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?

Workshop 1

Models of measurement: the general structure

Luca Mari

Università Cattaneo – LIUC, Italy

University of California, Berkeley
Wednesday, November 20, 2013

Abstract

Measurement is laden with stereotypes, rooted in its long history and diverse fields of adoption. The consequence is that even the basic terminology (e.g., quantity, scale, accuracy, calibration, ...) is often ambiguous, or least context-dependent. The workshop introduces a background ontology of measurement, from which a basic epistemological characterization is proposed: measurement as a both conceptual and experimental process implementing a property value assignment able to produce information on a predefined property with a specified and provable level of objectivity and intersubjectivity.

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

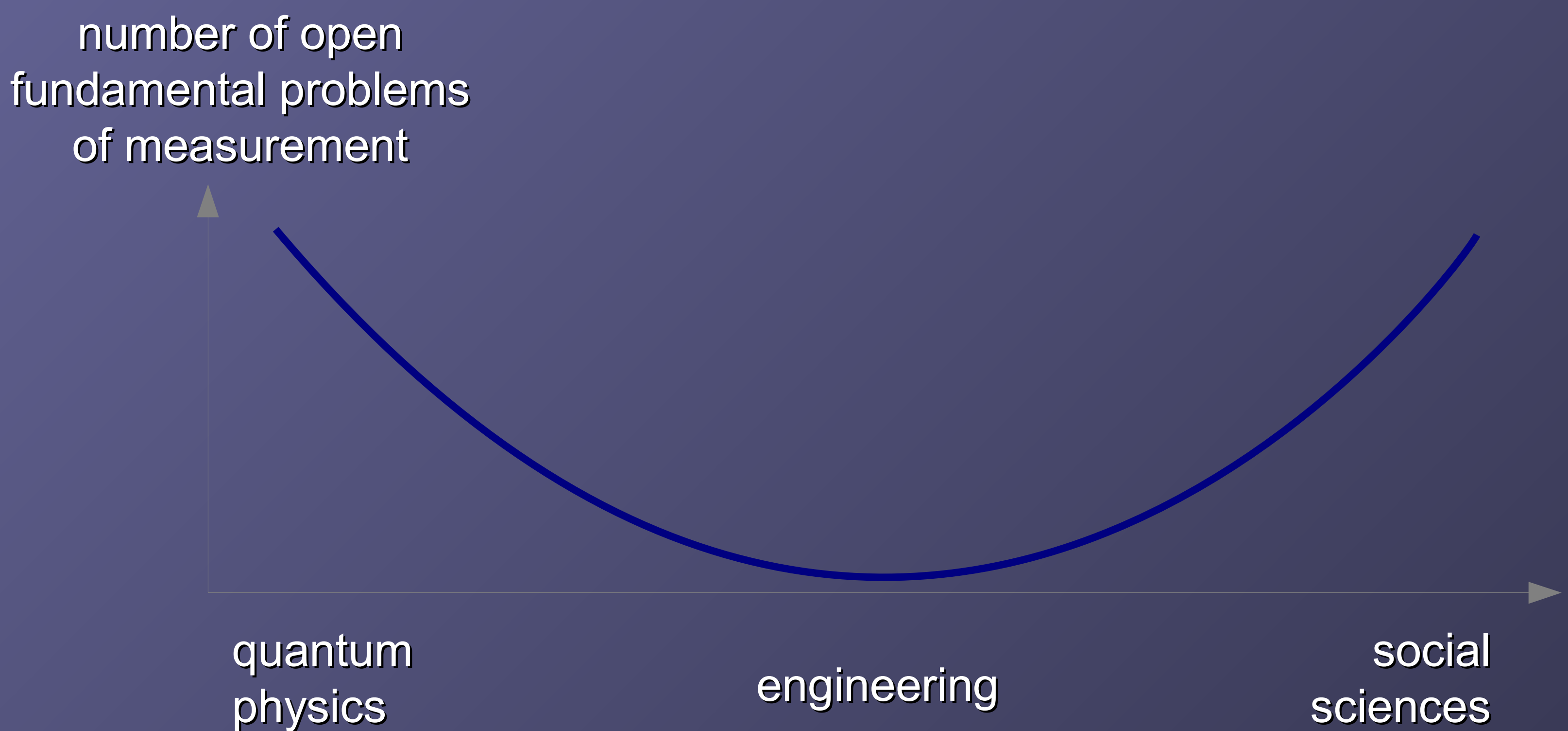
LM, **On (kinds of) quantities**, *Metrologia*, 2009

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

A customary opinion



Consequence:

never argue with an engineer if you are interested in fundamental problems of measurement

Correct?

Our basic question

What kind of information does a statement such as "the velocity of this car is 1.23 m/s" actually convey?

Some interpretations on the scientific role of measurement

A minimal note on semiotics

Towards a background ontology for measurement

From ontology to epistemology

Conditions for measurement

The different interpretations
on the scientific role of measurement
shed some light
on the different interpretations
of what measurement is

[α] The traditional interpretation of the scientific role of measurement

«[Newton’s mechanics] was a deductive science, exactly like geometry. Yet Newton himself asserted that he had wrested its functional principles from experience by *induction*. In other words, Newton asserted that **the truth of his theory could be logically derived from the truth of certain *observation-statements***.»

[K.R. Popper, On the status of science and of metaphysics;
in: Conjectures and refutations. The growth of scientific knowledge, 1962]

(preface written at Berkeley!)

