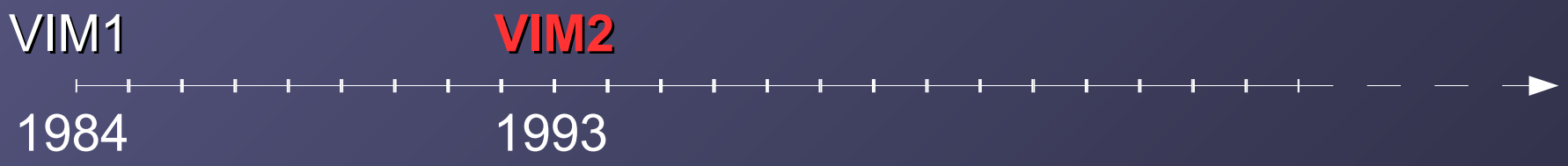


VIM2

International vocabulary
of basic and general terms in metrology

1993 [ISO Guide 99:1993]



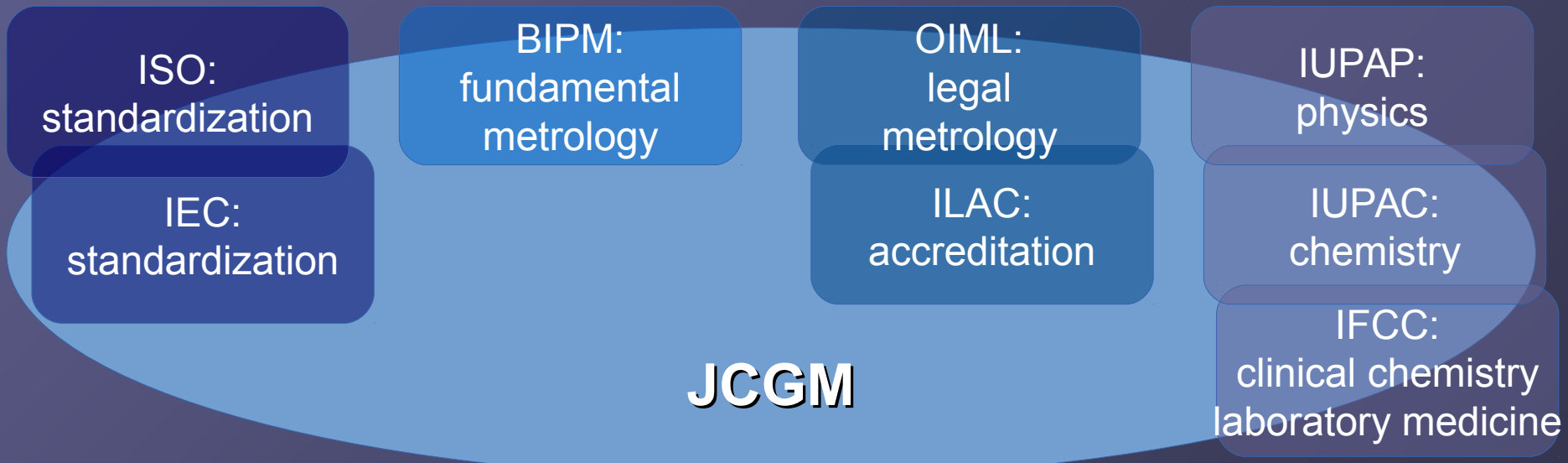


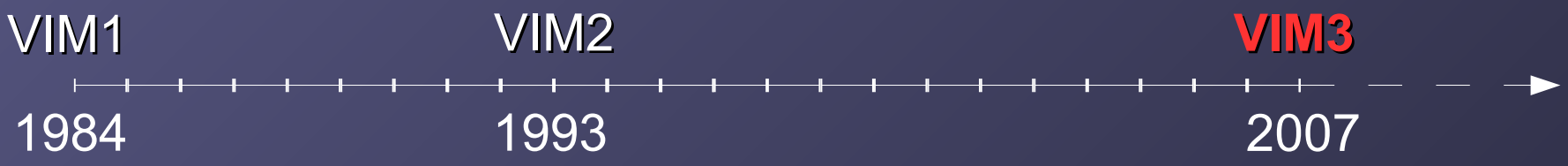
VIM3

International vocabulary of metrology

Basic and general concepts and associated terms

2007 (with corrections: 2012) [JCGM 200:2012]





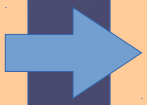
The VIMs as witnesses of change

These changes have been much more than a matter of political moves or lexical fixes

They witness that
fundamentals of measurement science are a moving target

An example: '**measurement**'

VIM1 & VIM2:
«set of operations having the object of **determining the value** of a quantity»



VIM3:
«process of experimentally **obtaining one or more quantity values that can reasonably be attributed** to a quantity»

(note that changing concepts while terms are maintained causes ambiguity)

Is measurement science a moving target?