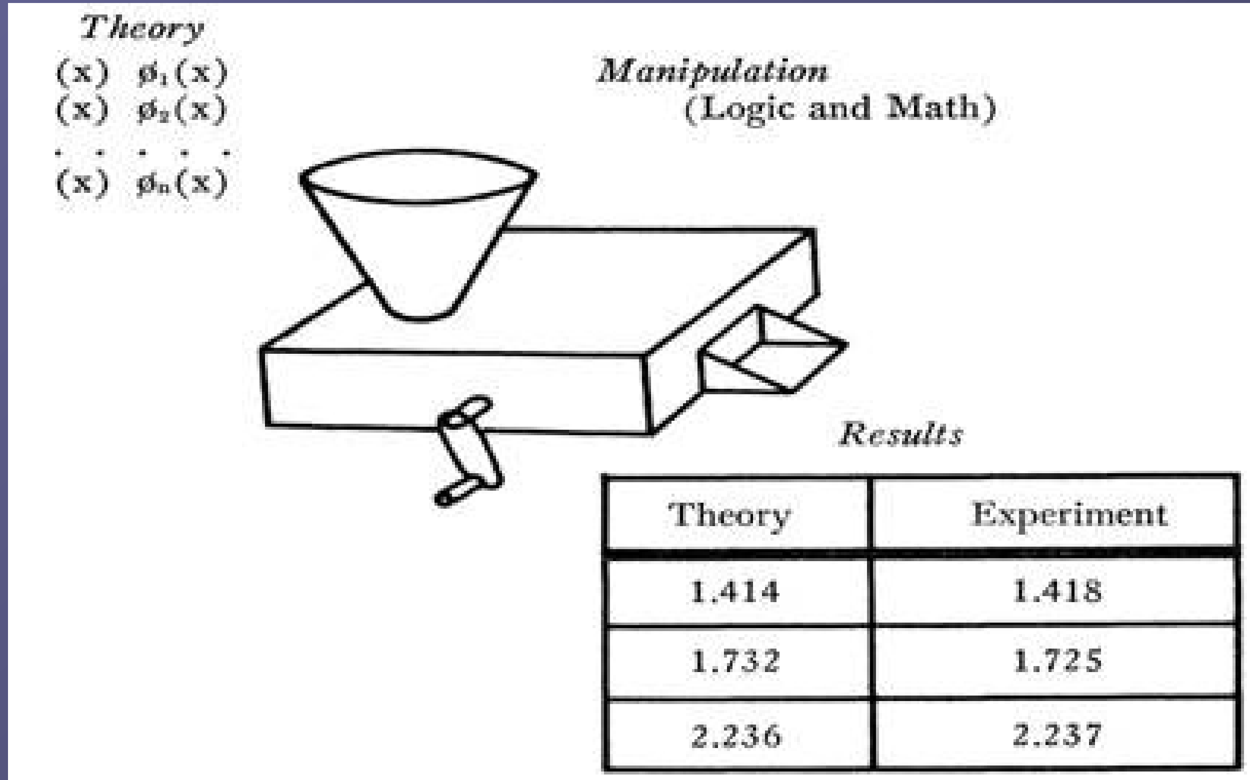
**Measurement is a (the?) tool
to obtain quantitative observation-statements**

[β] Falsificationism

(or a naïve version of it)

«Theories cannot be logically derived from observations. They can, however, clash with observations: they can contradict observations. This fact makes it possible to infer from observations that a theory is false. **The possibility of refuting theories by observations is the basis of all empirical tests**.»

[K.R. Popper, On the status of science and of metaphysics;
in: Conjectures and refutations. The growth of scientific knowledge, 1962]



«The results in the table seem to function as a test of theory. If corresponding numbers in the two columns agree, the theory is acceptable; if they do not, the theory must be modified or rejected.»

[T.S. Kuhn, The function of measurement in modern physical science, Isis, 52, 2, 1961]

This position does not imply a re-interpretation of the scientific role of measurement

[γ] A turning point

«Our most prevalent notions both about the function of measurement and about the source of its special efficacy are derived largely from myth.»

[T.S. Kuhn, The function of measurement in modern physical science, Isis, 52, 2, 1961]

... because «seeing is a "theory-laden" undertaking: **observation of *x* is shaped by prior knowledge of *x***.»

[N.R. Hanson, Patterns of discovery: An inquiry into the conceptual foundations of science, 1958]

... so that «pure or neutral observation-languages» do not exist

[T.S. Kuhn, The structure of scientific revolutions, 1962]

[δ] Constructivism

«The overwhelming case against perception without conception, the pure given, absolute immediacy, the innocent eye, substance as substratum, has been so fully and frequently set forth [...] as to need no restatement here. Talk of unstructured content or an unconceptualized given or a substratum without properties is self-defeating; for the talk imposes structure, conceptualizes, ascribes properties. Although conception without perception is merely *empty*, perception without conception is *blind* (totally inoperative). [...]

With false hope of a firm foundation gone, with the world displaced by worlds that are but versions, with substance dissolved into function, and with **the given acknowledged as taken**, we face the questions how worlds are made, tested, and known.»

[H.N. Goodman, Ways of worldmaking, 1978]

Scenarios...

[α]

Theories can be **verified** by measurement

[β]

Measurement only provides falsification means

[γ]

Measurement is unavoidably theory-laden

[δ]

Theories can be **constructed** by measurement

???

What is plausibly here to stay...

«**Without theoretical interpretation, observation remains blind uninformative**. [Even] everyday experience constantly operates with abstract ideas, such as that of cause and effect, and so it cannot be derived from observations.»

[K.R. Popper, On the status of science and of metaphysics;
in: Conjectures and refutations. The growth of scientific knowledge, 1962]

More or less explicit and structured interpretations
(let us call them: models)
are unavoidable also in measurement

Some interpretations on the scientific role of measurement

A minimal note on semiotics

Towards a background ontology for measurement

From ontology to epistemology

Conditions for measurement

(basics of) Semiotics

The concept of model requires some preliminary considerations, in the area of semiotics: human knowledge develops around three fundamental kinds of entities, let us call them
objects, **concepts**, and **designations**

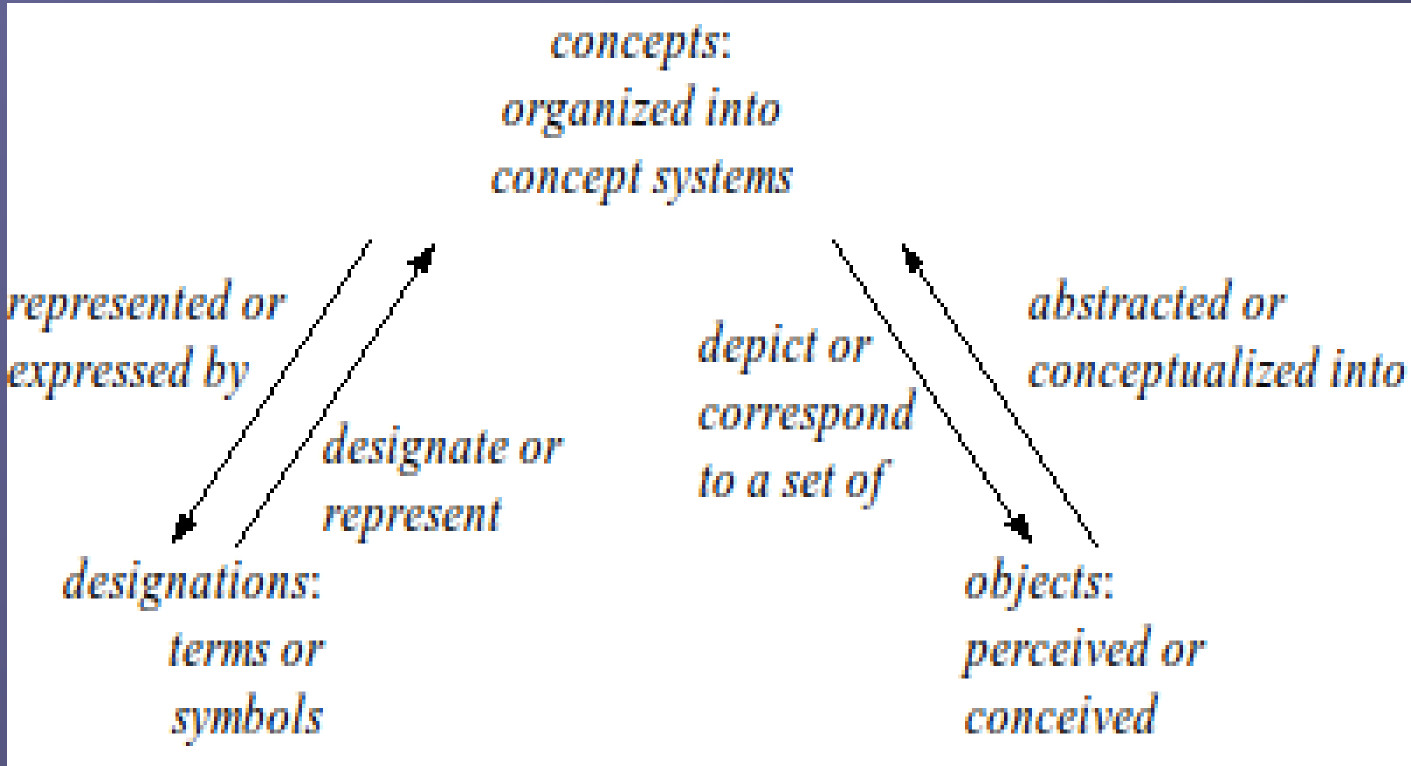
(the term “table” means something to me, because I have a concept ‘table’, and through it I may refer to an object, a table)

the concept
‘table’

the term
“table”

the object
table

(note the notational convention about delimiters)



INTERNATIONAL STANDARD

ISO 704

Third edition
2009-11-01

Terminology work — Principles and methods

Travail terminologique — Principes et méthodes

INTERNATIONAL STANDARD

NORME INTERNATIONALE

ISO 1087-1

First edition
Première édition
2000-10-15

Terminology work — Vocabulary —

Part 1:
Theory and application

The critical role of concepts

For example:

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

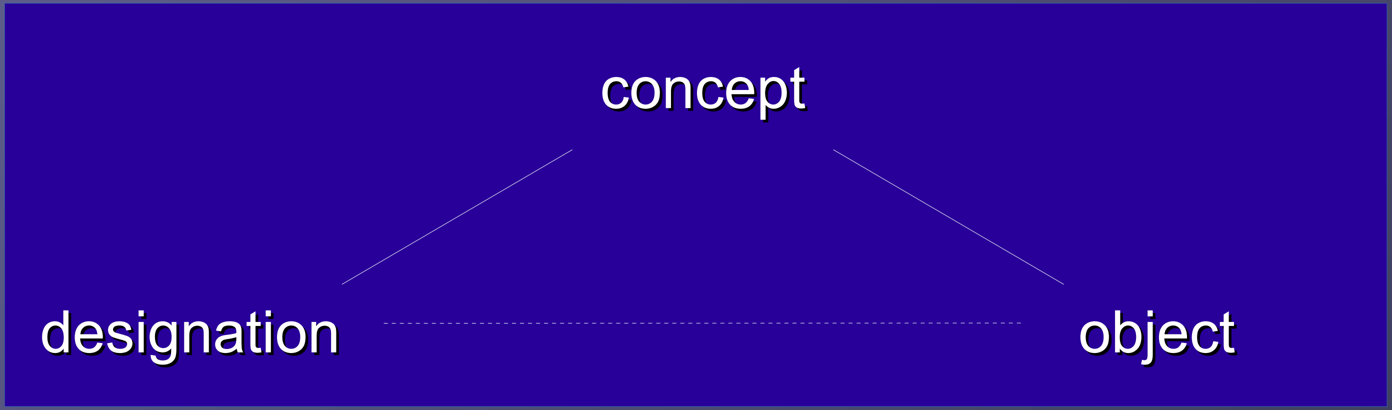
“measurement” a measurement

**The naïve assumption that
terms “designate directly” objects is reversed here:
the relation is mediated by concepts**
(even though there are some notable exceptions, as for proper names, IDs, etc.)