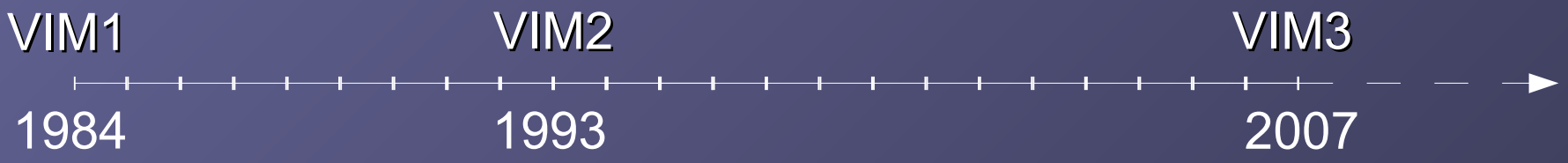
The VIMs can be considered as snapshots, taken

- from a **conservative** viewpoint
  (the existing widespread metrological infrastructure, standards, accreditation procedures, … have to be maintained)
- from a **political** viewpoint
  (changes require the consensus of all Member Organizations)

… and nevertheless some interesting changes can be found

- from the VIM1, mainly reflecting the traditional standpoint
- to the VIM3 (and beyond?)

From the VIM1 to the VIM3: what drivers of change?



- The domain of the VIMs widened:
  from physics to physics + chemistry + lab medicine
  (note that quantum physics is basically outside the scope of the VIMs)

- In the last decades the philosophical understanding of measurement has been changing

- Measurement science as such is evolving...

The VIMs as drivers of change?

… because the VIM is not a generic **dictionary**

(«collection of entries presenting information related to concepts or designations from one or more specific subject fields»)

but a **vocabulary**

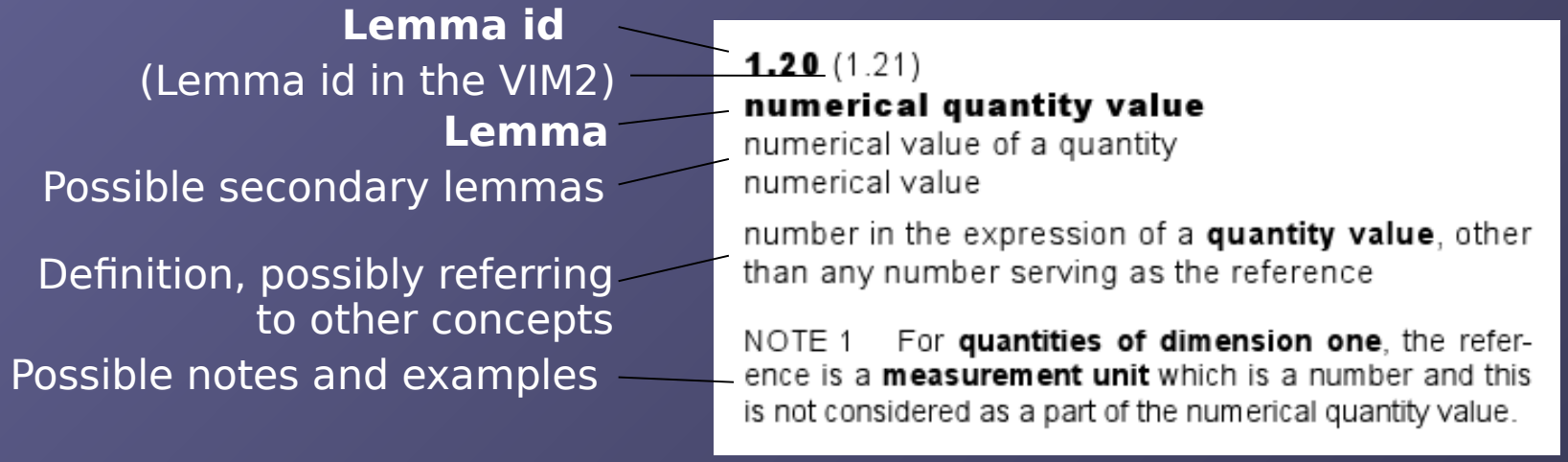
(«dictionary which contains designations and definitions»)

[adapted from ISO 1087-1:2000:
Terminology work - Vocabulary - Part 1: Theory and application]