Concepts are the pivotal entities of these “knowledge triangles”

“Knowledge triangles”

From:



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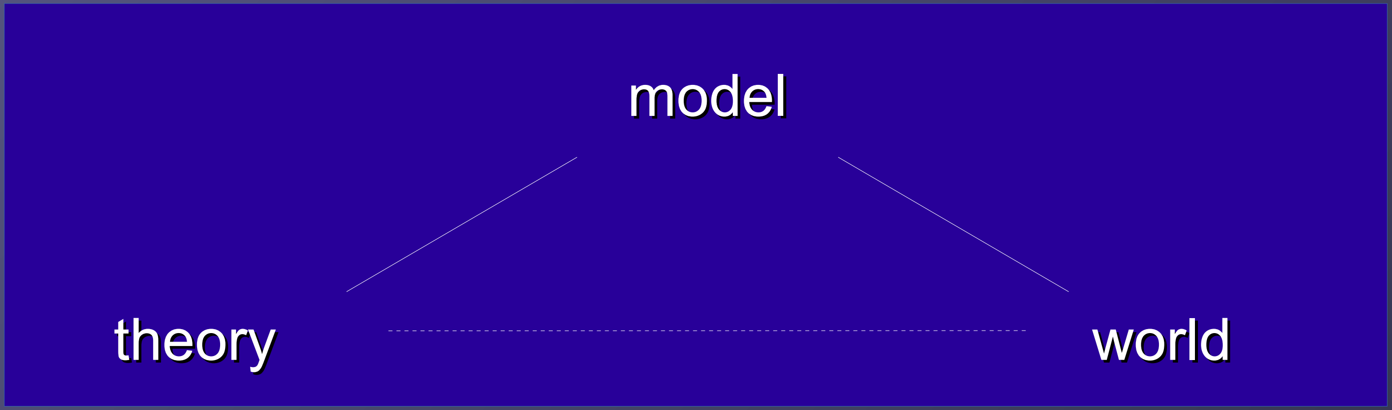

Conceptual creativity

animal with a horse's body
and a single straight horn

???

"unicorn" a unicorn

or: "Harry Potter"; "the current king of France"; "phlogiston"; …

1. There are multiple "modes of existence" for objects
2. The definition of a concept does not imply the empirical existence of the defined object

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Conditions for measurement

Towards a background ontology for measurement

Let us assume the minimal conditions that:

1. measurement implies the empirical existence of the measured entity (measurement is not a thought experiment)
2. what is measured is not, e.g., a table, but the length of it

Hence, a background ontology for measurement should include two kinds of entities:

- «phenomena, bodies, or substances» [VIM3], but also individuals, processes, organizations, …:
  → **objects** (under measurement)
- length, loudness, extroversion, …:
  → **properties** (of objects)

A lexical riddle

semiotics

object

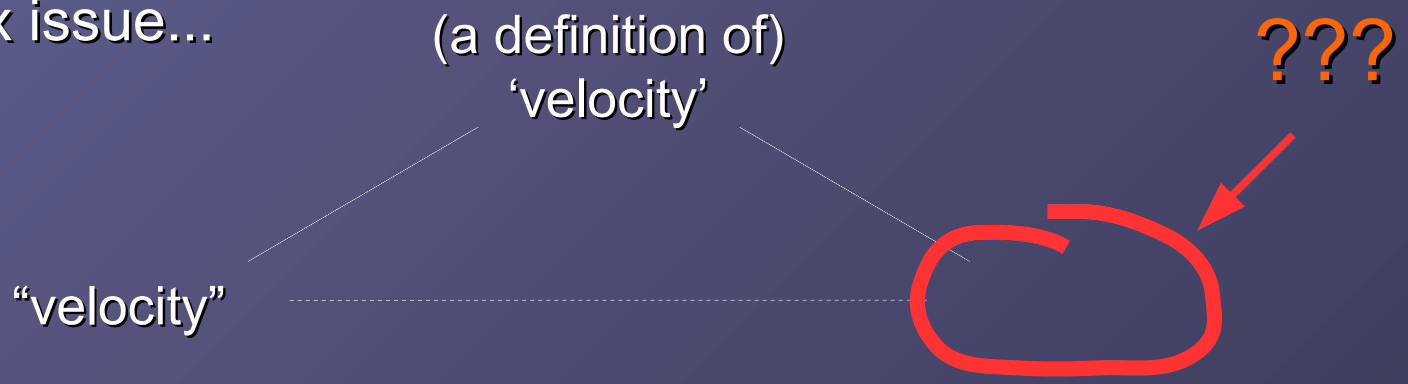
ontology

object

property

The problem of ontology of properties

A complex issue...