and in fact a **concept system**

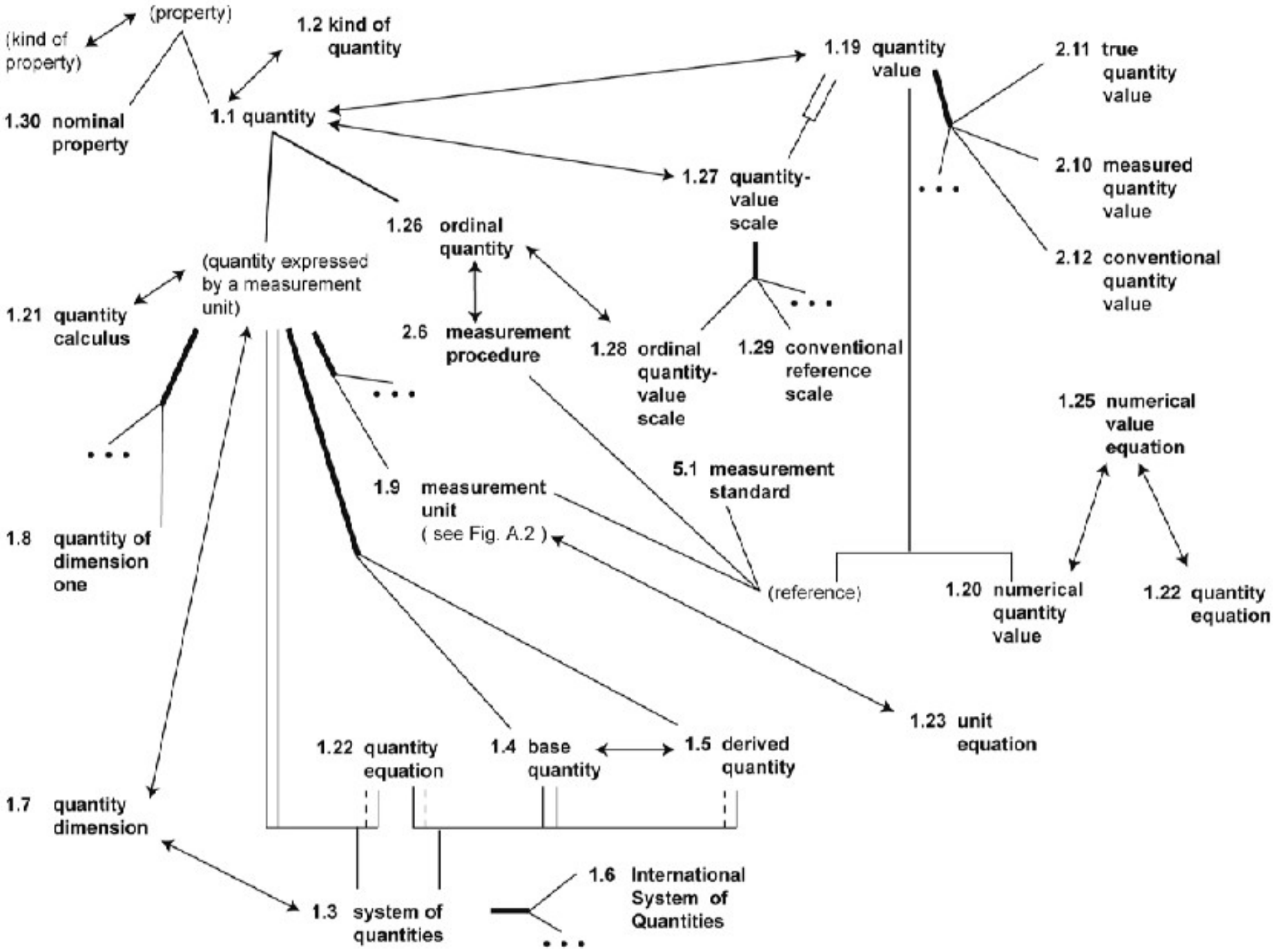
and in perspective it might become an **ontology**

The VIM as a concept system



«The *substitution principle* applies; that is, it is possible in any definition to replace a term referring to a concept defined elsewhere in the VIM by the definition corresponding to that term, without introducing contradiction or circularity.»

«In some definitions, the use of non-defined concepts is unavoidable. In this Vocabulary, such non-defined concepts include: system, component, phenomenon, body, substance, property, reference, experiment, examination, magnitude, ...»


(property)
(kind of property)
1.2 kind of quantity
1.19 quantity value
2.11 true quantity value
1.30 nominal property
1.1 quantity
2.10 measured quantity value
1.27 quantity-value scale
2.12 conventional quantity value
1.26 ordinal quantity
(quantity expressed by a measurement unit)
1.21 quantity calculus
2.6 measurement procedure
1.28 ordinal quantity-value scale
1.29 conventional reference scale
1.25 numerical value equation
5.1 measurement standard
1.9 measurement unit
(see Fig. A.2)
1.8 quantity of dimension one
(reference)
1.20 numerical quantity value
1.22 quantity equation
1.23 unit equation
1.22 quantity equation
1.4 base quantity
1.5 derived quantity
1.7 quantity dimension
1.3 system of quantities
1.6 International System of Quantities

The context: JCGM and its products

Some fundamental changes

What is measurable?

What is measured?

What is measurement?

Towards the future...

From the VIM1 to the VIM3: some fundamental changes

What is measurable?