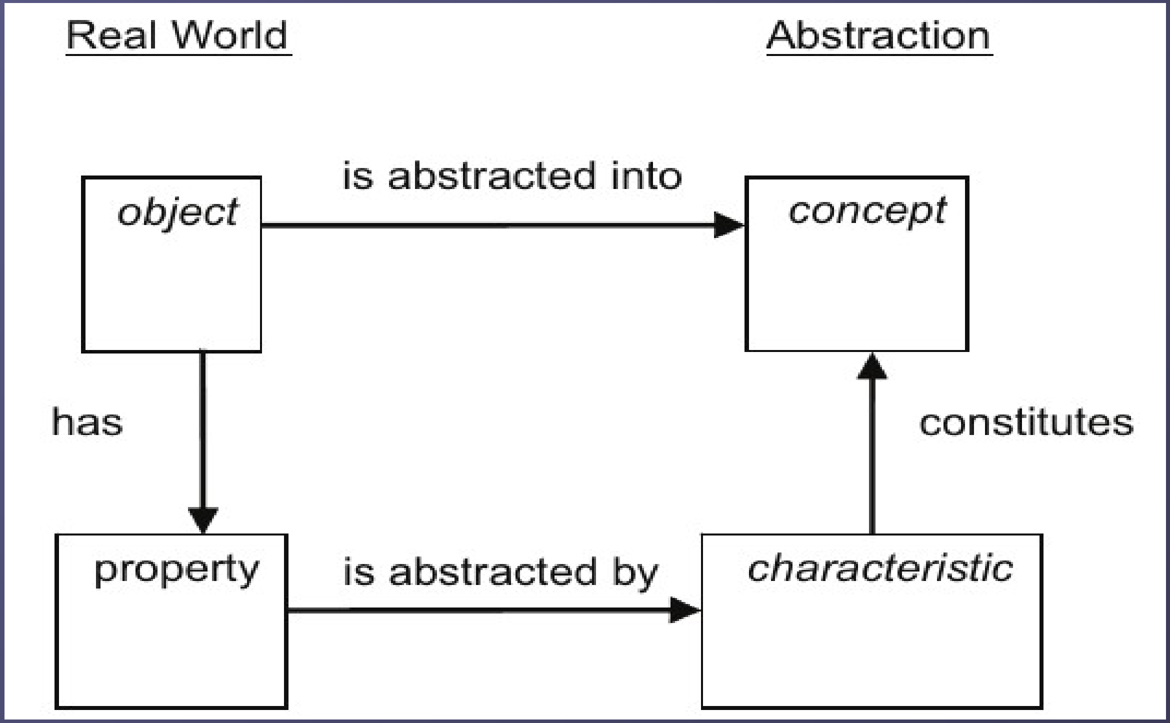


… also because we have to deal with entities such as:

- velocity
- velocity in meters per second
- velocity of this car
- velocity of this car in meters per second
- 1.23 m/s
- 1.23 ± 0.01 m/s

Properties and characteristics

According to ISO:



characteristic
(i.e., model of the property)

term for the property

property

Properties and quantities

quantity: «property of a phenomenon, body, or substance, where the property has a magnitude that can be expressed as a number and a reference» [VIM3, compliant with ISO]

but sometimes:

quality or quantity

term for the property　　　　property

i.e., a property is modeled as either a quality or a quantity

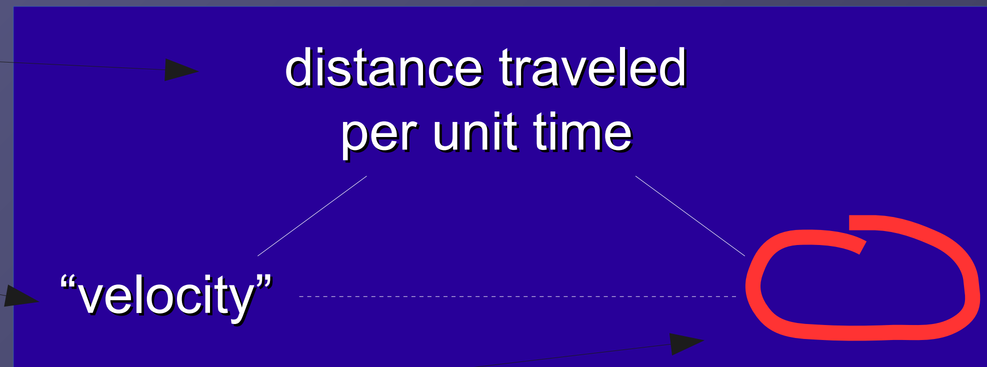
(I will stick to the VIM3 / ISO position)

What is (e.g.) velocity?

The concept defined as
«distance traveled per unit time»

is denoted by the term “velocity”

but what is the defined property?



Is velocity what is

- measured by given measuring instrument(s)?
- measured in units of lengths per units of time?
- ...

(note that we are looking for a criterion of empirical existence,
and “velocity is what is defined so and so” does not guarantee it...)

A simple ontology of properties

Two basic assumptions:

- objects can be compared with each other in terms of their **empirical distinguishability**
- each object has multiple **modes of comparison**

(so that, for two objects *a*, *b*, and two modes of comparison $\approx_1$, $\approx_2$, it might be that $a \approx_1 b$ and $a \not\approx_2 b$)

Properties are modes of comparison

(I will suppose that $\approx$ is an equivalence)

General properties and individual properties

In a measurement-related model:

- **general properties** are taken into account of some objects (*e.g., velocity, for cars but not for organizations*)
- a general property of an object is an **individual property** (*velocity of a given car*)
- a measurement problem is about a general property (*measuring velocity*)
- measurement is performed on individual properties (*measuring the velocity of this car*)

Three interpretations / notations

α: objects are compared with respect to a general property *P*

$$a \approx_P b$$

(the objects are not distinguishable with respect to *P*)

β: individual properties of specified objects are compared

$$P(a) \approx P(b)$$

(the *P* of the objects is not distinguishable)

γ: individual properties (of unspecified objects) are compared

$$p \approx q$$

(the *P*’s are not distinguishable)

Analysis

α: $\boldsymbol{a \approx_P b}$ β: $\boldsymbol{P(a) \approx P(b)}$ γ: $\boldsymbol{p \approx q}$

α and γ are ontologically opposite:

- α disposes of individual properties, as just shortcuts for 'objects from a given point of view'
- γ disposes of objects, by attributing an autonomous existence to individual properties

whereas β is ontologically the less parsimonious, but operatively the more flexible, taking into account objects (a, b), general properties (P), and individual properties ($P(a)$, $P(b)$)

α and β provide a way to describe object dynamics, by introducing time dependence, $a = a(t)$, so that $a(t_1) \approx_P a(t_2)$, or $P(a(t_1)) \approx P(a(t_2))$, specifies that a is not distinguishable for P in its versions in t_1 and t_2

Let us adopt (as usual) option β

Comparison is not enough

Measurement of *P* assumes the *P*-related comparability of objects:
for two generic objects *a* and *b*, $P(a) \approx P(b)$ or $P(a) \not\approx P(b)$

and adds a second condition:

a measurement result
is not about the relation of two unknowns
but about the relation of one unknown and one known

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Conditions for measurement

The epistemic assumptions for measurement

Let us suppose that two objects are known, s_1 and s_2, such that:

1. $P(s_1) \not\approx P(s_2)$
2. for all a, either $P(a) \approx P(s_1)$ or $P(a) \approx P(s_2)$
3. s_1 and s_2 are
   – P-stable and
   – easily P-clonable
   – to easily accessible objects,

   so that the two equivalence classes, $[P(s_1)]$ and $[P(s_2)]$, are worth to be identified as, say, v_1 and v_2 respectively

Let us call:

$\{s_1, s_2\}$ **standard set**

$P(s_1)$ and $P(s_2)$ **reference properties**

v_1 and v_2 **reference property values**

From comparison to value assignment

1. The object under consideration, a, is P-compared with the objects in the standard set, s_1 and s_2

2. The standard s_i is identified such that $P(a) \approx P(s_i)$

3. The corresponding value v_i is reported:

$$\boldsymbol{P(a) = v_i \;\; \text{[as chosen from the set } \{v_1, v_2\}]}$$

meaning:

the P of a and the properties in the class v_i are not distinguishable

i.e., a customary shortcut for:

$$\boldsymbol{P(a) \in [P(s_i)] \;\; \text{[as chosen from the set } \{s_1, s_2\}]}$$

meaning:

the P of a belongs to the class v_i

Let us complete our ontology...

… by taking into account **property values**:

they are not symbols / linguistic entities
(even though they are expressed by means of symbols)
and surely they are not physical realizations of symbols
(even though symbols are communicated by means of physical realizations)

They are (equivalence classes of) individual properties

Hence in:

$$P(a) = v_i \ \ in\ V$$

the measurand is
an individual property
known "by address"

the property value is
an individual property
known "by classification"

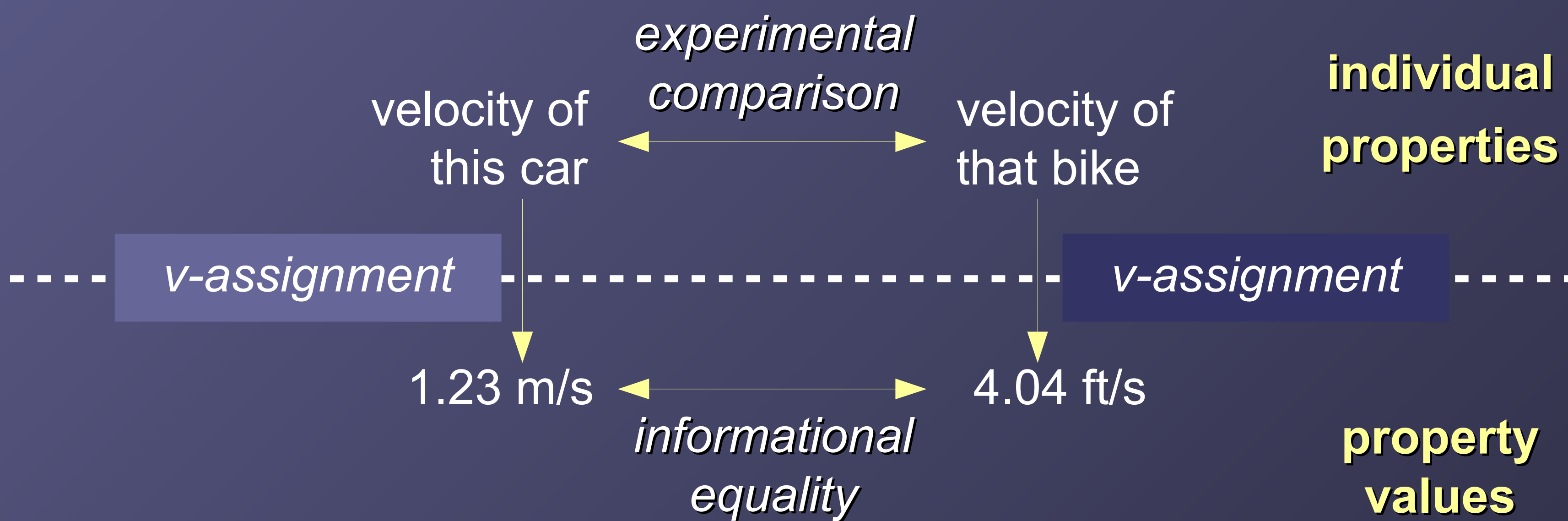
The role of v-assignment

Addressed quantities, such as the velocity of this car,	**Classifier quantities**, such as 1.23 m/s,
are elements of the world,	are elements of a classification,
are assumed to be unknown before measurement,	are assumed to be known before measurement,
are individuated in terms of a given object under measurement	are individuated independently of any object under measurement
as measurands	as quantity values
represented by quantity values	that represent measurands

Three kinds of relations

This ontology involves three kinds of relations:

- between individual properties: $P(a) \approx P(b)$
  this is an **experimental comparison** (*but not a measurement*)
- between property values: $v = v'$
  this is a **formal equality** (*surely not a measurement*)
- between an individual property and a property value: $P(a) = v$
  this is a **v-assignment** (*e.g., a measurement*)



The whole process: example

objects [this car]

general property [velocity]

individual properties [velocity of this car]

v-assignment

property values [1.23 m/s]

expression

symbols ["1.23 m/s"]

physical realization

objects [the utterance <1.23 m/s>]

The whole process

A good deal of confusion...

«When I say that the number of my room in a hotel is 187 I am not speaking of the same kind of thing as when I say that two and two are four. […] "Number" in the first sentence should be replaced by "numeral" […] A numeral is a material or quasi-material symbol, a black mark on a piece of paper or certain sounds which I utter.»