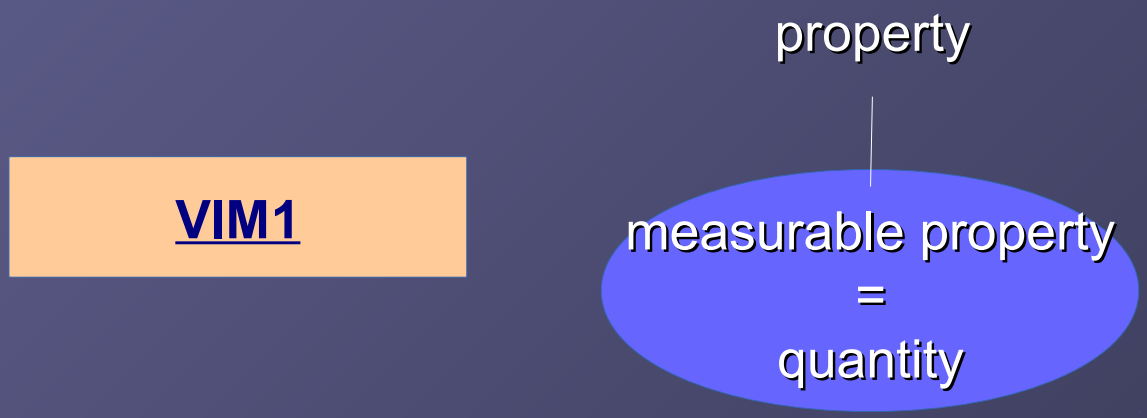
The traditional position:

Measurability is a feature of empirical properties
that can be compared with each other
in terms of their ratio

Properties and quantities

The VIM1 adopts the traditional position and presents it in reference to **quantities**, by assuming that:

1. quantities are specific properties
2. only quantities are measurable



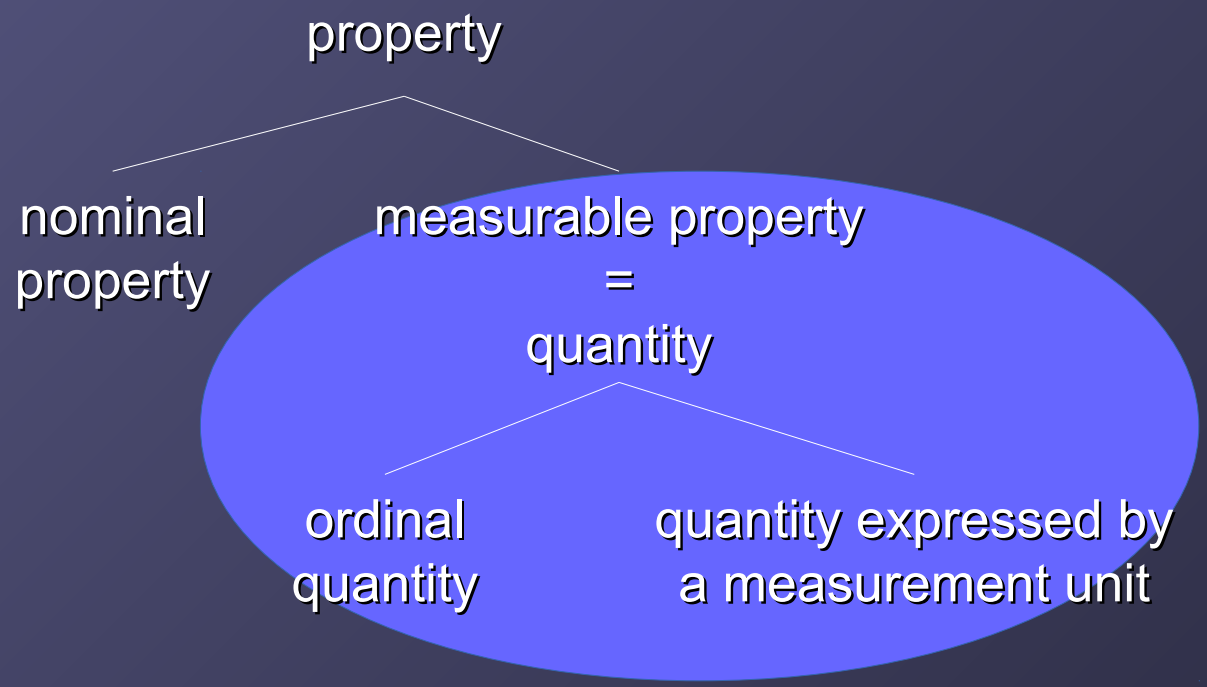
The status of ordinal properties remains (undefined and) ambiguous here...

Properties and quantities again

The VIM3 maintains the VIM1 assumptions, but defines ordinal properties as **ordinal quantities**

An **ordinal quantity** is a «quantity, defined by a conventional measurement procedure, for which a total ordering relation can be established, according to magnitude, with other quantities of the same kind, but for which no algebraic operations among those quantities exist»

VIM3



Measurability

Considering ordinal quantities as measurable entities is a break with the Euclidean tradition: is it justified?

The VIM3 position is:

1. ‘having magnitude’ is sufficient for measurability
2. quantities (including ordinal ones) ‘have magnitude’

A **quantity** is a «property of a phenomenon, body, or substance, where the property has a magnitude that can be expressed as a number and a reference»

But is measurability just a matter of lexical conventions?

Should the concept be further extended,
so to include nominal properties?

From the VIM1 to the VIM3: some fundamental changes

What is measured?