[N.R. Campbell, Physics – The elements, 1920]

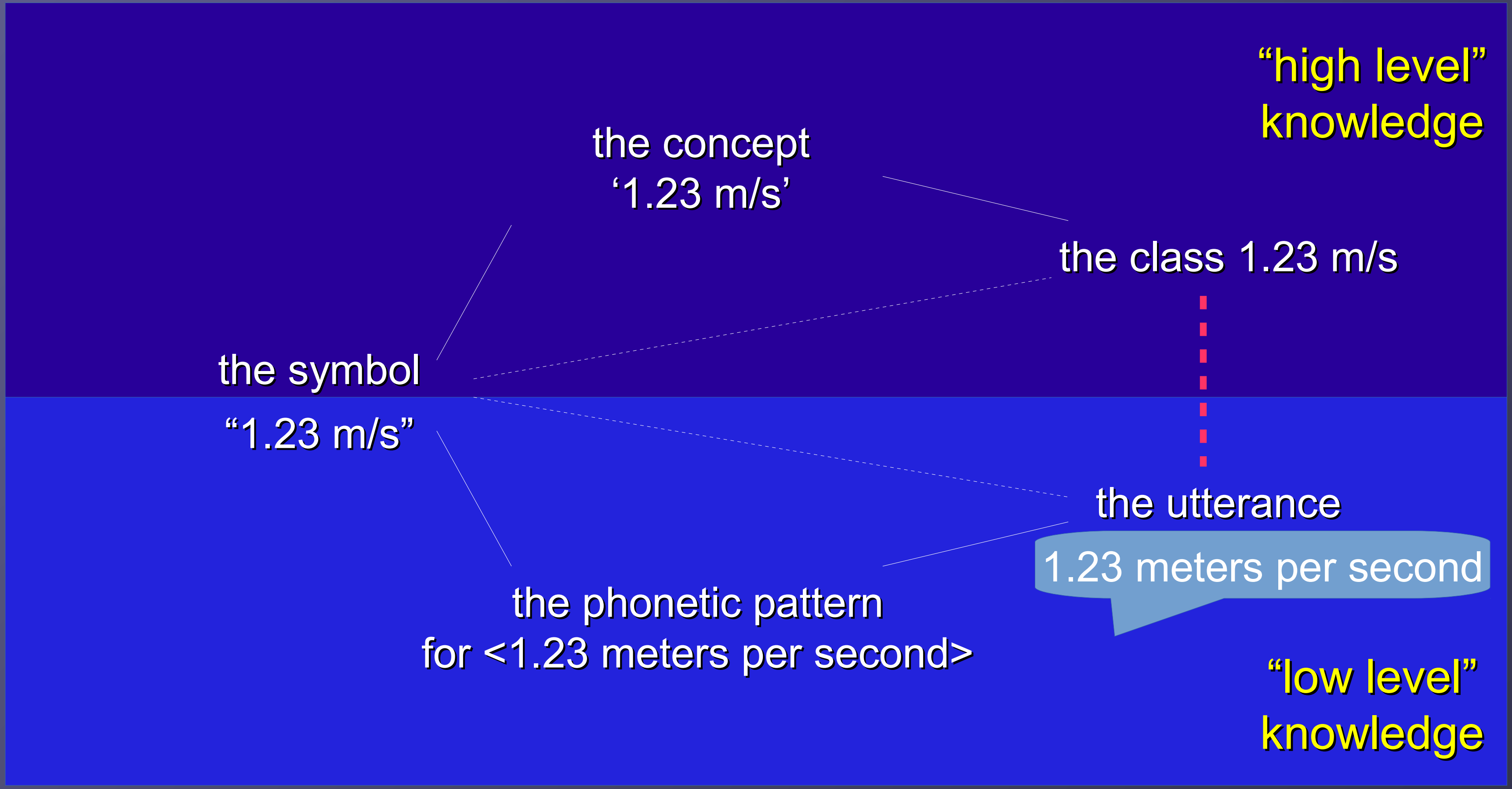
vs

'numeral': «a word, figure, or group of figures denoting a number»

[OED]

Coupled triangles, then...

Designations are linguistic entities, not their physical realizations



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<u>Conditions for measurement</u>

From v-assignment to measurement

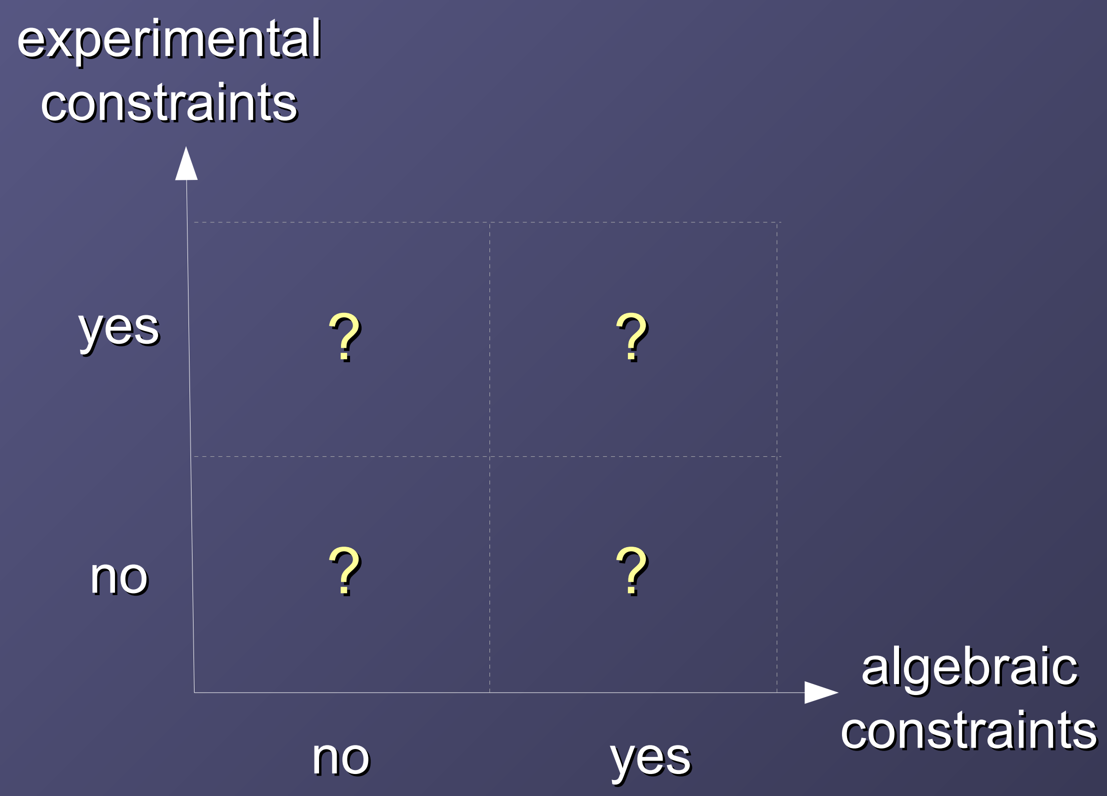
Measurement is an **informative property v-assignment**:
- a value assignment
- to a property
- so to convey information on it