The traditional position:

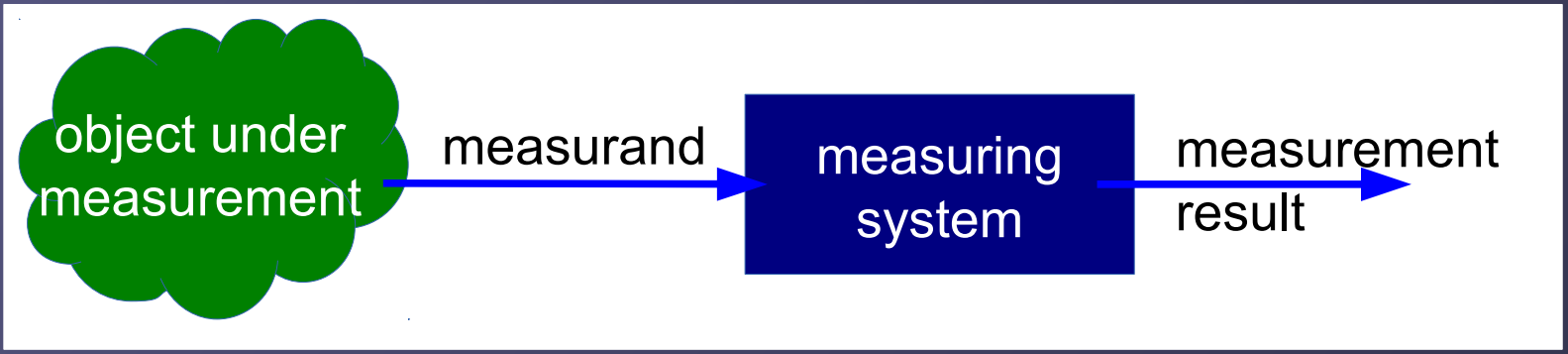
Measurement conveys uninterpreted information
on the empirical property
in input to the measuring instrument

Measurands

The VIM1 adopts the traditional position and presents it in reference to **measurands**, by assuming that:

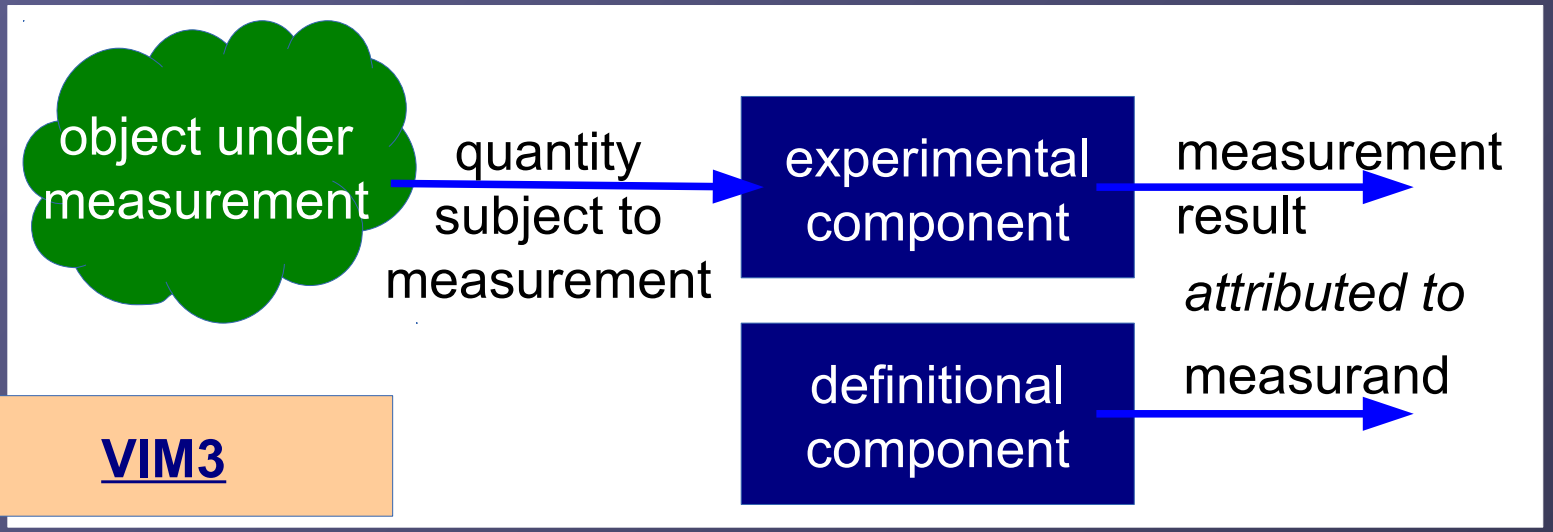
1. measurement is a «set of operations having the object of determining the value» of a measurand
2. a measurand is a «quantity subjected to measurement»

VIM1



Measurands again

The VIM3 redefines **measurand** as a «quantity intended to be measured»



The idea: we do our best to let the measuring system interact with the quantity we want to measure, but the measurement result will be attributed to the quantity as we have defined it, not to the (unknown) quantity with which the instrument actually interacted

Definitional uncertainty

Measurement uncertainty takes into account both the experimental and the definitional components:

definitional uncertainty: «component of measurement uncertainty resulting from the finite amount of detail in the definition of a measurand» [concept introduced in the VIM3]

and indeed:

«Definitional uncertainty is the practical minimum measurement uncertainty achievable in any measurement of a given measurand.»

Measurement results,
and in particular measurement uncertainty,
depend on definitional issues

From the VIM1 to the VIM3: some fundamental changes

What is measurement?

The traditional position:

Measurement is a purely experimental process

Measurement

The VIM1 adopts the traditional position and presents it in reference to **measurement**, by assuming that:

1. it is a determination process whose outcome preexists to measurement itself
2. the measurand has a single value

VIM1

Measurement is aimed at «**determining the** value of a quantity»

Measurement again

The VIM3 redefines **measurement** as a «process of experimentally obtaining one or more quantity values that can reasonably be attributed to a quantity»

How can this “reasonable attribution” be obtained?

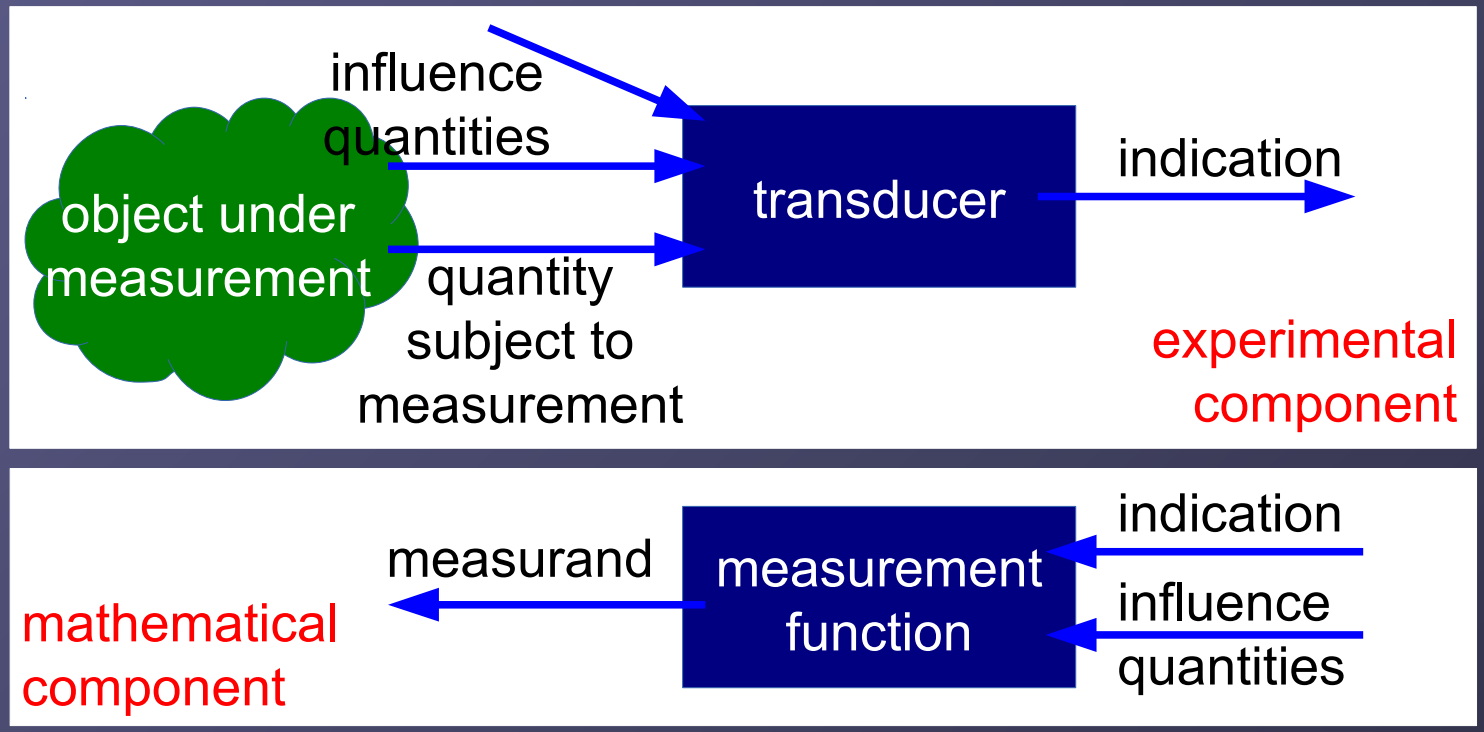
A model-based process

measurement model [*concept introduced in the VIM3*]:

«mathematical relation among all quantities known to be involved in a measurement»

... specialized in the **measurement function**:

measurand = *f* (indication, influence quantities)



Problem

How can the measurement function be known?

How is it obtained?

That is, how can measurement be modeled?