But not each informative property v-assignment
is a measurement
(e.g., subjective judgment and guess can also be informative property v-assignments, but usually they are not expected to be measurements):

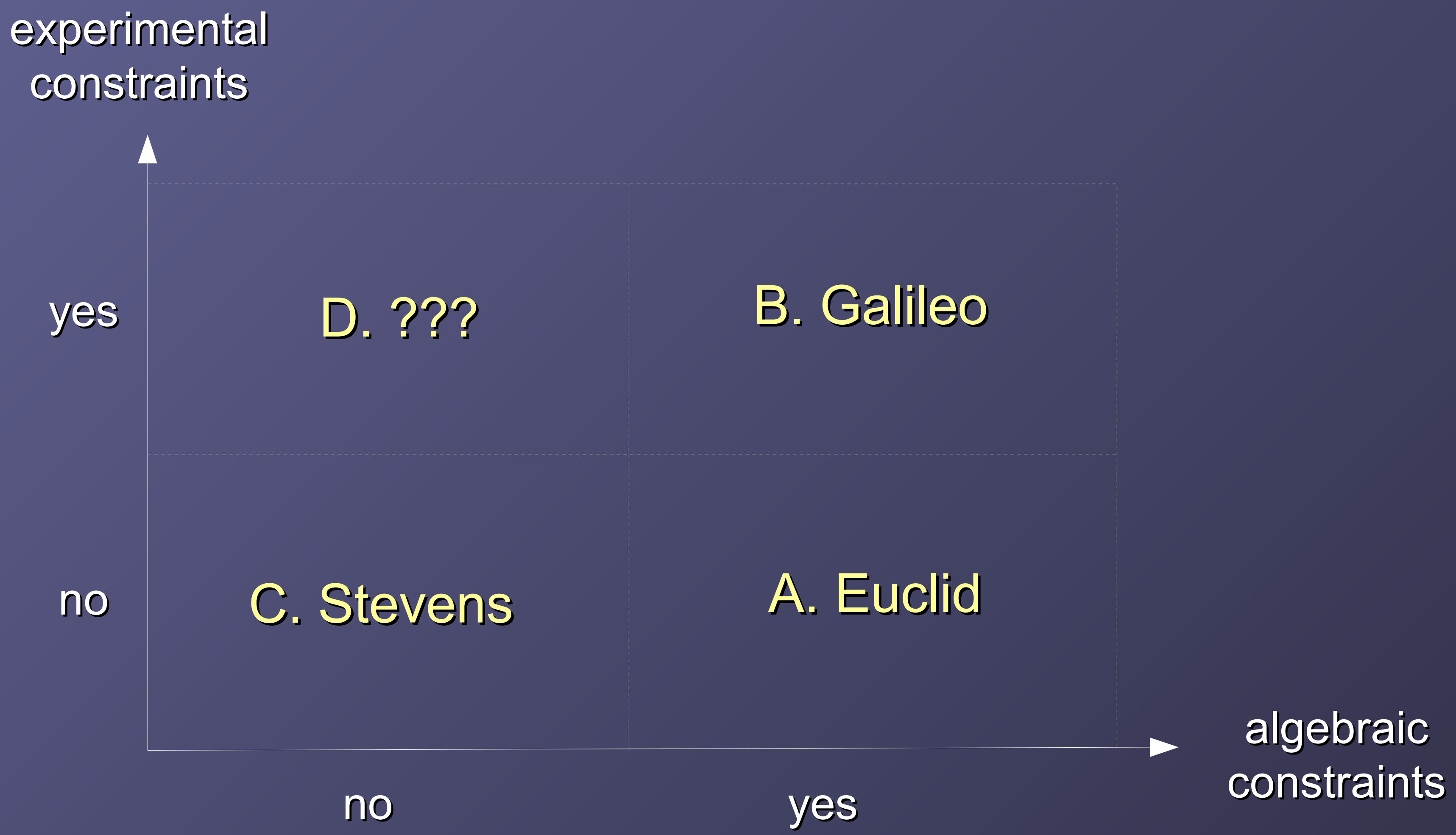
**how is measurement characterized
with respect to a generic v-assignment?**

Conditions for measurement

An option space...



For a conceptual history of measurement...



Exploring the option D

Measurement as an **informative property v-assignment** that delivers information:

- specifically related to the measurand and not to some other properties of the object under measurement or the empirical environment, which includes also the subject who is measuring
  → it is a condition object-relatedness,
  i.e., of **objectivity**

- univocally interpretable by different users in different places and times, thus implying that a measurement result has to be unambiguous and unambiguously expressed
  → it is a condition of subject-transparency,
  i.e., of **intersubjectivity**

Measurement and measuring systems

When measuring a physical property, these conditions are guaranteed by the measurement system itself:

- the output of the measuring instrument ideally depends only on the property under measurement, and it is independent of all other properties of the empirical environment
→ **this confers objectivity to the provided information**

- the measuring instrument is calibrated against a measurement standard, thus making measurement results traceable so that different measuring instruments calibrated within the same metrological system provide compatible information
→ **this confers intersubjectivity to the provided information**

A tentative definition

Measurement is a both conceptual and experimental process

implementing a v-assignment

able to produce information on a predefined property

with a specified and provable level
of objectivity and intersubjectivity

a lot to work on this...

THANK YOU
FOR YOUR KIND ATTENTION

Luca Mari

lmari@liuc.it