The fundamental concept

calibration

«operation that, under specified conditions,

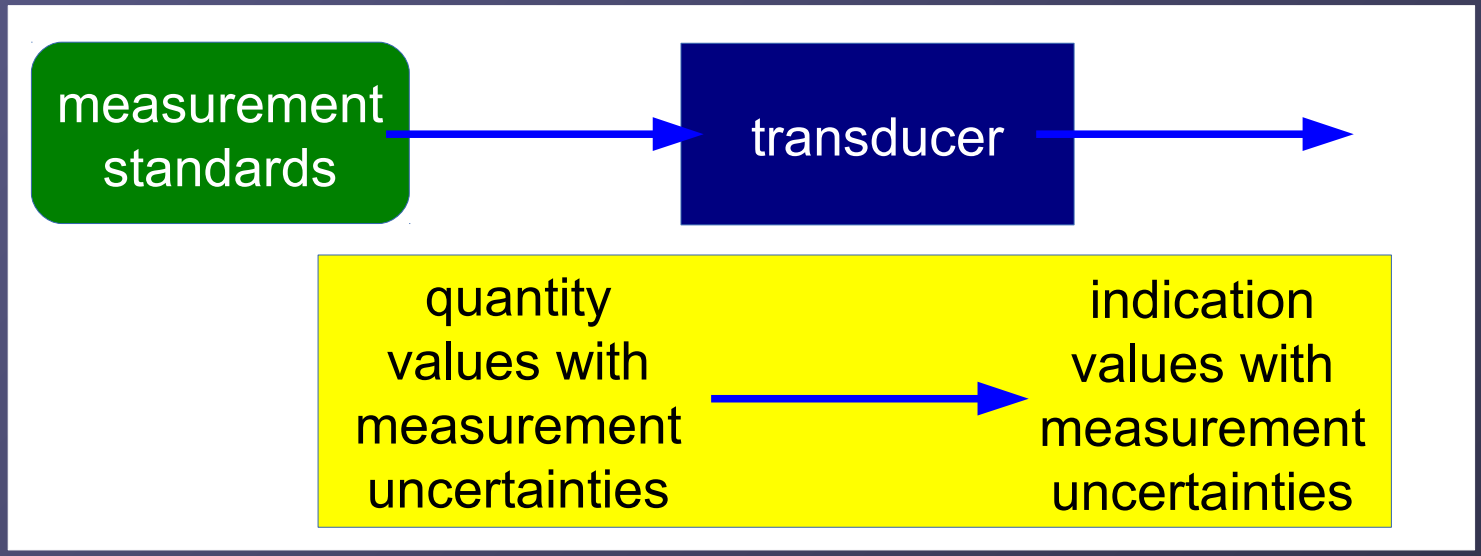
in a first step, establishes a relation between the quantity values with measurement uncertainties provided by measurement standards and corresponding indications with associated measurement uncertainties

and, in a second step, uses this information to establish a relation for obtaining a measurement result from an indication»

[definition significantly changed in the VIM3]

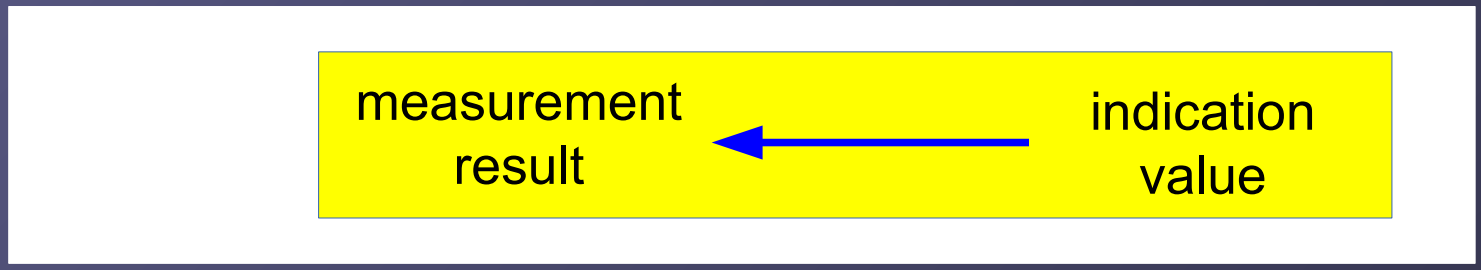
Calibration: in a first step...

«establishes a relation between the quantity values with measurement uncertainties provided by measurement standards and corresponding indications with associated measurement uncertainties»



... and in a second step...

«uses this information to establish a relation for obtaining a measurement result from an indication»

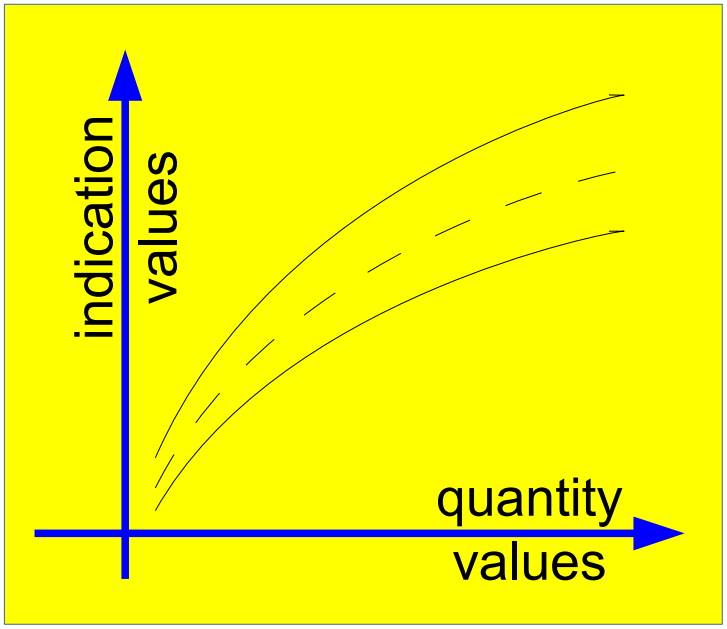


The synthesis

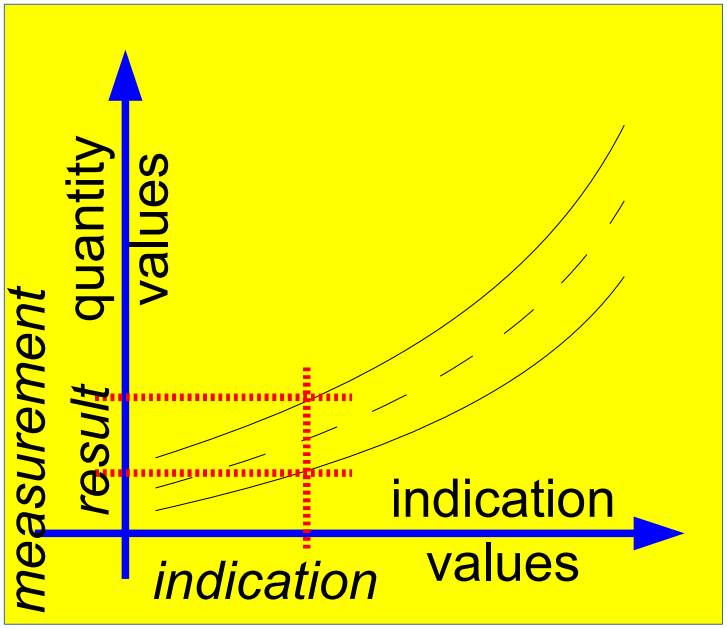
calibration diagram

«graphical expression of the relation between indication and corresponding measurement result»

[*concept introduced in the VIM3*]



first step



second step

Measurement as pragmatic process

Measurement uncertainty is the overall parameter to assess the quality of what a measurement produces in a costs/benefits analysis...

... and it is aimed at being compared to the

target uncertainty [*concept introduced in the VIM3*]

«measurement uncertainty specified as an upper limit and decided on the basis of the intended use of measurement results»

The context: JCGM and its products

Some fundamental changes

- What is measurable?
- What is measured?
- What is measurement?

Towards the future...

Towards the VIM4

The current edition of the VIM is still a half refined document,
and the JCGM has already approved a new edition
in a time frame of 5 to 10 years

Some acknowledged open issues...

Nominal properties

Should measurement be generalized to nominal properties?

According to the VIM3, «measurement does not apply to nominal properties» (and the term “examination” is introduced to denote the process of value attribution to nominal properties)

But «measurement implies comparison of quantities or counting of entities» and objects can be both compared with each other and counted also in reference to nominal properties...

What is the relation between quantitation and measurement?

True value, error, and uncertainty

The VIM3 defines **true value** as «quantity value consistent with the definition of a quantity»: is it a correct definition?

«There is not a single true quantity value but rather a set of true quantity values consistent with the definition»: is this concept of 'multiple true values' correct?

(note that the VIM3 defines measurement error as «measured quantity value minus a reference quantity value», instead of «minus the true value»)

Are ‘measurement uncertainty’ and ‘measurement error’ compatible with each other?

The VIM domain

«In this Vocabulary, it is taken for granted that there is no fundamental difference in the basic principles of measurement in physics, chemistry, laboratory medicine, biology, or engineering. Furthermore, an attempt has been made to meet conceptual needs of measurement in fields such as biochemistry, food science, forensic science, and molecular biology.»

Is it possible / appropriate / useful to further widen this domain so to encompass also social sciences?

THANK YOU
FOR YOUR KIND ATTENTION

Luca Mari
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Workshops

- Wednesday, November 20, 12:00 PM to 2:00 PM:
  Models of measurement: the general structure

- Thursday, November 21, 9:00 AM to 11:00 AM:
  Models of measurement: measuring systems and metrological infrastructure

- Thursday, November 21, 2:00 PM to 4:00 PM:
  An overview on measurement uncertainty: from the standpoint of the Guide to the Expression of Uncertainty in Measurement (GUM)

- Friday, November 22, 10:00 AM to noon:
  Is the body of knowledge on measurement worth to be a 'science', and what may be the scope of a measurement science?